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Front cover photo: Kairakau, Hawke's Bay. Photo taken after a storm in 2011 that illustrates the soil erosion protection provided by planted forests. Photo courtesy of Peter Scott, Above Hawke's Bay

Back cover photos: (top) Milled tōtara; (bottom) Harvesting coast redwood. Photos courtesy of Scion

Multiple use forestry

Trevor Best

Once upon a time, multiple use forestry was a 'new, new' thing. An industry version of the internet. It had its very own Act of Parliament aimed at making it the forest management approach used on publicly owned forest lands. It was the subject of a dedicated paper within the forestry Bachelors degree, with students who argued over whether it was a force of nature or just a blimmin' nuisance. It also seemed to have an engaged group of followers, both within the forestry management profession and amongst its various publics. Foresters were known to study Landscape Architecture and Recreation. Soil conservation was the primary management value, and people got to enjoy the recreational and aesthetic pleasures of exotic plantation forests like Whakarewarewa and Hanmer Forests.

And then it got parked. Having too many objectives is the enemy of efficiency, apparently. It also got in the way of the sale of forest assets. But then, did we actually need the language of multi-use to practice forestry in a way that maintained benefits over multiple rotations?

Multi-purpose forestry grew out of an environmental movement determined to see natural forests managed more for non-commercial environmental benefits than felled for wood products or bare land. As an idea and a movement it has been sustained in places where natural forests and habitats are particularly at risk of destruction with significant biodiversity and social consequences. In Aotearoa, the separation of natural and planted forests eliminated some of the need for a movement helped by a remarkably robust primary plantation species, a demonstrated commitment to re-planting and working in relatively resilient landscapes.

Forest owners also did their best to reassure by largely embracing market-driven environmental governance structures like Forest Stewardship Council certification (the management of approximately 65% of the country's plantation estate is now certified by FSC). As a concept, multi-use forestry seemed to be a bit of a family heirloom – interesting to dust off periodically as a reminder of another age, but not something we actually needed to mind. A bit like stage coaches or walking canes. Is it just me or has that now changed?

Policy and community interest in the non-wood benefits and costs of forests seems to break out on a semi-regular basis. People with no previous history of engaging in plantation forestry have been coming out with opinions that range from 'Whew, thankfully we planted some trees, we've got this' to 'Tut tut, can we trust those people to do the right things by the land and our people?' And, just like that, the language of multi-use forestry is back. Some of that language (like soil conservation, water quality, onshore processing and farm conversion) is exactly the same as it ever was, but some of it includes relative newcomers like health and safety, particulate control at ports and carbon. Some of it is due to now having clear-felled our way through some very difficult country, and some of it is down to changes and challenges in the world at large.

What has changed, however, is the way a broader view of costs and benefits of plantation forests is being encouraged. When you no longer own the forest a simple amendment to the Forests Act 1949 will no longer cut it. In this world, there are carrots (carbon credits, direct planting subsidies, Te Uru Rākau) and sticks (NES-PF, HSWA 2015). As it always is when complexity raises its head, the language is jargonistic and full of acronyms. But on the upside, the need for ethically applied expertise based on a distinct body of knowledge becomes greater. Someone has to lead the way through the maze.

In this and the next edition of the Journal, some of our best thinkers on the subject of multiple use forest management get to show off their work. Scion has been working with the Hawke's Bay Regional Investment Company and the Hawke's Bay Regional Council to understand the opportunity for a self-sustaining regional afforestation strategy aimed at using the potential of land to produce a commercial forestry return while reducing soil erosion and other environmental benefits. The papers in this edition introduce the project and then look at: identifying sites for potential afforestation across the erodible landscapes of the Hawke's Bay and the suitability of tree species within those sites; the afforestation of headwater riparian areas; the biomass and processing opportunities within the region; and the use of the Forest Investment Framework for valuing specific non-wood benefits.

In addition to the Scion contribution, there is a critique of some of the accounting approaches of the ETS. The 'Last word' wraps things up with an analysis of the structural conflicts that impact the sale and process of afforestation. All of it should give both Foresters and policy-makers something to think about when it comes to policy settings and decisions about what tree to plant and where.

Exploring the afforestation potential of steep eroding hill country in the Hawke's Bay region

Michelle Harnett

Abstract

We explore the opportunities for afforestation in the Hawke's Bay region of New Zealand to reduce soil erosion and to provide economic and environmental benefits. The work analyses broad-scale spatial information across a range of tree species and forest systems drawing on existing forestry projects and knowledge. The tools and information produced will help decision-makers understand the implications of different afforestation options to develop a self-sustaining regional afforestation strategy.

Introduction

Around 120,000 ha of land in the Hawke's Bay has been identified as highly susceptible to erosion, losing material at a rate of 1,000 tonnes per square kilometre per year (Figure 1). The majority of this comes from sediment moving from areas not protected by vegetation cover into waterways.

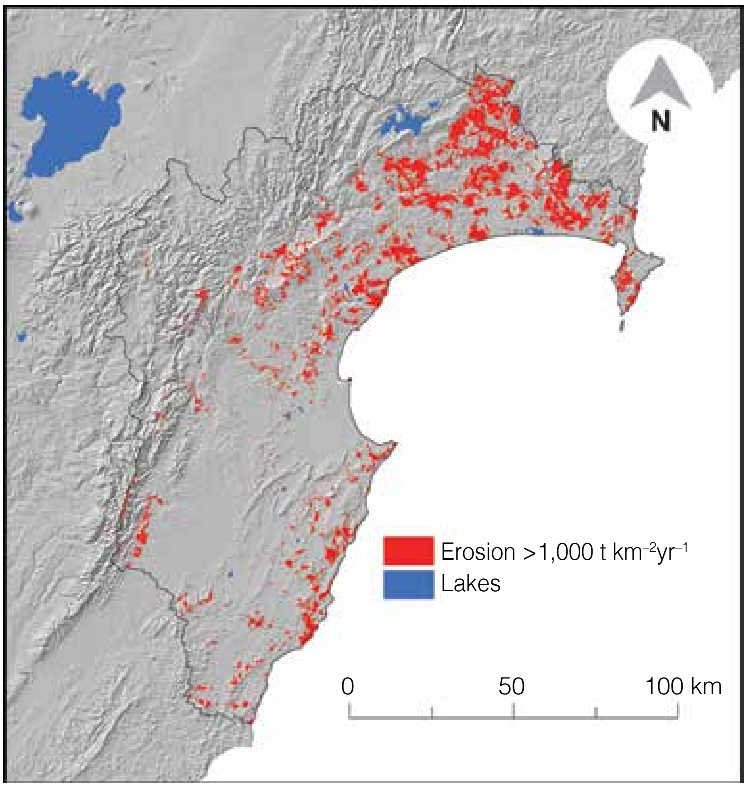

Figure 1: Areas where sediment yields greater than 1,000 tonnes of material per square kilometre per year can be expected across the Hawke's Bay region. Source: SedNetNZ

The Hawke's Bay Regional Investment Company (HBRIC) and the Hawke's Bay Regional Council (HBRC) want to explore and understand investment opportunities for afforestation, reducing soil erosion and providing both economic and environmental solutions to land use. The aim is to develop a self-sustaining regional afforestation strategy.

Erosion can be slowed and controlled by afforesting these vulnerable and unstable landscapes. Trees help protect the land from intense storm events by providing a canopy that intercepts rainfall, and roots that provide a structural integrity by binding the soil matrix together. Trees provide a range of benefits including water filtration, increased carbon sequestration, habitats for native flora and fauna, and opportunities for recreation and other ecosystem services.

The Ministry for Primary Industries (2019) One Billion Trees Programme has sparked discussions about what tree species to plant, where to plant them and for what purpose (right tree, right place, right purpose). The aims of the One Billion Trees Programme are to create employment, optimise land use, mitigate climate change, support Māori values and aspirations, protect the environment, and support New Zealand's transition to a low emissions economy. The Government has budgeted $120 million through the One Billion Trees Fund for grants to landowners, particularly farmers, to include trees on their farms.

This work explores broad-scale spatial information across a range of tree species and forest systems to provide a sound platform for future decision-making (Figure 2). This information will provide tools to ensure the HBRIC and HBRC have the right tree planted in the right place in the landscape, for the right purpose, to achieve positive outcomes for the environment, the economy and communities.

Right tree, right place, right purpose – regional screening

Identifying sites for potential afforestation across erodible landscapes in Hawke's Bay

Land Use Classes (LUC) and other factors (such as the degree of erosion, slope angle and whether slopes face the direction intensive storm events normally hit from) have been used by Scion spatial scientists to develop a series of 'Afforestation Groupings'. While LUC tends to be coarse in scale, incorporating the extra

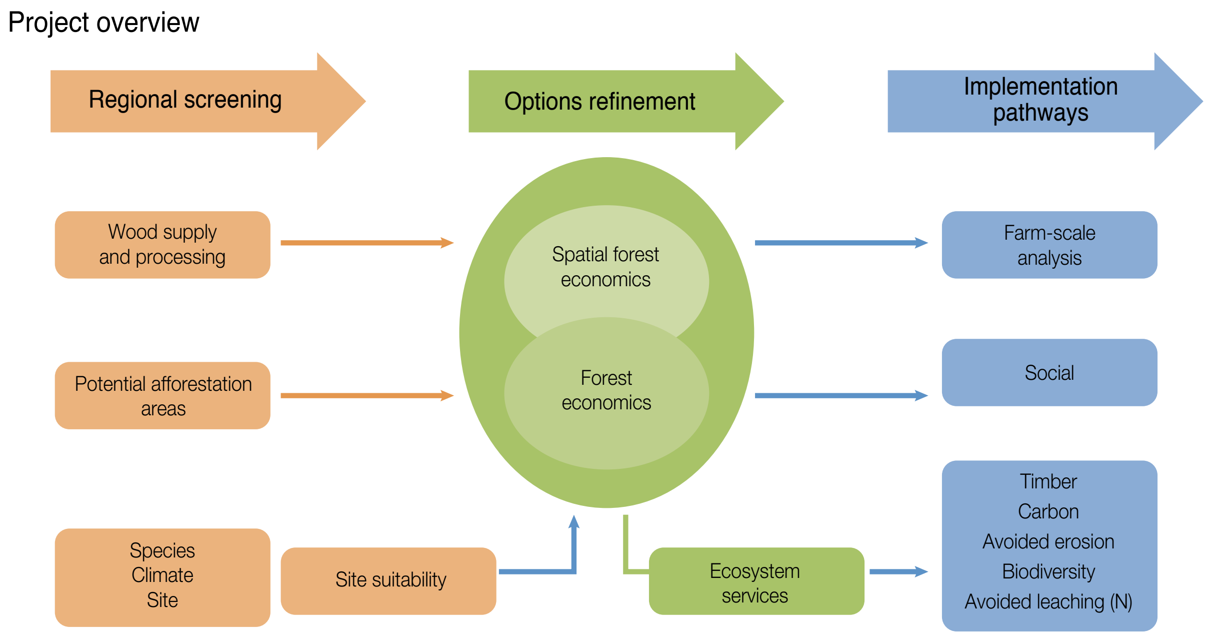

Figure 2: An overview of the 'Planting Eroding Hill Country in the Hawke's Bay Region: Right Tree, Right Place, Right Purpose' project

factors using fuzzy logic allows for the identification of highly erodible sites at a 625 sqm resolution. This level of detail will assist landowners with decision-making around which parts of their property would be most suitable for commercial forestry, or if permanent forests might be a better choice.

Spatial mapping of tree species site suitability for Hawke's Bay

Productive trees are those that survive and thrive under the conditions on a particular site. Maps of tree species site suitability in the Hawke's Bay have been developed by considering the environmental and climatic conditions where different species are currently growing, and the trees' productivity. The factors that come into play include temperature, rainfall, altitude, soil fertility and moisture availability, orientation to the sun, exposure to damaging winds or salt-laden sea spray.

Scion spatial scientists have developed tree species site suitability maps that show which species (or group of species) may be best suited to local conditions. However, it is not possible to claim that one forest system is better than another. The most important consideration is to optimally match each site and landowner to a forest system (or systems) considering site suitability, how well a species controls erosion, financial and market risk, and landowner aspirations.

Tree biomass resources and timber processing opportunities in Hawke's Bay

Increased afforestation on the scale proposed above has the potential to triple the Hawke's Bay timber supply over the next 30 years. The region has an existing plantation forest resource and an associated timber processing industry. The current wood supply is already adequate for timber processing to expand to provide around 500 jobs, $500,000 in GDP, and reduce the region's carbon footprint by utilising the surplus logs currently exported. With a growing supply, timber processing could expand, as could other industries that use large quantities of biomass such as biofuel production. Processing facilities that specialise in non-radiata species (e.g. coast redwood) will be needed if significant planting of other plantation species is to take place.

Forest economics – options refinement

Forestry options for planting eroding hill country in Hawke's Bay

A financial model has been developed to generate cashflows and financial outputs of potential species and regimes for afforestation in Hawke's Bay to assist individual landowners, the HBRC and HBRIC and local communities understand the implications of large-scale afforestation. The model can be used to compare the potential returns of different forest systems and species on different sites, and to understand how targeted incentives or regulations may be needed to achieve a desirable species mix (i.e. ensure native or other species are as equally attractive as radiata pine to a landowner). The model also provides data in a form useful for agricultural comparisons. (Note: The paper below will be published in the next issue of *New Zealand Journal of Forestry*.)

Spatial economic assessment of ecosystem services for potential afforestation areas in Hawke's Bay

Trees and forests provide benefits beyond timber, fuel and fibre. These include carbon sequestration, erosion control, flood mitigation, improved water quality, biodiversity and recreation resources. Together, the benefits people gain from the environment are known as ecosystem services. While many of these services do not have a market value, a non-market 'value' can often be calculated to better understand or appreciate these benefits compared with timber value.

The spatial economic tool Forest Investment Framework (FIF) developed by Scion has been used to quantify the broader value of potential forests in the Hawke's Bay for avoided erosion, reduced nutrient leaching and carbon storage.

The annual value of non-timber ecosystem services in highly erodible areas is typically one-and-a-half to two times greater than the value of timber. Or, for each dollar earned from timber, the region gains one-and-a-half times that value in ecosystem services. Other ecosystem benefits that have not been assigned values in this work include habitats for species such as kiwi and karearea, increased opportunities for recreation, and improved water quality.

Afforestation of headwater riparian areas – a review

Many of the areas identified for afforestation in the Hawke's Bay are in steep, erodible headwater catchments. These areas have the highest density of stream and riparian areas and comprise a large percentage of total stream length in many catchments. Unlike riparian areas downstream, those in steep headwater streams tend to be narrow and closely linked to their terrestrial and aquatic environments. Disturbances such as landslides, debris flows, droughts and floods (along with forest management activities) will have a strong influence on their function and condition. The state of headwater streams also influences the health of downstream waterways and their biological communities.

The ecosystem services provided by forested riparian areas in headwater streams may be able to be assigned non-market values using the economic modelling tool Forest Investment Finder.

Encouraging afforestation – implementation pathways

Knowing where and what to plant is only one factor. Landowners will have to be convinced that afforestation makes financial, environmental and social sense. Understanding financial implications, desired environmental outcomes and the effects on communities, the HBRC and HBRIC can consider how best to support landowners considering afforestation initiatives with

Erosion at the East Cape, near Gisborne

targeted funding (e.g. with knowledge and know how). The papers described below will be published in the next issue of *New Zealand Journal of Forestry*.

An overview of the economic advantages of planting production forestry on pastoral land

AgFirst Hawke's Bay demonstrates that there is a tipping point where trees make more sense than keeping land in pasture. Using a complementary approach, where less productive land is afforested and higher quality land is managed more intensively, can lead to higher overall farm returns. Land use assessment needs to be done at a whole-farm level, rather than on a gross margin/ha basis. Landowners need to analyse their returns down to a LUC level and be aware of the relativities that exist between these classes. Not doing this can lead to the value of the better land being underestimated while the value of poorer land is overestimated.

Higher resolution land inventory mapping would facilitate the process of comparing and selecting appropriate areas to consider for forestry. Wider education addressed to farmers and other rural professionals on forestry, the benefits of better land use selection and its potential would be also help with efforts to afforest highly erodible land.

Landowner attitudes to afforestation in the Hawke's Bay region of New Zealand

Business consultants, Fresh Perspective Insight, have delved into landowner attitudes to afforestation. Each landowner's situation is unique and therefore has its own blend of factors, drivers and barriers when it comes to looking at tree planting or any other strategic-level decisions about land use. However, there are a set of core drivers and barriers that can be understood and addressed to increase the likelihood of landowners planting trees. This includes an approach that looks at each property individually and recognises that the range of potential benefits can be achieved through purposeful tree planting.

There is also a clear gap (and opportunity) for a central support and guidance system to work alongside landowners to understand their objectives and constraints, and to develop long-term plans that fit with the needs and expectations of landowners.

Summary

Planting highly erodible land in the Hawke's Bay in plantation forests could increase financial returns from land and, for each dollar earned, provide one-and-a-half times the value in avoided erosion, avoided nitrogen leaching and carbon sequestration. Also, new forests could provide habitat for species like kiwi and karearea, and the benefits from regenerating headwater streams and riparian areas would flow to downstream waterways.

Landowners have valid concerns around the financial, environmental and social implications of afforestation for them, their land and the wider community. Detailed information on the areas that are most susceptible to erosion and which alternative tree species and forest systems are most suitable on these sites, and the financial implications of investing in afforestation, will assist landowners with decision-making.

The HBRC/HBRIC can use the same information as a basis to develop environmentally sustainable and economically self-sustaining afforestation in the region. This is likely to include working alongside landowners to understand their objectives and constraints and develop a long-term plan that fits with the needs and expectations of the landowner, providing support from consultants and industry experts and using targeted funding to ensure desired species are planted. Non-market benefits beyond erosion also need to be promoted, as does job provision to increase community acceptance of wider tree planting.

A community dynamic that encourages responsible planting activity is also highly desirable. This can be helped by promoting non-market benefits beyond erosion to include increased resilience to climate change and carbon sequestration to support a move toward regional carbon neutrality. It is also important that new forests are seen to be providing jobs, whether opportunities for local people to participate at all stages of the forestry value chain through to new timber processing plants and high-value secondary processing.

The project is potentially transformational and integrates existing forestry projects and knowledge. It provides tools and information that will help decision-makers (including iwi, landowners, the wider community, and regional and national government) understand the implications of different afforestation options to develop a strategy that sees the right tree planted in the right place for the desired outcomes.

Acknowledgements

The project was a major collaborative effort that brought together people from forestry and farming, the council and the wider Hawke's Bay community, with about 70 people contributing to the final work. The main contributors included Scion, PF Olsen, AgFirst Hawke's Bay, Fresh Perspective Insights and RedAxe Forestry Intelligence. Special thanks also to Dave Bergin (Environmental Restoration Ltd), Stephen Lee and Maggie Olsen (Manuka Farming New Zealand) and Paul Millen (New Zealand Dryland Forests Initiative). Funding was provided by MPI/Te Uru Rākau under the One Billion Trees Programme.

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Identifying sites for potential afforestation across erodible landscapes of the Hawke's Bay region

David Palmer, Kit Richards, Robin Black, James Powrie, Tim Payn and Mike Marden

Abstract

Identifying the right landscape in which to establish a plantation species is critical for economic and environmental sustainability. Hawke's Bay, like the rest of New Zealand, has a range of landscapes from the fertile low-lying alluvial plains through to elevated steep land. As the landscapes become increasingly elevated and steep, so do environmental issues related to commercial forestry operations. Typically, with higher elevations and steeper landscapes soils can become increasingly eroded and skeletal, leaving them vulnerable to degradation when not protected by woody vegetation. In this paper we identify landscapes that are skeletal, eroded, vulnerable and suffering from climatic extremes, which are best suited to retirement plantings that will retain environmental quality and hold these landscapes together. Conversely, we also identify landscapes that have potential for commercial forestry. This project's mapping approach utilises Land Use Capability (LUC) to delineate tree landscape (TreeScape) classes by identifying locations where commercial afforestation is suitable, compared to landscapes that should be retired. Greater mapping detail is gained by combining the LUC maps with the erosion, slope and direction of intense storm events maps.

Introduction

The planting of trees across New Zealand's most vulnerable and unstable landscapes provides benefits, including reducing soil erosion. The potential for plantation forestry to reduce erosion by up to 95% is well documented. This occurs after an initial six to eight-year window of vulnerability until the newly planted crop develops and canopy closure takes place (Marden & Rowan, 1993; Baillie & Neary, 2015).

To ensure the right tree is in the right place, for the right purpose, the Hawke's Bay region requires a strategy that identifies: (1) the purpose of the afforestation (e.g. commercial, erosion protection, water filtration, carbon sequestration, biodiversity); (2) which tree species we should plant (e.g. exotic or native, their potential for surviving in different environments, disease resistance, resistance to drought and low nutrient substrates); and (3) where these plantings can or should take place (e.g. landscape position, erodible landscapes, riparian setbacks).

In this paper we divide the landscape at a broad level using the New Zealand Land Use Capability (LUC) classification, supported by expert knowledge and statistical approaches to delineate the landscape at a finer scale than that possible with the broad 1:50,000 LUC mapping. The aim was to partition the landscape into: Afforestation Groupings that are suitable for commercial plantation forestry for timber; and other groupings more suited to a permanent forest cover and the provision of other ecosystem services, such as erosion control or non-timber forest products like honey production.

Methods

Partitioning the landscape – LUC spatial data

LUC classifications enable the land to be described according to its capacity to support long-term sustained production based on an assessment of factors, such as climate, the effects of past land use and the potential for erosion (Lynn et al., 2009). The New Zealand LUC comprises eight classes with lower classes (1, 2, 3, 4 and 5) generally suitable for a wide range of land uses, such as dairying, cropping and horticulture. Higher classes (6, 7 and 8) are generally less suitable for intensive agriculture, with production forestry usually confined to low-producing pasture on classes 6 and 7, whereas class 8 is generally better suited to indigenous protection forests.

The LUC classification maps were developed at coarse (>1:50,000 map scale) spatial resolutions. In other words, 1 cm on a map represents 50,000 cm (500 m) on the Earth's surface, which is considered to represent the regional level. Although this information is extremely useful in the delineation of erodible land suitable for forestry at a coarse scale, deriving information useful at the 'farm-scale' remains problematic.

Using the New Zealand Land Resource Inventory and LUC extended legends for the Hawke's Bay and local expert forestry knowledge, we developed the Afforestation Groupings 1 to 9 (Table 1 and Figure 1). Generally, lower values occur across down lands and alluvial landscapes where gentle slopes and erosion are minimal, and where there are few limitations to commercial forestry for timber. However, as grouping values increase, so does the risk and severity of erosion across steeper landscapes where rock and soil types are prone to erosion.

Skeletal soils have been specifically identified as generally unsuited to large-scale afforestation for timber harvesting as they are vulnerable to mass failure (e.g. shallow landslides), resulting in debris flows such as during intense and/or prolonged periods of rainfall. As these problems are likely to become more frequent with changing climate patterns, much of the land in Group 7 should be retired. Group 8 lands (non-productive, high altitude and highly eroding landscapes) should also be retired and permitted to revert to native forest.

'Earthflows' are deeper-seated forms of mass failure, and although widespread they are slow moving. Large-scale tree planting options, including poplars and willows, are well proven in these areas subject to other constraints and landowner objectives.

Table 1: Afforestation Groupings overview

Group	Area (ha)	Description	Potential predominant use
1	233,568	Generally alluvial valleys or terraces, fertile, lower altitude	Commercial timber forests
2	98,180	Generally rolling-to-steep on hard geology, fertile and lower altitude	Commercial timber forests
3	74,289	Rolling-to-steep, prone to some forms of sheet, rill or gully erosion	Commercial timber forests
4	42,656	Area with varying topographies and climatic, altitudinal and erosion limitations	Commercial timber forests
5	273,235	Moderate-to-steep landforms that are prone to soil slip or sheet and gully erosion under pasture	Commercial timber forests
6	14,560	Limited productivity under grazing on steeper terrains and prone to gully erosion	Commercial timber forests
7: Skeletal	319,777	Limited productivity under grazing, thin soils on steeplands, vulnerable to debris flow/debris avalanche initiation	Permanent forest cover
8: Reversion	323,210	Generally steep uplands subject to high rates of natural or induced erosion	Permanent forest cover
9: Earthflow	125,630	Generally moderate-to-rolling hill country subject to deep-seated mass earthflow erosion	Commercial timber forests

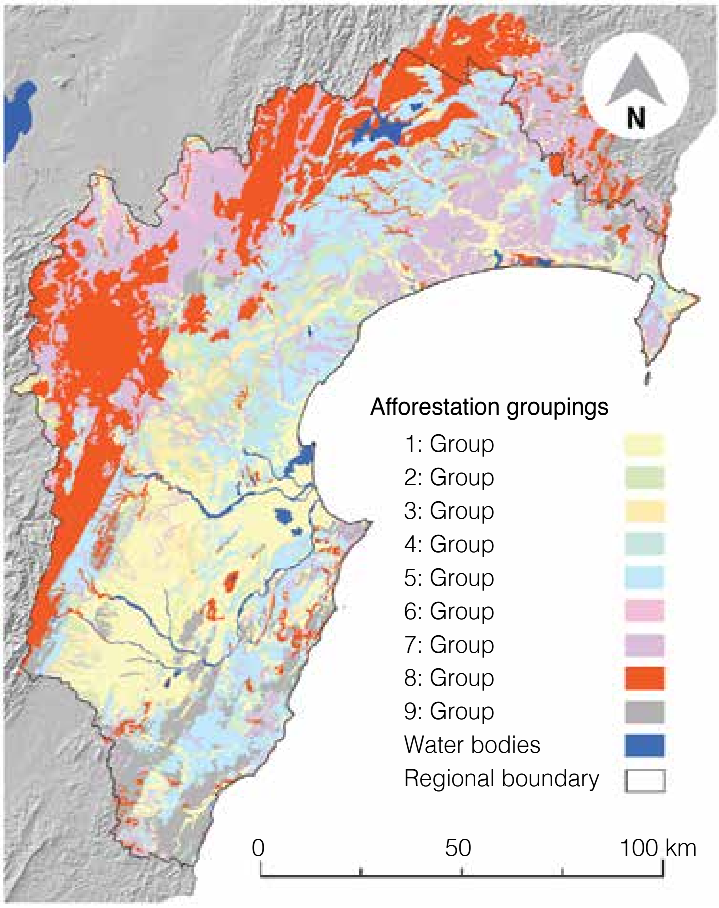

Figure 1: The nine Afforestation Groupings representing the Hawke's Bay region catchments developed by grouping LUC units

Refining the Afforestation Groupings using fuzzy logic

An analysis using the LUC data at the regional level is appropriate for assessing regional trends, but it is unable to delineate forestry information at the land user level desired in this project. Consequently, we explored methods that could provide improved spatial representation of erosion relevant to afforestation.

We used fuzzy logic to improve the spatial resolution of the LUC units and the Afforestation Groupings. Fuzzy logic approaches are used to manage vague and fuzzy concepts and potential uncertainty. Fuzzy membership (fuzziness) provides an indication as to what degree a property of interest belongs to a class, or degree of membership (DOM). In geospatial terms, fuzzy logic can be used to manage uncertainty and vagueness in a property where a statement can be true (value = 1.0), false (value = 0.0), or somewhere in-between.

Both the literature and expert knowledge have suggested that prime candidates for use in the fuzzy logic approach were degree of slope, direction or aspect and sediment yields. The workflow used in this project is illustrated in Figure 2.

Effect of slope – slope fuzzy membership

Erosion can occur to some slight degree on slopes less than 5°, then increases substantially from around a 15° slope to a maximum between a 35° and 40° slope according

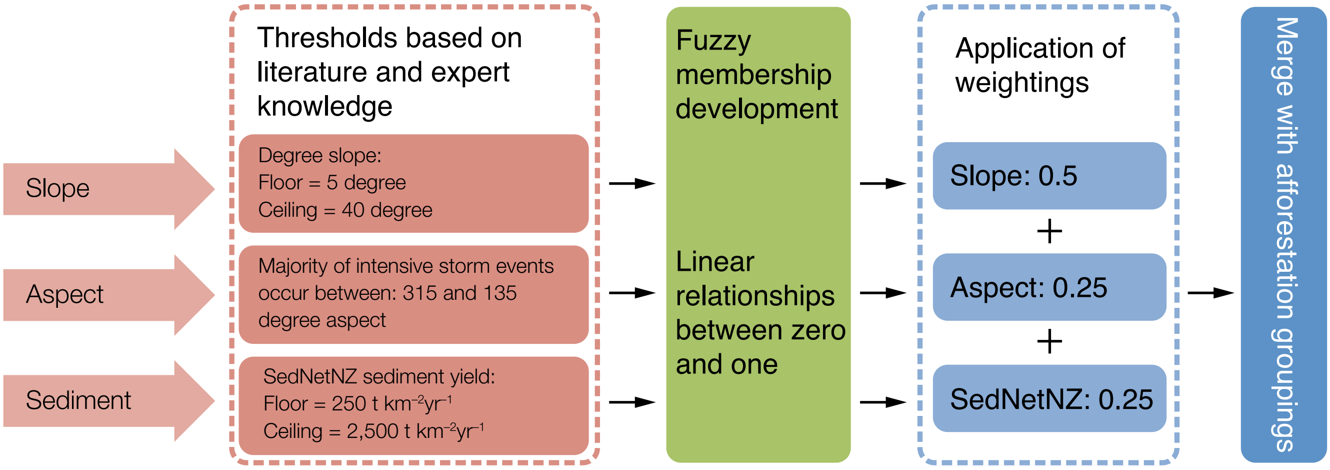

Figure 2: Workflow used in the development of greater detail for LUC and the Afforestation Groupings

to the New Zealand erosion literature (Betts et al., 2017; Dymond et al., 2006). This is shown as a theoretical response curve in Figure 3, which is based on expert knowledge and represents what is considered the typical or expected impact of slope on erosion suitable for use in fuzzy membership calculations. Where slope is below a floor of 5°, erosion is unlikely to occur (degree of fuzzy membership = 0.0 false); above a 40° ceiling, erosion will definitely occur (degree of fuzzy membership = 1.0 true).

Effect of the direction storms approach from – aspect fuzzy membership

Historic data for the North Island of New Zealand (Hancox & Wright, 2005; Marden & Rowan, 1995) and erosion experts suggest that most intense storms approach from the northwest to southeast aspects (M. Marden, pers. comm., 2019). However, for the East Coast region, the dominant direction tropical cyclones arrive from is the northeast. Southerly storm events have less impact on slope failure and erosion contribution.

We therefore assumed the DOM for aspect would be highest for northeasterly-facing slopes, i.e. the aspect has an impact that is true (value = 1.0 true). West, south and southwest-facing slopes were assumed to have a low DOM, but as there is still likely to be some erosion risk on these slopes we used 0.04 to reflect this low risk. In-between slope aspects were assigned intermediate DOMs (see Figure 4 for details).

Effect from the level of sedimentation – sediment fuzzy membership

The SedNetNZ model predicts the mean annual suspended sediment for each sub-catchment throughout a river network (Palmer et al., 2013). Land with SedNetNZ yields greater that 1,000 t km^{-2} yr^{1} is considered highly erodible (Betts et al., 2017; Dymond et al., 2016). Using SedNetNZ sediment yield, we developed a sediment response curve where sediment yields <250 t km^{-2} yr^{-1} were valued as zero (degree of fuzzy membership = 0.0 false) along a continuum rising to a ceiling of 2,500 t km^{-2} yr^{-1} (degree of fuzzy membership = 1.0 true) (Figure 5), to identify locations that would benefit from the planting of protective forests.

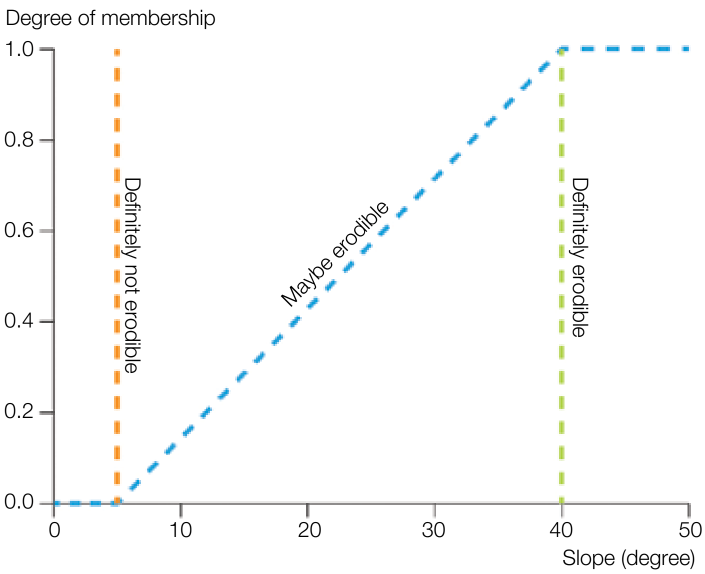

Figure 3: Response curve development for slope in relation to erosion showing a theoretical floor (5° slope) and ceiling (40° slope)

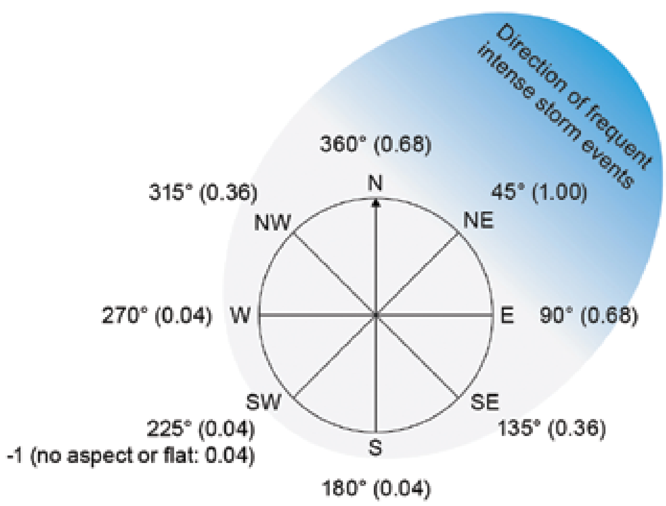

Figure 4: The predominant direction that frequent intense storm events approach the Hawke's Bay region. Fuzzy membership values associated with the degree of truth are given in brackets

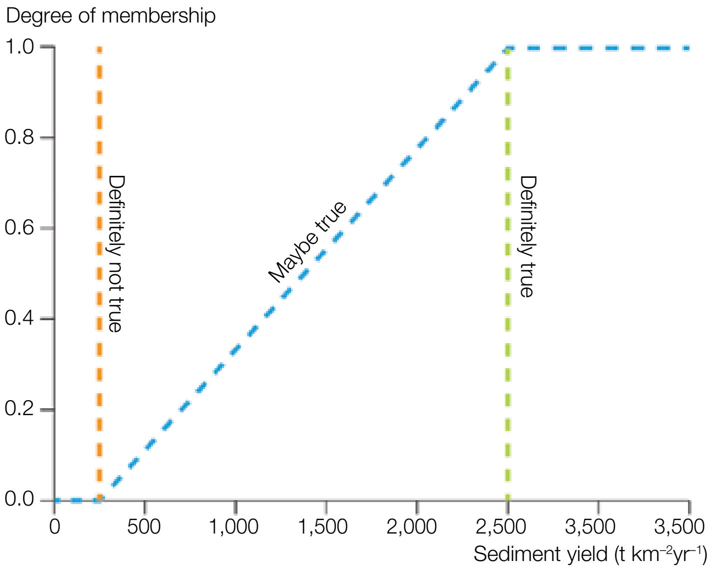

Figure 5: Fuzzy membership response with a sediment yield floor of 250 t km^{-2} yr^{-1} through to a sediment yield ceiling of 2,500 t km^{-2} yr^{-1}

The Hawke's Bay Regional Council believes that sediment yields greater that 1,000 t km^{-2} yr^{1} is a reasonable target above which to aim for protection from some type of woody vegetation (Barry Lynch, HBRC, pers. comm., 2019).

Weighting of fuzzy values in the development of Afforestation Groupings

For slope, aspect and sediment yield we used the floor and ceiling values defined above, and normalised the remaining data to values between zero and one, to develop digital surfaces at a 25 m cell size resolution with a New Zealand Transverse Mercator (topological) projection.

The three variables – slope, aspect and sediment – will have different degrees of effect on the refined groupings and need to be weighted to reflect that. Therefore, we applied a weighting to each layer or raster, based on the authors', industry and local expert knowledge, and used Equation 1 to bring the fuzzy membership rasters together into one value.

Total fuzzy membership weightings = (slope x W) + (aspect x W) + (sediment yield x W) (1)

where W refers to the weighting for each property

As an example, the slope weighting was set to 0.50, and aspect and sediment both set to 0.25 to generate Afforestation Groupings for the area around Lake Tutira (Figure 6).

Results and discussion

Using the fuzzy data, we were able to refine the Afforestation Groupings to a finer scale. Note that fuzzy membership relationships were not applied to Afforestation Grouping 9, earthflow erosion, as it is driven by different erosion factors compared to other erosion types.

An example of the Hawke's Bay area around Lake Tutira demonstrates the impacts of including fuzzy membership (Figure 6) in identifying areas that could benefit most from afforestation to control erosion (darker blue and purple areas). Local, industry and spatial experts attending a workshop in May 2019 assessed the results and stated that the Afforestation Groupings with fuzzy membership were a substantial improvement providing spatial detail of erosion risk not available from the LUC classes alone.

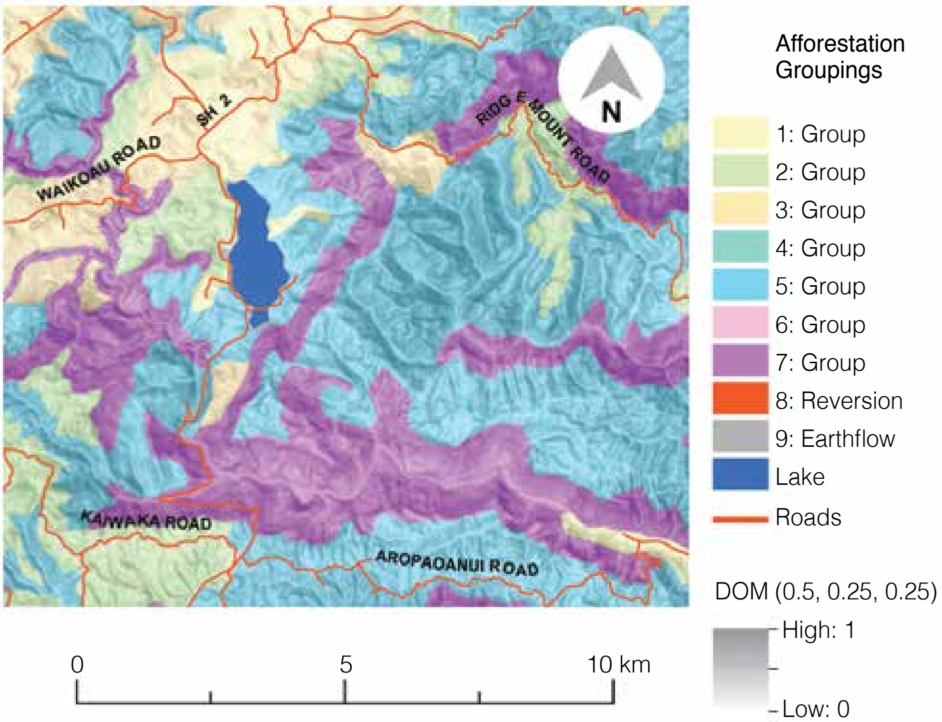

Figure 6: Close-up map of Lake Tutira area showing the effect the Afforestation Groupings together with fuzzy membership weightings of slope 0.5, aspect 0.25 and sediment yield 0.25

Other spatial datasets that represent erosion are all derivatives to some degree of the LUC and Land Resource Inventory (LRI) data that we used to develop the Afforestation Grouping layers. Therefore, to use the Highly Erodible Land (Dymond et al., 2006) the New Zealand Empirical Erosion Model (Dymond et al., 2010), or the Erosion Susceptibility Classification (ESC) (Bloomberg et al., (2011), would likely over-represent erosion during any fuzzy membership analysis.

In the future, should a national modelling of Afforestation Groupings be required then a possible candidate to replace the SedNetNZ erosion data (as national coverage is not available) would be the ESC (Bloomberg et al. 2011). The

ESC has the advantage that it represents a continuum of erosion severity, it has been updated in recent years to reflect forestry management needs, and it is recognised for its applicability in national environmental standards for plantation forestry.

Sediment generation and delivery using SedNetNZ currently operates at a 15 m cell size resolution. SedNetNZ utilises data that is dependent on the information originally associated with the coarse resolution (~1:50,000 map scale) LUC units, as do most New Zealand erosion models and surfaces. The development of slope and aspect at finer resolutions has the potential to improve representation of the landscape and erosion modelling. To improve sediment, or more generally erosion modelling, requires future work that could utilise new remote frontier technologies. For example, this could be achieved through the capture of LIDAR data, with enough ground returns to represent the landscape at cell size resolutions between 5 m and 10 m.

Conclusion

The Afforestation Groupings we have developed will help landowners and regional bodies make informed decisions around the right tree in the right place in the landscape. The fuzzy membership approach was used to improve the spatial resolution at which soil erosion risk can be mapped, and therefore the protection that could be obtained from forests established on these landscapes. With visual inspection of the Afforestation Grouping fuzzy membership maps, the improvement seems realistic.

The overarching premise for developing the Afforestation Groupings from the LUC units was to identify locations in the Hawke's Bay suited to afforestation with commercial plantings, compared to sites with limitations that may require:

- Approaches such as retirement, reversion or potentially carbon sinks with permanent forest cover, or
- Other ecosystem services, such as the filtration of water and erosion reduction. Afforestation Groupings will provide a useful resource in the decision-making process for positioning the right tree, for the right purpose, in the best position in New Zealand's landscape.

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Wood supply and timber processing options in the Hawke's Bay

Peter Hall and Michelle Harnett

Abstract

The existing and projected future wood supply in the Hawke's Bay could support expanded timber processing. Unpruned log supply is forecast to dip between 2034 and 2044, but planting 10,000 ha of radiata pine over the next five to 10 years under a short to mid-length rotation regime could stabilise this supply. Increasing afforestation would open up options for establishing processing clusters with other industries, using wood and forest residues to replace industrial fossil fuels and produce liquid biofuels such as diesel. Increasing processing options would lead to increasing employment, contribute to New Zealand's gross domestic product (GDP) and reduce greenhouse gas (GHG) emissions.

Introduction

The Hawke's Bay has an existing plantation forestry resource of around 133,710 ha and an associated wood processing industry. The age class distribution of the existing forest resource is uneven and therefore the potential harvest volume over time is uneven. Approximately 98% is planted in radiata pine. The other species established as plantations in the Hawke's Bay are Douglas-fir (446 ha), cypresses (372 ha), 919 ha of other softwoods, 927 ha of *Eucalyptus* and 498 ha of other hardwoods.

The current harvest is around 3 million m^3/p.a., which equates to around 4,600 ha/year. Onshore processing takes around 1.3 million m^3/p.a. (~44% of the annual harvest). The rest is exported, largely as logs. Logs are also supplied to other regions when log demand and forest locations make sense for this to happen (e.g. northern part of Wairoa District to Gisborne).

Establishing new plantation forests to address issues of hill country soil erosion, water quality, water supply and carbon capture will increase the volume and types of wood available. In this paper, we assess the existing planted forest resources and wood processing infrastructure and the potential for expanded onshore processing with increasing afforestation.

Wood supply

Available log volume over time in the Hawke's Bay can be estimated using the Ministry for Primary Industries (MPI) National Exotic Forest Description (NEFD) (MPI, 2018) and MPI yield tables. Further data is available from the MPI wood availability forecast for the Hawke's Bay (MPI, 2014). We used Scenario 3 from the Hawke's Bay wood availability forecast (MPI, 2014) to estimate *Pinus radiata* resources, as it was considered the most likely of the possible future wood supply and harvest volume options and is similar to most of the other scenarios (2, 4 and 5). The exception is Scenario 1, which has no smoothing of the peak in wood supply associated with the 1990s planting boom. Volumes of forest harvest residues can also be derived from the potential harvest volumes based off estimates of the proportion of a crop that is discarded on cutover and at landings (Hall, 1994, 1998 & 1999). Estimates for volumes from other species were derived from the 2018 NEFD (MPI, 2019).

Log supply variation

The potential log supply over time in the Hawke's Bay is shown in Figure 1. Pruned log volumes decline over time with long-term sustainable availability to the order of 250,000 m^3/p.a. Pulp log supply is relatively steady with long-term availability at around 500,000 m^3/p.a. Unpruned log supply drops significantly between 2034 and 2044, but is likely to be more than 1.5 million m^3/p.a. in the long term. The unpruned sawlog grades (S, A and K) have similar trends (not shown).

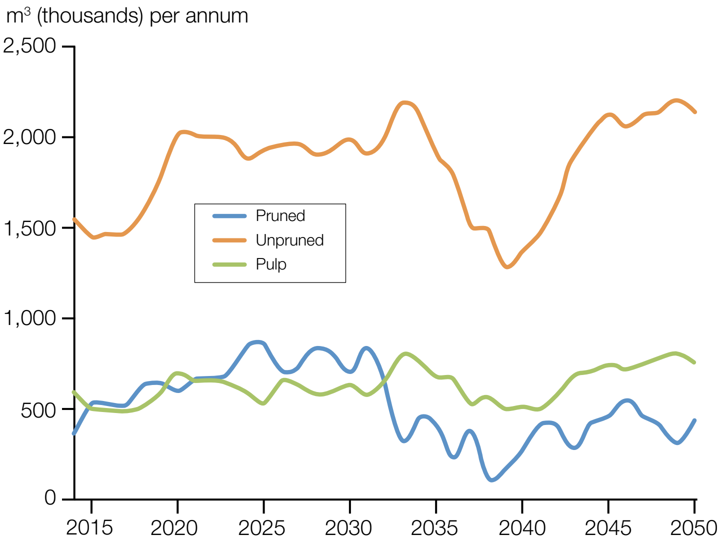

Figure 1: Estimated log supply in the Hawke's Bay

The inconsistency in supply by log grade is a problem when it comes to developing expanded domestic wood processing. However, the reduction in supply occurs around 2035 to 2037 onwards. The log supply could be stabilised at its the current level by planting 10,000 ha of radiata pine over the next five to 10 years. Utilising a 16 to 17-year rotation, and a stocking rate of 500 stems/ha with no thinning, could give a harvest volume of around 500 m^3/ha depending on the site (West, 2018a & 2018b). This regime gives a mix of log grades, including small knot logs.

The long-term wood supply available for expanded wood processing under this medium length rotation scenario would be in the order of 1.6 to 1.7 million m^3/p.a. of unpruned saw logs.

Expanding wood processing

The wood processing industry is dynamic and a complete dataset of all processors is not publicly available. However, 12 were identified in the Hawke's Bay (processing about 1.3 million m^3/p.a.) using the Scion wood processing database (Scion, 2017), which captures all major wood processors along with many of the smaller and secondary ones. The log surplus of around 1.8 million m^3/p.a. is currently mostly exported from Napier. This surplus could support expanded processing, especially if the wood supply is smoothed out as suggested above.

The opportunities for expanding wood processing can be modelled using the WoodScape model (Jack et al., 2013), which estimates the expected returns from various wood processing options from a common basis. The principal measure used is return on capital employed (ROCE). We modelled the primary and secondary solid wood processing of radiata pine, including mills that would fit with the long-term wood supply from the existing plantation resource. Large pulp and fibre panel mills were not included as their volume demands are larger than the supply.

The processing options with high-risk adjusted ROCEs (>20%) that fit with wood resources were:

- Manufacture of big squares from K grade logs
- Optimised Engineered Lumber™ (OEL™) using K grade logs
- Appearance and/or structural sawmill with a CLT plant, or one that is involved in the remanufacture of appearance grade products
- Where adequate log supply for the plywood mill is marginal, but has a ROCE of 29%, the mill would have to use a mix of log grades to make an industrial ply.

If this expanded wood processing was taking around 700,000 m^3/p.a., it would provide about 430 to 440 direct jobs and contribute $440 to $450 million to the country's gross domestic product (GDP).

New radiata planting impact on processing opportunities

Smoothed wood supply

Increasing long-term wood supply in the Hawke's Bay to approximately 3.0 million m^3/p.a., by eliminating the dip in wood supply around 2035 to 2045, would allow timber processing to expand further to about twice the size of that based off the current estate.

The expanded wood supply would have a minimal effect on the ROCEs of the various timber processing options listed above, meaning the selection of these options would not change. A plywood mill taking around 600,000 m^3/p.a. of log intake might be considered, but with an ROCE of about 29% under current conditions this is marginally lower than the return from the sawmilling, cross-laminated timber (CLT) and remanufacture options.

Planting for erosion control

If half of the approximately 130,000 ha of erodible land in the Hawke's Bay that has been identified as suitable for afforestation were planted in radiata pine, a considerable future resource would come online in the next 20 to 30 years. A forest establishment plan spreading the planting and using regimes with different rotation lengths could ensure a stable wood supply of 4.5 million m^3/p.a. The expanded estate would allow a significant expansion of onshore wood processing in the long term.

Beyond timber processing

Industrial symbiosis

An 'industrial symbiosis' is a local collaboration where different industries provide, share and reuse materials, energy, water and/or by-products to create shared value. Resources are used more efficiently by the group than by any individual company. The possibilities of establishing industrial clusters to reduce

Milled tōtara

waste and greenhouse gas (GHG) emissions, create jobs and contribute to New Zealand's bottom line are substantial.

Opportunities for industrial symbiosis based around wood processing have been identified in the Hawke's Bay using maps of forestry resources and industrial process heat demands, a model to estimate wood and harvest residue supply, and the WoodScape model (Figure 2).

The significant quantity of logs being exported from the Hawke's Bay via the Port of Napier (and wood and forest residues) represents an opportunity to expand wood processing and use wood resources for industrial heating. This could replace the coal that is currently being used for industrial heating at Awatoto near the port of Napier, and at Wairoa.

There are sufficient residues from in-forest harvesting to meet two-thirds of the demand for industrial heating at Awatoto if the suite of wood processing options (sawmill, CLT, remanufactured wood and OEL™) mentioned above was established. While these processing plants would require substantial capital investment (~NZ$204 million), they could provide up to 566 direct jobs and up to 1,503 indirect. The total increase in GDP would be in the order of $518 million p.a. and GHG reductions around 15,000 tonnes/p.a.

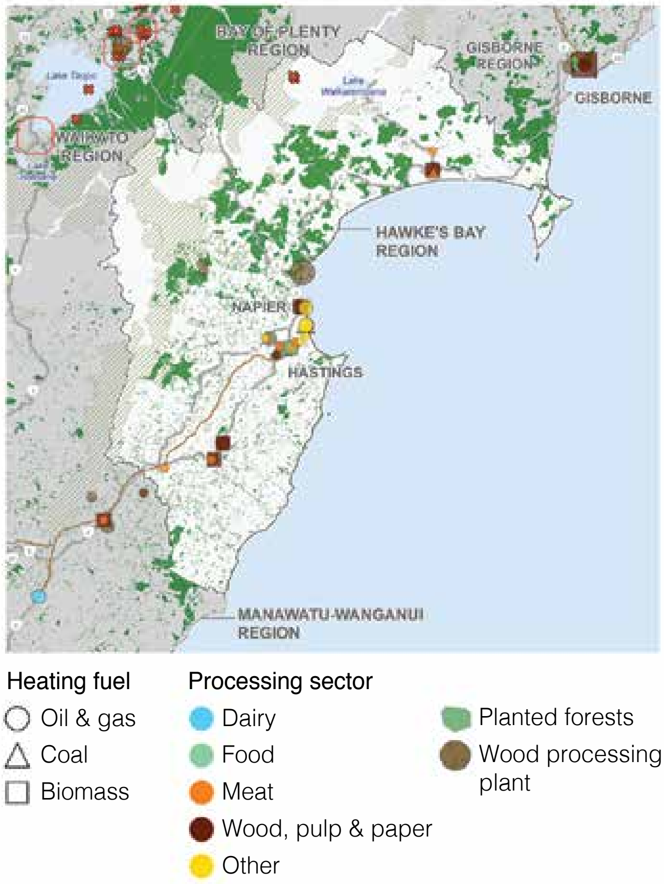

Figure 2: Planted forests and existing wood processing and other industries in the Hawke's Bay – opportunities for wood energy industrial symbiosis

In Wairoa, there is sufficient wood supply and in-forest residues to allow expanded wood processing and meet the energy demand of the local coal-fired meat works. A plant at Wairoa would require around $57 million of capital investment and could have up to a 30% return on investment. It would provide 81 direct jobs and 216 indirect, while adding $159 million to GDP, and reduce GHG emissions by 30,000 tonnes/p.a.

Biofuel opportunities

Biofuel production from forestry waste is another processing option. The Scion report – *New Zealand Biofuels Roadmap: Growing a Biofueled New Zealand* (Scion, 2018) – found that large-scale biofuel production to produce drop-in diesel, petrol and other fuels was feasible. The work started from the premise that fuel would still be needed for vehicles such as heavy trucks, farm and construction vehicles, and machinery and shipping that may be difficult or impractical to electrify. Using heat to reduce biomass to a crude bio-oil (pyrolysis), followed by upgrading the bio-oil, was found to be one of the most promising technologies, especially when primary processing was located close to forests.

The most suitable places for planted energy forests included the Hawke's Bay and the East Coast. In one scenario for Gisborne/East Coast, establishing biofuel production would require an extra 75,000 ha of forest, building pyrolysis and upgrading plants (with nearly one billion dollars in capital investment), and create over 1,000 jobs.

Non-radiata pine timber species

Non-radiata pine timber species are in a catch 22 situation. Small volumes and processing uncertainty affect price certainty, which in turn tends to limit planting.

The current supply volume in the Hawke's Bay region is very modest (Table 1). The only species that have current attractive financial metrics for wood processing are some *Eucalyptus* species and coast redwood. Cypresses from some stands are not attractive for processing, largely due to the comparatively low recovery rates of quality lumber that sometimes occur. Douglas-fir has limitations on where it should be planted due to its propensity to create wildings.

Table 1: Long run supply volume (m^3) – no new planting

Region	Douglas-fir	Cypresses	Eucalypts
Hawke's Bay	2,000	3,000[1]	1,000

[1] = after 2038

Options for processing timber from other species will depend on the volume available on an annual basis. For quantities up to 10,000 m^3/p.a., a portable sawmill is a viable option. Tōtara, cypresses, *Eucalyptus* etc could be milled this way. Another processing option could be a small (<25,000 m^3/p.a. of logs in) specialty mill able to process a range of species, or a small sawmill with a head rig with the ability to process a mix of species with a capacity of 30,000 to 50,000 m³/p.a. Ideally, sawmills would be aligned with secondary processors manufacturing value-added products suited to the species, such as using cypress for cladding/outdoor furniture, tōtara for furniture or carving, *Eucalyptus* for flooring, and coast redwood for cladding or to export to the US. Any mill/processor would need the capacity to carry out specialist drying regimes. *Eucalyptus*, for example, often require long periods of air drying.

New non-radiata pine forest impact on processing opportunities

The impact of any new plantings of non-radiata pine timber species on processing opportunities can only be assessed after analysis of the area to be planted and the planting schedule. This impact is unlikely to change the processing type, or the cost of logs, and will have no effect on the price of the products. However, it may influence the scale of the operations that are possible. Larger operations tend to have some advantage from economies of scale.

If there is the desire to promote the planting of different species mixes, it is important that the Hawke's Bay Regional Council (HBRC) and Hawke's Bay Regional Investment Company Ltd (HBRIC) consider options for primary and secondary processing, as well as the marketing of specialty timber, well in advance.

Summary and recommendations

The Hawke's Bay has a significant planted forest estate of around 133,000 ha, the vast majority of which is radiata pine. The log supply varies over time. A dip forecast for the 2030s could be smoothed by planting 10,000 ha of radiata pine over the next five to 10 years and growing them under a medium length rotation regime of 16 to 17 years. Under this scenario, 1.6 to 1.7 million m³/p.a. annum of unpruned saw logs could be produced from the existing and potential new forest estate.

Expanded timber processing is possible as currently the supply of radiata pine saw logs exceeds local processing demand and around 700,000 m³/p.a. are exported. Based on the existing planted forest estate, sawmilling coupled with CLT and the remanufacturing of lumber were assessed as being financially attractive, along with OEL™ and the sawing of L grade logs into big squares for export. Expanded timber processing would provide in the order of 430 to 440 direct jobs and contribute about $440 to $450 million to GDP.

Smoothing the supply using a medium length rotation regime would allow timber processing to expand to about twice the size of that based on the current estate.

Further production forestry planting of around 60,000 ha for erosion control (half the land identified as highly vulnerable) adds to the resources available, and it opens up the possibility of building energy self-sufficient primary production processing clusters. Clusters near Napier and Wairoa would reduce the reliance on fossil fuels (reducing GHG emissions) and contribute hundreds of jobs and hundreds of millions of dollars to the country's GDP. Turning forests and forest residues into liquid biofuels is a further option for utilising forest biomass.

Only a few thousand hectares in the Hawke's Bay are planted in non-radiata timber species. Of those, only some *Eucalyptus* species and coast redwoods have attractive financial metrics for timber processing. If the regional council and other bodies are serious about developing an alternative timber industry, there is a need for investment in developing options for primary and secondary processing and market development.

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Afforestation and ecosystem services in the Hawke's Bay region

Richard Yao and David Palmer

Hawke's Bay landscape illustrating the soil erosion protection provided by planted forests and the vulnerability of steep slopes to erosion when woody vegetation is absent. Source: Peter Scott of Above Hawke's Bay

Abstract

Plantation forests provide benefits beyond timber. However, these non-timber benefits (avoided erosion, avoided nutrient leaching) do not have market values and are often overlooked in decision-making. This study describes a spatial economic assessment of the timber and non-timber values of potential plantation forest areas in the Hawke's Bay. The assessment tool – the Forest Investment Framework (FIF) – was used to spatially quantify the value of timber, carbon sequestration, avoided erosion and avoided nitrogen leaching provided by a 28-year rotation of radiata pine grown on identified highly erodible sites in the region. Spatially explicit estimates of timber and non-timber values can support targeted forestry investment decisions, and thus address the issue of limited resources. If the purpose of a potential forestry programme was to improve the environment, areas that provide the highest non-timber values can be identified and prioritised. Spatial estimates of values can also be used to prioritise areas with high timber values.

Introduction

Plantation forests provide benefits beyond timber and fibre, including carbon sequestration, erosion control, flood mitigation, improved water quality, biodiversity and recreational resources (MEA, 2005; Dhakal et al., 2012; Yao et al., 2013; Barry et al., 2014). Together, the benefits people gain from the environment are known as ecosystem services, but many of these services provided by forests do not have a market value. As a result, benefits (such as avoided erosion or avoided nutrient leaching) are usually less understood or appreciated for plantation forests compared with log and timber values.

The invisibility of the less tangible ecosystem services in decision-making has provided the opportunity for researchers, practitioners and businesses to work together to address this issue (MEA, 2005; TEEB, 2010). Various models and frameworks have been developed to quantify and value these services so as to account for them in decision-making (Neugarten et al., 2018).

One group of frameworks increasingly gaining attention are the spatially explicit economic models that use ecosystem services approaches to help decision-makers account for the broader value of forest ecosystems (Villa et al., 2009; Sharp et al., 2014; Yao et al., 2016). The frameworks not only account for both the market and non-market values of ecosystem services, but also for space, time and geographic scale, which enables the presentation of an increasingly holistic view of the goods and services for managing and sustaining their provisions. In New Zealand, an ecosystem service assessment tool – the Forest Investment Framework (FIF) – has been designed to assess the financial viability of forests in this country in combination with the non-market ecosystem services they provide (Yao et al., 2019a).

Valuing ecosystem services using the FIF

Around 120,000 ha of land in the Hawke's Bay has been identified as highly vulnerable to erosion. Planting production or permanent forests would be one way to reduce erosion on this vulnerable land. We used the spatial economic tool, the FIF, which combines economic valuation techniques, environmental modelling and Geographic Information System (GIS) technology (Yao et al., 2016) to quantify the broader value of potential plantation forests on highly erodible land in the Hawke's Bay. The tool has already been used in more than 20 New Zealand case studies that have assessed the value of ecosystem services in existing and proposed planted forests (Yao et al., 2019a).

Market values – logs and carbon

The FIF's log viability component has been used to model radiata pine log production costs and revenues from sites identified for afforestation in the Hawke's Bay. Production costs include the expenses associated with establishment, silviculture, internal roading, landing, harvesting and transport. The FIF accounts for impedance factors such as slope and soil type. Areas in steeper slopes and harder soils would have higher roading costs.

The Carbon C-change model is embedded in the FIF (Beets et al., 2009), which quantifies the volume of carbon sequestered, allowing the sequestration value over one or more forestry rotations to be calculated. The quantification of carbon sequestration net benefits includes the cost of monitoring the carbon sequestration credit units and revenues from carbon credits. As the identified, highly erodible sites exclude areas with existing plantation forests, all these new forests will be classified as post-1989 and are therefore compliant with the accreditation requirement of the New Zealand Emissions Trading Scheme (ETS).

The carbon sequestration value that we estimate here for one rotation of radiata pine therefore represents the market value of carbon. The estimated return for carbon is calculated based on productivity using the non-declining yield approach (Buongiorno & Gilles, 2003) so the revenue may be slightly underestimated. The formula for carbon sequestration value can be found in Barry et al. (2014, p. 9). At the time of the study (29 August 2019), the price of one New Zealand Unit (NZU) of carbon dioxide sequestered was $24.75.

Non-market values

The FIF incorporates environmental models such as the New Zealand Empirical Erosion Model (Dymond et al., 2010) and the land use spatial function from Ausseil et al. (2013). We used the FIF to quantify and value the non-market environmental benefits of avoided erosion and nutrient mitigation. A value for avoided erosion was calculated as the potential volume of sediment movement that can be avoided by afforesting the target sites. The calculation includes a component that accounts for higher levels of erosion after planting and before canopy closure, and the harvesting and post-harvest period.

Details for calculating the value of avoided erosion can be found in Barry et al. (2014). In this study, we used a social discount rate of 3% to calculate the value of avoided erosion and avoided nitrogen leaching (Maseyk et al., 2015). To calculate the value of avoided nitrogen, we used the nitrogen leaching rate based on Ausseil et al. (2013) and assumed that this rate will change to about 3 kg/ha/yr with afforestation (Menneer, 2004). We then multiplied this difference by a one-off payment of $400/kg of nitrogen leached (Duhon et al., 2011). This product is then annualised using the social discount rate of 3%.

Results

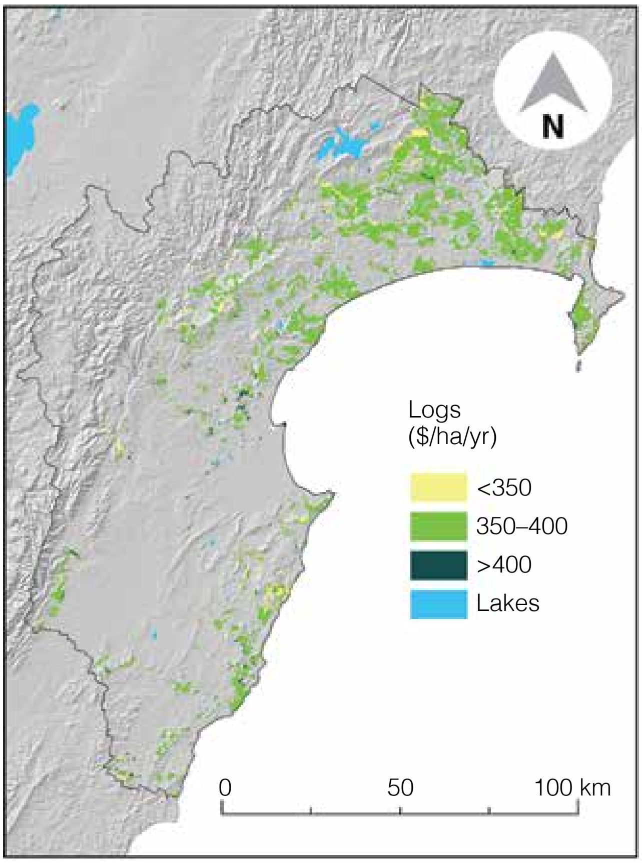
The market and non-market ecosystem services values calculated for a 28-year rotation of radiata pine grown on highly erodible sites in the Hawke's Bay are summarised in Table 1. Areas where the greatest values could be obtained are shown in Figure 1a (log values), Figure 1b (carbon sequestration), Figure 1c (avoided erosion) and Figure 1d (avoided nitrogen leaching). The value of carbon is expected to be higher in the future, rising from $24.75/tonne of CO_2 equivalent as of August 2019 to $30/tonne of CO_2 equivalent in 2024 (CommTrade, 2020).

As expected, afforesting the steepest areas would provide the highest average avoided erosion values (greater than $200/ha/yr). The results also suggest that the greatest average value of avoided nitrogen from afforestation would be gained if the areas shaded in red (Figure 1d) were converted from their existing land use to forestry.

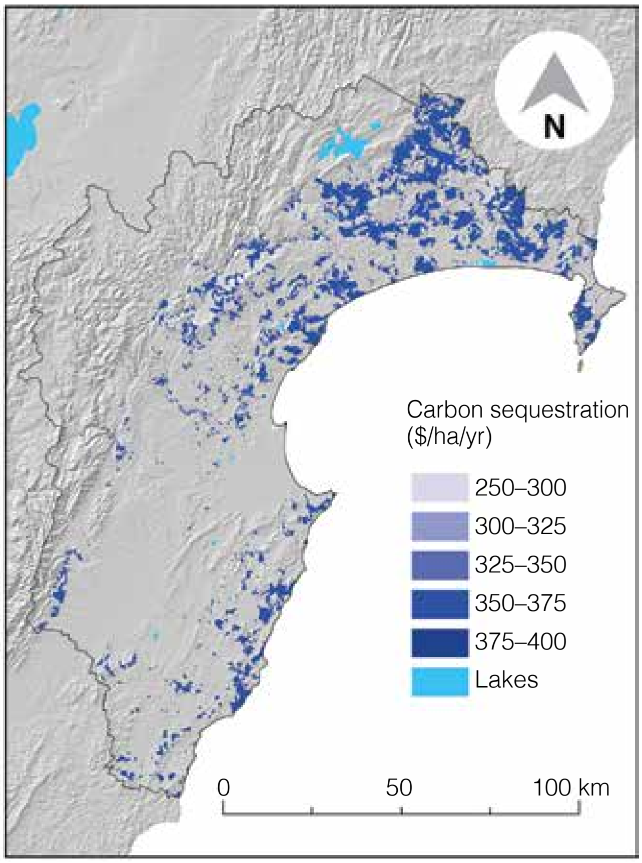
Table 1: Market and non-market ecosystem services values calculated for a 28-year rotation of radiata pine grown on highly erodible sites in the Hawke's Bay

Ecosystem service	Value* ($ ha^{-1} yr^{-1})
Logs	330–640
Carbon sequestration	260–380
Avoided erosion	150–300
Avoided nitrogen leaching	50–270

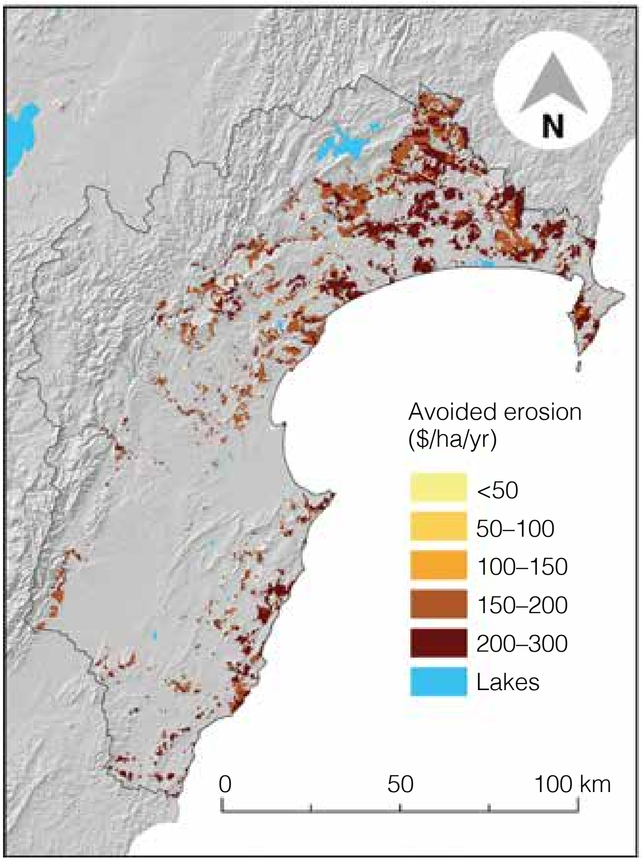
*Assuming an annualised net present value (NPV), with a financial discount rate of 6% for logs and a social discount rate of 3% for the environmental values of carbon sequestration, avoided erosion and avoided leaching



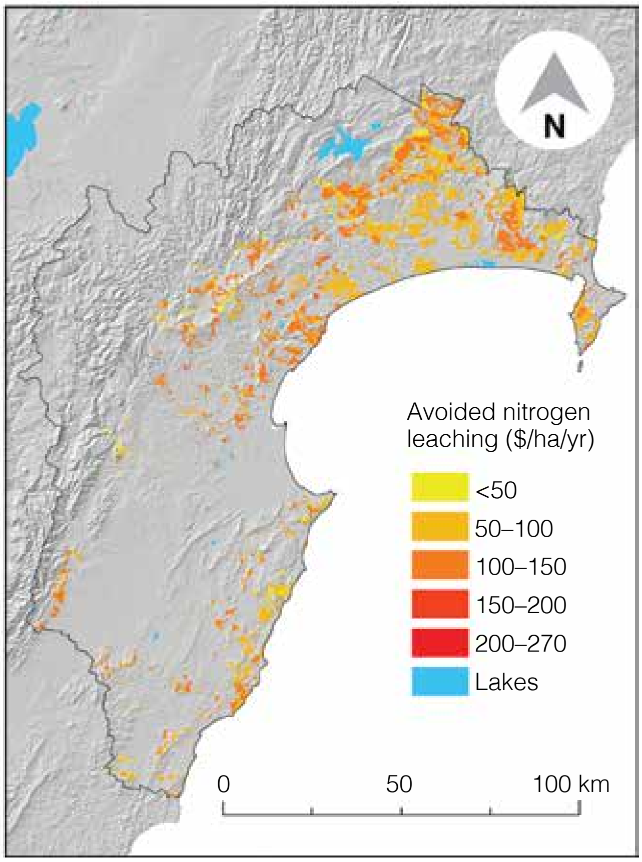
a: Annualised radiata pine log value



b: Annualised carbon sequestration value



c: Annualised avoided erosion value



d: Annualised avoided nitrogen value

Figure 1: Ecosystem services values for highly erodible sites identified as suitable for afforestation in the Hawke’s Bay

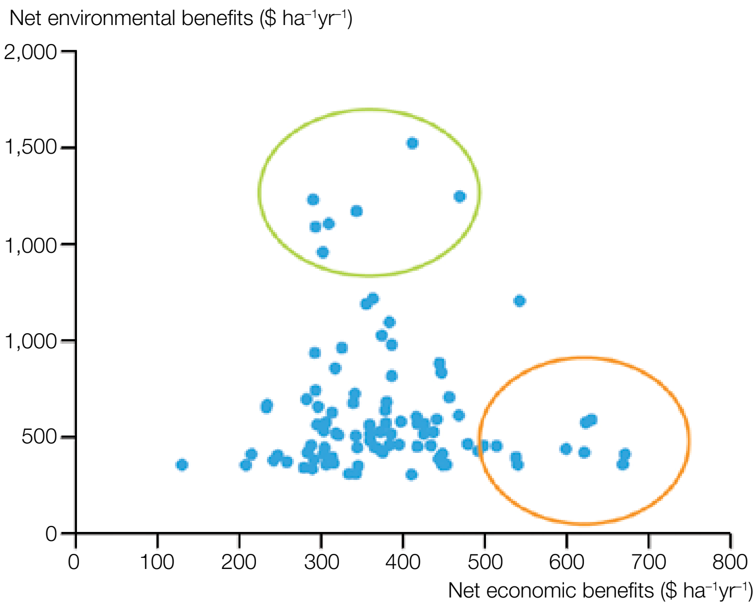


Figure 2: Net environmental vs net economic benefits of afforestation of marginal livestock areas in the Hawke's Bay where the environmental benefits are carbon sequestration, avoided erosion and leaching reduction (after Pannell, 2008)

Making targeted investment decisions

In general, resources for afforestation programmes are limited and it is unlikely that new forests would be established in all the highly erodible sites identified as suitable for afforestation. There is a need for targeted efforts depending on the objective of an afforestation programme. The quantified value of ecosystem services can be used to carry out an analysis that takes into account both the net public (environmental) and net private (economic) benefits of afforestation.

Using a framework developed by Pannell (2008), the net public benefit from forest ecosystem services and net private benefits from logs, for example, can be visualised (Figure 2). If the objective of afforestation were to provide environmental benefits, afforestation in the areas circled in green should be prioritised. If economic benefits or log profits are given precedence, the data points for the areas circled in orange should be prioritised.

We have taken the ratios between the total value of the non-log ecosystem services and logs to identify areas in the Hawke's Bay that produce a higher proportion of public benefits. Figure 3 shows that afforestation of a few marginal livestock areas in the region provides ecosystem services to log ratios of 3:1 or higher. That is, for every $1 in annual profit provided by new forests, the value of non-log ecosystem services is at least $3. This figure can be interpreted as the environmental value provided over and above the profit from log production. Figure 3 also shows that a significant proportion of the highly erodible land identified as suitable for afforestation would have provided ecosystem services to log ratios of 1.5 or greater.

In areas where significant non-market ecosystem services values can be potentially realised, it is recommended a potential afforestation programme should offer landowners the incentive to afforest (e.g. subsidised establishment cost), as long as the value of the benefits from cleaner water (through avoided erosion and nutrient mitigation) and climate regulation outweigh the costs of the incentive package.

Increased biodiversity

Increased afforestation will extend the habitat available for native flora and fauna. Plantation forests are home to a surprising number of different species, including more than 118 threatened native species (Pawson et al., 2010), such as kiwi, karearea (bush falcon), native orchids, kākābeak, frogs, lizards and insects.

A significant population of brown kiwi are already found in the region (see www.kiwisforkiwi.org). Afforestation (with predator control) would potentially allow them to extend their range. Karearea also thrive in planted forests, with Kaingaroa Forest supporting the largest population in this country. New Zealanders value their native plants and animals and would be prepared to financially support conservation initiatives on both private and public land, even in exotic plantation forests (Yao & Kaval, 2010; Yao et al., 2019b).

Conclusions

Afforestation of the highly erodible sites identified will provide multiple benefits to society such as logs, carbon sequestration, improved water quality through

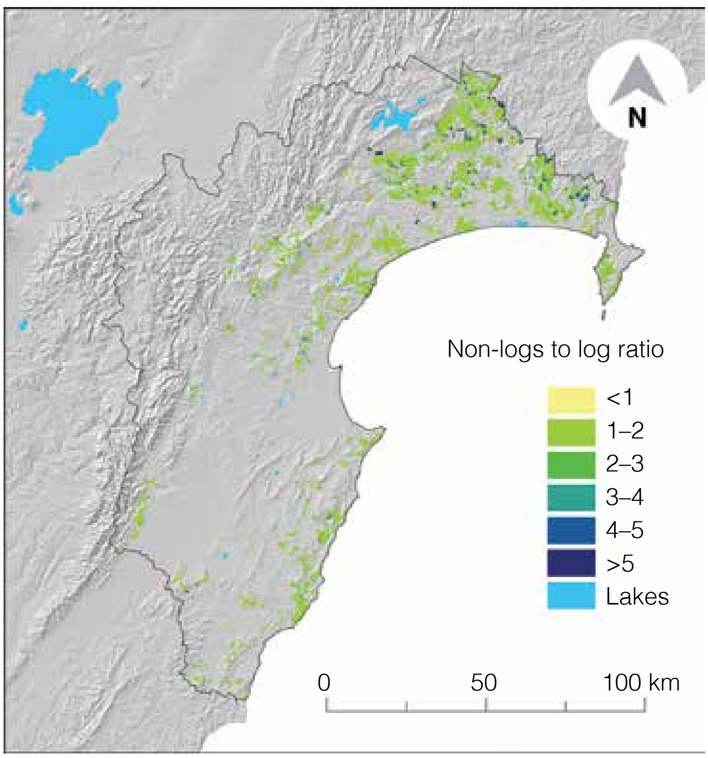


Figure 3: Ratio between non-log ecosystem service values and log values

a reduction in nutrients and avoided erosion, and conservation of iconic species. On most of the land the value of the ecosystem services benefits would likely be at least one-and-a-half times, and in some places up to six times, greater than the log value.

This work has focused on radiata pine, but input parameters for modelling market returns for other species are needed. It is likely that other species with longer rotations and different growth and carbon uptake rates could provide even greater ecosystems service benefits. Data on permanent and selectively harvested native forest is also needed.

This work allows us to recognise and understand how afforestation affects non-log ecosystem services across the Hawke's Bay region and how these might affect its economy, environment and society. Communities that would benefit from a future biodiversity enhancement would be likely to financially support such initiatives. It is advantageous to consider both the private and public benefits from potential afforestation programmes in policy and investment decision-making. Using a spatially explicit framework such as the FIF to evaluate the costs and benefits of expensive afforestation programmes enables decision-makers to be more targeted and cost-effective.

It is important to note that plantation forests have additional environmental and social values other than those studied here, including water flow regulation, flood mitigation, water filtration, recreation, educational values and human health benefits. Due to the limited scope of the project, these benefits have not been accounted for. We recommend that future assessment of ecosystem services for afforestation should quantify these other important services to represent a fuller suite of benefits of forestry.

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Forested headwater riparian areas – functions and benefits

Brenda Baillie

Riparian area in a New Zealand planted forest

Abstract

Riparian areas occupy a unique location within the landscape as transitional areas between aquatic and upslope terrestrial ecosystems. These areas are valued for their high biodiversity and the wide range of functions, processes and ecosystem services they provide. Hence, their importance often exceeds the proportion of space they occupy within the landscape. While afforestation of steep and highly erodible catchments provides the opportunity to enhance both the financial and non-financial benefits from this land, the riparian areas have the potential to contribute to non-financial ecosystem services. Headwater areas have the highest density of stream and riparian areas and comprise a large percentage of total stream length in many catchments. This paper outlines some of the key functions and benefits provided by forested riparian areas in steep headwater catchments.

Because of their location in the landscape, forested riparian areas also have the potential to deliver a range of beneficial ecosystem services to downstream users. Also, well-planned riparian areas established at the afforestation stage will assist in minimising the impacts of forest management activities on waterways, particularly during end-of-rotation harvesting operations. Under the National Environmental Standards for Plantation Forestry (NES-PF) (New Zealand Government, 2017), afforestation is prohibited within certain distances of a waterbody and setback distances are outlined in the Standards. Possible options for forest restoration for protection purposes within these setback riparian areas in steep headwater catchments are discussed.

Introduction

Afforestation of steep erosion-prone land has the potential to provide additional non-economic benefits beyond the traditional financial returns from timber (e.g. sediment and nutrient reduction, improved water quality and enhanced biodiversity). Forest restoration within the riparian areas in steep headwater catchments provides an opportunity to contribute to these wider non-economic benefits.

Riparian areas are considered the transitional areas between the aquatic and upland terrestrial ecosystems. They often form natural boundaries defined by a combination of changes in slope, vegetation, soil characteristics, surface hydrology and flood-plain borders. As a result, the widths of riparian areas are naturally highly variable. The importance of riparian areas is often greater than the proportion of area that they occupy because of their location within the landscape, their unique biophysical features, ecosystems, disturbance regimes and biodiversity, and the range of functions, processes and environmental benefits they provide (Gregory et al., 1991; Richardson & Danehy, 2007).

Headwater streams and their riparian areas make up a large percentage of total stream length in many catchments (Gregory et al., 1991; Richardson & Danehy, 2007). In steep headwater catchments these riparian areas may be quite narrow. The linear nature and high edge-to-area ratio of riparian areas increases their susceptibility to edge effects from upslope management activities. This, in turn, increases their vulnerability, and response and recovery time, to both upslope and in-stream disturbances such as droughts, floods, landslides and debris flows.

Riparian management zones differ from natural riparian areas in that they are usually defined by set widths, within which a range of management activities may be undertaken under certain conditions to meet defined management objectives (e.g. the National Environmental Standards for Plantation Forestry (NES-PF)) (New Zealand Government, 2017). These widths may extend well beyond the natural boundaries of the riparian area and can vary from a few metres to several hundred metres (Gregory et al., 1991; Neary et al., 2011; Verry et al., 2004).

Benefits from forested riparian areas

Forested riparian areas provide a broad suite of functions, processes and ecosystem services, as outlined in Figure 1.

Shade and stream temperature

The benefit of stream shade and cooler stream temperatures provided by forested riparian areas is maximised in smaller headwater streams, but will be influenced by the riparian vegetation characteristics and stream width (Richardson & Danehy, 2007). In smaller-sized streams, re-establishing forest cover can reinstate shade and water temperature regimes typical of those in native forests.

Streambank stability

The root reinforcement provided by forested stream margins contributes to maintaining bank stability (Collier et al., 1995; Hubble et al., 2010), reducing bank erosion and sedimentation, and enhancing the habitat diversity provided by undercut banks and tree roots.

Filtration/trapping of diffuse/fine sediment, nutrients and other contaminants

Riparian areas are uniquely situated in the landscape to intercept *diffuse* sources of sediments, nutrients and microbial contamination from upland areas before they enter the stream system. Their effectiveness will depend on the incoming contaminant loads, and the characteristics of the catchment and the riparian areas (Collier et al., 1995; Parkyn 2004). For example, riparian areas in headwater catchments tend to be narrow, and high shade from afforestation may restrict undergrowth, limiting their filtration capacity. Greater gains in nutrient, microbial and fine sediment reductions will most likely result from the removal of stock and afforestation of the upslope catchment areas. Afforestation of agricultural land has been shown to improve water quality, mainly through the reduction of agricultural contaminants, and is particularly effective in smaller-sized catchments (Baillie & Neary, 2015).

Riparian areas in steep headwater catchments are less effective at intercepting and storing *point sources* of sediment channelled along concentrated flow paths, given the high connectivity between the upslope generation point and the receiving stream environment (Neary et al., 2011; Phillips et al., 2017; Richardson & Danehy, 2007). However, riparian areas on flatter topography can be effective at trapping some of the sediment and woody debris transported off-slope and downstream during floods and debris flows.

Channel roughness

The root systems and stems of riparian vegetation increase channel roughness. This slows the speed of floodwaters during bank overflow, particularly in small-to-moderate flood events, which decreases the erosive capacity of floods and aids the retention of sediment, debris and floodwaters.

Organic matter inputs

Forested riparian areas provide a diverse range of food resources for both aquatic and terrestrial ecosystems and are the main source of food (i.e. litter, terrestrial insects) in small shaded headwater streams. The availability of this food resource is highly dependent on the capacity of the stream system to retain and process the organic material, sediment and dissolved nutrients for biological uptake.

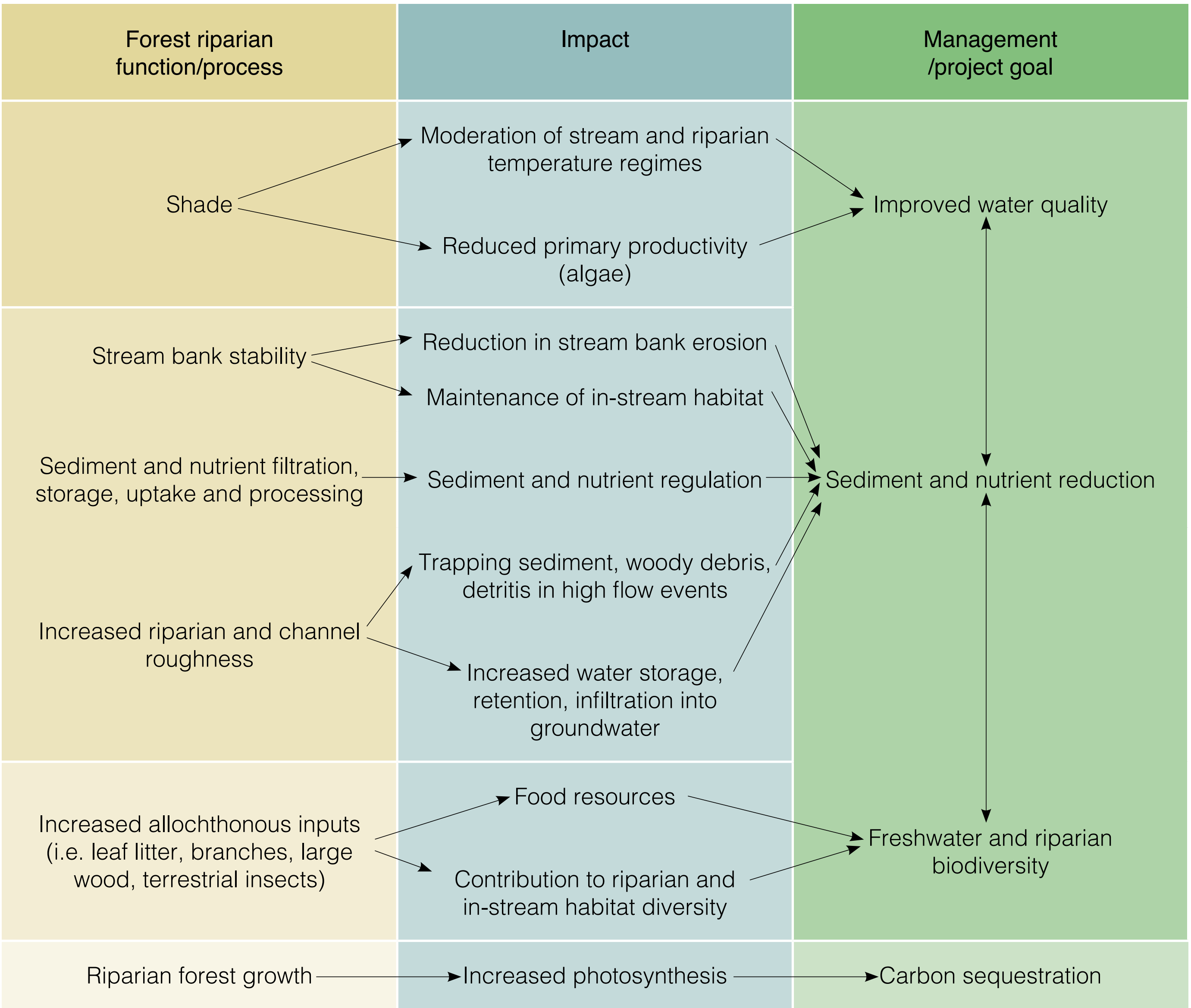

Figure 1: Selected key functions and processes in forested riparian areas

Forested riparian areas are also key providers of larger pieces of wood to stream systems. These pieces are an important component of forested stream ecosystems, influencing stream flow characteristics, habitat provision and the retentive capacity of streams (Gomi et al., 2002; Gregory et al., 2003; Gregory et al., 1991; Richardson & Danehy, 2007) (see photo). Over time, afforestation of headwater riparian areas will re-establish a source of wood supply to streams.

Forest carbon sequestration

Afforestation of riparian areas will increase carbon sequestration in these areas, as the vegetation transitions from pasture to woody vegetation and the active planting of trees can accelerate this process (Dybala et al., 2018). However, as riparian areas comprise a small portion of the total land area, the highest gains in carbon sequestration are likely to come from plantings in the remainder of the catchment.

Terrestrial and aquatic biodiversity

Indigenous forest riparian areas in headwater streams are a source of high biodiversity and species richness. The variability in topography, microclimate, soil moisture, disturbance regimes and spatial extent (both longitudinally and laterally) and high edge effects supports structurally diverse plant and animal communities. Their location and extent within a headwater catchment facilitates movement, dispersal and (re-)colonisation pathways for both terrestrial and aquatic plants and animals (Gregory et al., 1991, 2018; Richardson & Danehy, 2007). Also, woody debris inputs have a strong influence on aquatic biodiversity in small headwater streams, as they are major determinants of both the food resources and habitats of aquatic invertebrates and native fish (Baillie et al., 2013, 2019).

One study in the Waikato region illustrates the potential for the afforestation of headwater catchments to improve aquatic biodiversity. The pasture catchments

An example of large wood in a forested stream retaining sediment and organic matter, modifying stream flow and creating habitat

were planted in mainly *Pinus radiata* and the riparian areas were fenced off and either left to naturally regenerate or planted with poplars or indigenous vegetation. After six years, the invertebrate community composition in these streams was trending toward those in indigenous forest streams. The most rapid recovery in stream conditions was associated with the riparian areas planted in indigenous vegetation (Quinn et al., 2009).

Importance of headwater streams in landscape

Headwater stream and riparian systems occupy a high point in the landscape. Because of this, headwater stream systems influence the delivery of water, sediment, nutrients and organic matter to downstream reaches. This provides a range of possible beneficial ecosystem services to downstream users such as high water quality, reduced nutrient and sediment loads, cooler water temperatures and sources of biota for re-colonisation. These combined processes and inputs from upstream tributaries influence physical and biological processes in the downstream reaches and the composition of the biological communities living within them (Gomi et al., 2002; Richardson & Danehy, 2007).

The benefits of establishing forested riparian areas in smaller headwater streams are more readily identifiable. These benefits can be seen within a shorter timeframe compared to larger downstream river systems, where the influence of riparian areas declines and riparian effects can be compromised by multiple land-use stressors (that dilute or override the benefits of riparian management interventions). Therefore, there are benefits in prioritising the establishment of forested riparian areas when undertaking afforestation projects in highly erodible headwater catchments before progressing their implementation downstream (Gomi et al., 2002; Parkyn 2004; Richardson & Danehy, 2007). For example, in the Hawke's Bay region, the potential stream length available for riparian reafforestation is estimated at 4,375 km where erosion rates are greater than 1,000 t km^{-2} yr^{-1}, and nearly doubles in length when taking into consideration areas with lower erosion rates (8,095 km; >500 t km^{-2} yr^{-1}).

Connectivity to indigenous remnants in the landscape

The re-establishment of indigenous vegetation in the riparian areas of steep erosion-prone land provides the opportunity to assess potential linkages with nearby indigenous terrestrial and aquatic areas that would maximise beneficial ecosystem service and biodiversity outcomes. An example is the broad-scale assessment and prioritisation of the remaining indigenous biodiversity in terrestrial, lake and river ecosystems undertaken by Leathwick (2017) in the Hawke's Bay region. This assessment also looked at connectivity, highlighting the opportunities between stream and riparian areas and existing remnants of indigenous vegetation that can be leveraged throughout an entire river system.

End-of-forest rotation benefits

Well-planned and established riparian zones that promote forest restoration at the afforestation phase can provide significant protection to waterways during the rest of the forest rotation. As harvesting is the forest management activity having the largest impact on headwater streams and their riparian areas (Baillie & Neary, 2015), most studies have assessed the effectiveness of differing forested riparian widths in minimising harvest impacts. The results are understandably variable, given the range of site and riparian conditions and different harvesting practices.

However, Table 1 shows that in general forested riparian buffers less than 10 m in width are limited in the extent of their ability to mediate harvesting impacts. The greatest benefits are associated with shade retention, channel bank stability and limiting the transport of logging slash into streams. While there is a progressive gradient on increasing benefits to riparian and stream functions and processes with increasing buffer width (as shown in Table 1), studies on forest management activities have suggested widths up to 30 m or more on both sides of the stream to limit the effects of harvesting and to maintain both riparian and stream ecosystem function and biodiversity (Davies & Nelson, 1994; Kiffney et al., 2003; Phillips et al., 2017).

Depending on a range of criteria, under the NES-PF compulsory 5 m and 10 m planting setbacks are required from perennial rivers, wetlands and lakes to provide protective riparian margins (New Zealand Government, 2017). These setback planting boundaries may need to extend beyond the natural riparian edge into wider riparian management zones, particularly in steep V-shaped headwater stream systems where natural riparian areas can be quite narrow. As headwater streams are particularly sensitive to harvesting, buffer widths of greater than 10 m may be necessary to meet management goals and regulatory standards for water quality and riparian and in-stream biodiversity.

The development of a harvesting plan prior to afforestation would assist with this process (Visser & McConchie, 1993). Different widths are needed to achieve different outcomes for stream and riparian

Table 1: Ability of riparian areas to mediate impacts of clear-fell harvesting

Riparian width	Effect	Reference
5 m and 30 m	Whangapoua Forest, Coromandel Peninsula: Median daily air temperatures were 3.2°C lower in the 5 m wide forested riparian buffer and 3.4°C lower in the 30 m buffer, compared with an open clear-fell area.	(Meleason & Quinn, 2004)
10 m	Venlaw, Southland: The 10 m forested buffer reduced inputs of logging slash, and provided partial shade and a limited capacity to filter fine sediment and nutrients. There was an increase in algal growth and a decrease in-stream substrate size. Changes in aquatic invertebrate communities resulted in a decrease in sensitive taxa and an increase in taxa utilising algae and organic matter. Overall, the narrow riparian buffer reduced some of the physical and biological changes in the Venlaw site compared to sites without riparian buffers.	(Thompson et al., 2009)
Harvested pine: width <10 m (mean = 5.4 m); width >10 m (mean = 19.6 m). Mature pine: width <10 m (mean = 3.6 m); width >10 m (mean = 18.5 m)	Whangapoua Forest: Harvested sites without a riparian buffer or a narrow buffer (<10 m) averaged 33.3% and 63.4% native species cover, respectively. The wider buffers (>10 m) averaged 83.9% cover, similar to mature pines (narrow and wide riparian buffers) and native forest sites (range 81.6–99.8% cover). The mean number of adventive species was highest in the harvested sites with no or narrow riparian buffers (particularly where harvest disturbance was high), followed by the wider riparian buffers, and significantly lower in the mature pine (narrow and wide riparian buffers) and native forest sites. The percentage of pioneering species was also highest in the harvested sites with no or narrow riparian buffers. Vegetation community composition and structure in the harvested sites with wider riparian buffers was often (but not always) similar to the mature pine (narrow and wide buffers) and native forest sites. The authors note that adventive species are likely to be shaded out by the next rotation of trees.	(Langer et al., 2008)
Mean width 18 m	Whangapoua Forest: Riparian buffer of native shrubs and trees. Total fish numbers were highest at the logged sites (with and without riparian buffers) compared with the mature pine and native forest sites. The abundance of all fish species was highest at the logged sites with buffers. The abundance of banded kokopu (*Galaxias fasciatus*) was significantly higher at the logged sites with buffers compared with logged sites without buffers. The abundance of longfin and shortfin eel (*Anguilla dieffenbachii* and *A. australis*) was not influenced by the different site treatments.	(Rowe et al., 2002)

Riparian width	Effect	Reference
Range 6.5–27 m	Whangapoua Forest: Bank erosion was highest at the harvested sites with no buffer compared to harvested sites with buffers and the reference mature pine and native forest sites. Stream lighting was highest at the clear-cut sites and influenced by riparian vegetation and stream size. Periphyton (algae) biomass was highest in the harvested sites, followed by harvested sites with riparian buffers, and lowest in the pine (with and without native riparian buffers) and the native forest sites.	(Boothroyd et al., 2004)
Harvested pine: continuous riparian buffers (range 8–27 m); discontinuous riparian buffers (range 6.5–25 m)	Whangapoua Forest: Invertebrate community composition and a range of biotic integrity indices in harvested sites without riparian buffers differed from harvested sites with a continuous riparian buffer and the mature pine (with and without native riparian buffers) and native sites. Invertebrate communities at the harvested sites with a discontinuous buffer were intermediate between these two groups. Logging impacts were strongly influenced by increasing periphyton biomass, water temperature, channel instability and fine sediment. Intact riparian buffers were effective at mediating the impacts of harvesting.	(Quinn et al., 2004)
Initially ≈150 m reduced to 30 m as harvesting in the catchment progressed	Golden Downs, Nelson: Harvesting to the stream edge increased sediment and logging slash loads in the stream, increased water temperature extremes, and there was a decline in the more sensitive aquatic invertebrates and a reduction in native fish abundance (*Galaxias divergens* and *A. dieffenbachi*). The downstream death of brown trout (*Salmo trutta*) was attributed to upstream harvest practices. The riparian buffer mediated harvest impacts with minor changes in the physical habitat and aquatic fauns.	(Graynoth, 1979)
Harvested sites: 0–50 m (analysis 0–10 m, 10–30 m and 30–50 m); unharvested sites >50 m	Tasmania, Australia, *Eucalyptus* forest: Increased volume of woody debris, periphyton cover, length of open stream and stream temperature at harvested sites with buffers <10 m. Increase in superficial silt where buffers were ≤30 m compared with wider buffers and unharvested streams. Significant differences in aquatic invertebrate community composition occurred at sites with buffers <30 m wide, including community composition, total abundance, abundance of *Ephemeroptera* (mayflies) and *Plecoptera* (stoneflies). The abundance of brown trout declined where buffers were <30 m, but no significant differences were found in biomass.	(Davies & Nelson, 1994)
Harvested sites: 30 m, 10 m buffers and clear-cut to the stream edge	British Columbia, Canada, coastal western hemlock biogeoclimatic zone: Significant reductions in light reaching the stream surface from clear-cut – 10 m to 30 m buffer – unharvested control. Mean daily water temperatures decreased with increasing buffer width in winter, spring and summer, and similarly for maximum water temperatures in spring and summer. There were no significant differences in dissolved nutrients (N and P) between the treatments after harvesting. Periphyton biomass decreased with increasing buffer width. Chironomidae abundance decreased with increasing buffer width, as did mayfly abundance, although it was not statistically significant. Overall, ecological impacts were greatest in the clear-cut and 10 m buffer treatments.	(Kiffney et al., 2003)

health, and riparian widths advocated for larger river or agricultural systems may not necessarily be appropriate for smaller headwater streams (Parkyn 2004; Richardson & Danehy, 2007). A further complicating factor is the establishment of a riparian area to meet regulatory requirements and non-timber objectives in headwater systems, where a high density of stream networks may reduce the area for timber production to the point where it is no longer economically viable.

Options for re-establishing native vegetation in steepland riparian areas

The re-establishment of native vegetation in steepland riparian areas has the potential to provide a range of non-economic benefits. The most cost-effective option for converting pasture riparian areas to native vegetation cover is to implement setback distances from the stream edge and let natural regeneration take its course (Martin et al., 2019; Norton et al., 2018). However, this option is only viable if there is a readily available seed source within or nearby to the riparian area.

An example is kānuka, a hardy, native pioneering species that re-establishes readily in some regions of New Zealand when pasture is left to revert to native vegetation. This species provides an ideal nursery cover for other regenerating native vegetation. Naturally regenerating mānuka fulfils a similar role, although it has a shorter lifespan than kānuka and may collapse before successional species have had time to fully establish (Martin et al., 2019). Even so, weeds may re-establish within the riparian area and either out-compete or slow down the natural regeneration of indigenous vegetation.

Another option is to establish a nursery shade crop to facilitate natural regeneration. However, in the absence of any naturally regenerating native vegetation, Horgan et al. (2019) recommended planting a high proportion of faster growing shrubs to provide a nursery crop along with a lower proportion of tree species. When assessing the overall costs of this option, the higher costs of planting at high densities to assist with weed control and to achieve canopy closure in a shorter timeframe need to be compared with the reduced costs of lower planting density, along with additional costs for weed control and any other management interventions needed until canopy closure is achieved (Horgan et al., 2019; Martin et al., 2019; Norton et al., 2018). This may be expensive in steepland riparian areas where the major benefits are associated with non-economic ecosystem services and environmental outcomes. The synergies in undertaking riparian planting in conjunction with planting the remainder of the catchment may assist in reducing these costs.

In catchment areas identified as unsuitable for timber production and that are managed for other purposes, such as carbon sequestration and reversion to continuous indigenous forest cover, the riparian areas would be an integral component of the overall restoration and planting design. Given the complexities involved, and the limited information available on the afforestation of riparian areas in steep headwater catchments, a multi-disciplinary approach to riparian design would be advantageous.

Conclusions

Afforestation of steep erodible headwater catchments can potentially provide multiple benefits to society. Afforesting riparian areas in these headwater systems would enhance a range of beneficial ecosystem services, including high water quality, flood mitigation, reduced nutrient and sediment loads, cooler water temperatures and sources of biota for re-colonisation.

The state of downstream waterways and their biological communities will be influenced by the processes occurring upstream. There would be significant benefits in prioritising the establishment of riparian areas when undertaking afforestation projects in the headwater catchments before progressing their implementation downstream. Restoration and enhancement of riparian headwater areas, and maximising connectivity to the remaining indigenous forest remnants, will also contribute to goals of improving water quality and biodiversity.

It would be advantageous to identify species suitable for planting in headwater riparian areas to aid the re-establishment of an indigenous vegetation cover as their site characteristics will differ from upslope areas and downstream riparian areas. However, some of these options are expensive, all will require some degree of pest and weed control, and the largely non-economic benefits in afforesting headwater riparian areas will need to be assessed against the costs (both in terms of dollars and the loss of potentially production land).

The next step may be advancing to a case study scenario and carrying out a more in-depth assessment and mapping of riparian areas, and the identification of suitable plant species and restoration options to achieve the management goals. Long-term landowner and community buy-in and managing expectations of what riparian restoration can achieve will be critical to the success of this project.

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Spatial mapping of tree species site suitability for the Hawke's Bay region

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Abstract

Planting the right tree in the right place and for the right purpose is an adage commonly used in the discussion of where to establish new plantations. In reality, information to support landowner decisions around the establishment of new forests is not in a readily available or in an intuitive format. The mapping of Tree Species Site Suitability Indices for Hawke's Bay was developed to provide landowners with easy-to-understand maps to support decision-making and to complement field investigations. Specifically, tree species site suitability methodology was developed to match the species *Pinus radiata* (radiata pine), *Sequoia sempervirens* (coast redwood), *Cupressus lusitanica*, *Eucalyptus* (generic scenario), *Leptospermum scoparium* (mānuka) and *Podocarpus totara* (tōtara) to their preferred growing environments across the Hawke's Bay region. National tree species site suitability characteristics include ranges of average annual temperatures, total rainfall, elevations above sea level, site fertility including soil water availability, rooting depth, and soil fertility and tolerance to both wind exposure damage and salt water spray.

This information was compiled from existing permanent sample plot (PSP) location data, published information and expert knowledge for each of the species, to help inform us of the preferred environmental conditions for each species. Tree species growing conditions were mapped using response curves and to assign fuzzy logic (membership) values between zero and one, with one being an optimal degree of membership (DOM), and zero being no DOM. For example, is the establishment location for a tree too hot, too cold, too wet or too dry and so forth. The outcome of this project provides the regional council and landowners with maps by which to assess and compare potential tree species suitable for their local site conditions – Tree Species Site Suitability Indices – and as a basis for more detailed assessment and planning.

Introduction

The Hawke's Bay Regional Council (HBRC) wants to use afforestation as an approach to mitigating erosion. At the same time, the Government's One Billion Trees Programme (MPI, 2019) has a budget for grants to landowners, particularly farmers, to include trees on their farms. To make sure the tree species planted deliver both economic and environmental benefits, we need to identify which tree species are suited to which environmental conditions – plant the right tree in the right place.

Tree species site suitability maps can assist stakeholders with decisions around which species, or group of species, are best suited to local conditions. Site suitability combines the idea of productivity associated with a tree species, and whether or not a species will survive when established. For example, at some locations a species may grow quickly and be highly productive. However, in cooler, wetter or increasingly eroded landscapes, the species choice may simply be based on reducing erosion, improving water infiltration or carbon sequestration, albeit slowly.

This work develops maps of tree species site suitability for *Pinus radiata* (radiata pine), *Sequoia sempervirens* (coast redwood), *Cupressus lusitanica* (cypress), *Eucalyptus* spp (generic scenario), *Leptospermum scoparium* (mānuka) and *Podocarpus totara* (tōtara) across the Hawke's Bay region. We have used data on growing conditions to develop response curves and fuzzy logic to predict where a species can be planted, survive and grow from poorly to successfully, while providing an estimation of suitability between species.

Materials and methods

Defining tree species environmental and climatic characteristics

Site suitability methodology was developed to establish where the species *Pinus radiata* (radiata pine), *Sequoia sempervirens* (coast redwood), *Cupressus lusitanica* (cypress), *Eucalyptus* spp (generic scenario), *Leptospermum scoparium* (mānuka) and *Podocarpus totara* (tōtara) could be successfully established across the Hawke's Bay region.

Characteristics include ranges of average annual temperatures, total rainfall, elevations above sea level, site fertility including soil water availability, rooting depth, soil fertility, landscape aspect, frost tolerance, and tolerance to both wind exposure damage and salt water spray. These characteristics were compiled for each of the species to inform us of their preferred environmental conditions.

Published empirical data plus permanent sample plot (PSP) data was kindly provided by a number of companies and private forest holdings for radiata pine, coast redwood and cypress. Empirical data to determine site suitability characteristics for *Eucalyptus*, tōtara and mānuka honey regimes were not available. We used reports, grey literature and expert knowledge to fill in the knowledge gaps.

In the case of *Eucalyptus*, a multi-species scenario was developed, because for many of this species the specific characteristics were unknown. It was considered better to cover a wide range of environmental conditions in which *Eucalyptus* species are found across the Hawke's Bay region (Paul Millen, pers. comm., August 2019).

Mānuka for honey production also required special consideration, with two characteristics from a modelling perspective: (1) optimal conditions for growth, flowering and nectar production; (2) and the

Table 1: Spatial datasets and the values used in the response curves applied in the development of fuzzy membership maps for the tree species site suitability maps

Spatial layer	Species	DOM 0	DOM 0.5	DOM 1
Elevation (m)	*Pinus radiata*	>1,020		<375
	Sequoia sempervirens	>585		<335
	Cupressus lusitanica	>590		<340
	Generic *Eucalyptus*	>700		<450
	Podocarpus totara	>500		<350
	Leptospermum scoparium	>500		<300
Total annual rainfall (mm)	*Pinus radiata*	<755, >2300 [x]		1165 – 1620
	Sequoia sempervirens	<925, >2215 [x]		960 – 1660
	Cupressus lusitanica	<1145, >3195 [x]		1380 – 1875
	Generic *Eucalyptus*	<500, >2500 [x]		900 – 1500
	Podocarpus totara	<750, >2100 [x]		1000 – 1200
	Leptospermum scoparium	<750, >1800 [x]		900 – 1300
Mean annual temperature (°C)	*Pinus radiata*	<7.7		>14.1
	Sequoia sempervirens	<9.8		>13.4
	Cupressus lusitanica	<10.4		>14.5
	Generic *Eucalyptus*	<11.0		>16.0
	Podocarpus totara	<9.8		>14.1
	Leptospermum scoparium	<12.0		>15.0
Profile available water (PAW) (mm)	All species except *Leptospermum scoparium*	–	89	>250
Distance from coast (km)	*Sequoia sempervirens*	<1.5		>5.5
	Cupressus lusitanica	<1.5		>5.5
Wind exposure	*Sequoia sempervirens*	>1.36 (exposed)		<1.17 (sheltered)
	Cupressus lusitanica	>1.36 (exposed)		<1.17 (sheltered)
	Generic *Eucalyptus*	>1.36 (exposed)		<1.17 (sheltered)
Frosts October (days)	Generic *Eucalyptus*	>5		0
Rain December/January (days)	*Leptospermum scoparium*	>10		<8
December/January temperature (°C)	*Leptospermum scoparium*	<10		>14
Aspect	*Leptospermum scoparium*	–	South	North

[x]: Rainfall was developed as a trapezoid response curve, hence the upper value was set to twice that of the maximum value where it becomes a zero degree of membership (double the upper values become a DOM of zero)

ideal conditions for bees to forage for food in December and January. This gave us information for the 10 variables listed in Table 1, which we then combined to give overall suitability maps for each species across the Hawke's Bay region using a fuzzy logic approach.

Fuzzy logic

We used fuzzy logic to spatially define landscapes suitable for the species of interest. Fuzzy logic approaches are used to manage vague and fuzzy concepts and potential uncertainty. Fuzzy membership (fuzziness) provides an indication as to what degree a property of interest belongs to a class, or degree, of membership. In geospatial terms, fuzzy logic can be used to manage uncertainty and vagueness in a property where a statement can be true (value = 1.0), false (value = 0.0), or somewhere in-between.

Response curve and spatial dataset development

We developed response curves for each variable, defining the values that indicate a site is totally unsuitable (degree of fuzzy membership = 0.0) and those that indicate optimal suitability (degree of fuzzy membership = 1.0 true). In most cases, all other values were assigned using a linear relationship between 0 and 1. The response curve for rainfall is trapezoidal as high rainfall can be as limiting as low rainfall.

For radiata pine, coast redwood and cypress, values were assigned using summary statistics. For the generic scenario, mānuka and tōtara, values for the response curves were developed from the literature and expert knowledge where observed data was not available. The degree of fuzzy membership (DOM) values used for different species are listed in Table 1.

Developing tree site suitability maps

Modules were developed using the ArcGIS Python library (https://developers.arcgis.com/python/) for the input layers representing elevation, total annual rainfall, mean annual temperature, profile available water (PAW), distance from the coastline, wind exposure, days of ground frost, number of rain days in December and January, average temperatures for December and January, and aspect (https://data.linz.govt.nz/). Input data at each pixel on the map was converted from actual value (e.g. X mm of rainfall) to fuzzy values between 0.0 and 1.0.

A final Python module combined these values by calculating the product of the fuzzy input layers to produce a site suitability map for each tree species. The advantage with this approach is that the input parameters from the site suitability characteristics can easily be reset and maps updated as new information becomes available.

Results

The site suitability maps developed for *Pinus radiata*, *Sequoia sempervirens*, *Cupressus lusitanica*, *Eucalyptus* (generic scenario), *Podocarpus totara* and *Leptospermum scoparium* are shown in Figure 1.

The results suggest that radiata pine can be planted across much of the Hawke's Bay region, but is especially suited in the northern areas and along the southern coastal areas. Overall, the map suggests higher altitude areas as not suitable, whereas total annual rainfall values are unsuitable along the inland coastal areas, and mean annual temperature reduces suitability across most elevated areas of Hawke's Bay.

Coast redwood has a similar spatial pattern to radiata pine for elevation and temperatures. However, rainfall values are more restrictive along the inland coastal region. Coast redwood has the additional limitation of salt intolerance, while exposure to wind can cause damage to plantations.

Cupressus lusitanica is mostly suitable at lower elevations in the northeastern regions of Hawke's Bay. Its patterns for elevation and temperatures are only subtly different visually from radiata pine and coast redwood, but rainfall is limiting in the south of the region.

Eucalyptus species may be most suited from the northern coastal regions and inland to reasonably elevated locations. The maps also suggest that this species could be grown along coastal Hawke's Bay, and in the south, although with a lower suitability compared to the northern regions. However, rainfall eliminates a substantial region in southern Hawke's Bay. Also, wind exposure and the number of days of ground frost restrict a substantial part of the elevated regions of Hawke's Bay.

Elevation, total annual rainfall, mean annual temperature, the number of rain days in December and January, temperature in December and January, and the influence of aspect all play substantial roles in mānuka site suitability. Mānuka for honey tends to be most suitable in the warmer parts of the region. Mānuka site suitability is as much about the bees' ability to forage for nectar, as it is for mānuka to grow and produce flowers that are not affected by weather conditions.

A substantial part of the Hawke's Bay region is suitable for the establishment of tōtara. We have used tōtara as an example to demonstrate the connection between the characteristic response curves and the spatial information developed from them to represent site suitability spatially. Figure 2 illustrates the effect of elevation, total annual rainfall, and mean annual temperature for the site suitability of tōtara. Elevation is important, with sites over 500 m elevation considered unsuitable. Mean annual temperature also limited site suitability for tōtara, with values less than 9.8°C considered unsuitable. Total annual rainfall was also important, with sites between 1, 000 mm and 1,200 mm considered optimal for tōtarasite suitability, and those with less than 750 mm rainfall unsuitable. Rainfall values above 1,200 mm also reduce site suitability.

Discussion

Response curves and fuzzy membership have been used to develop tree species site suitability maps

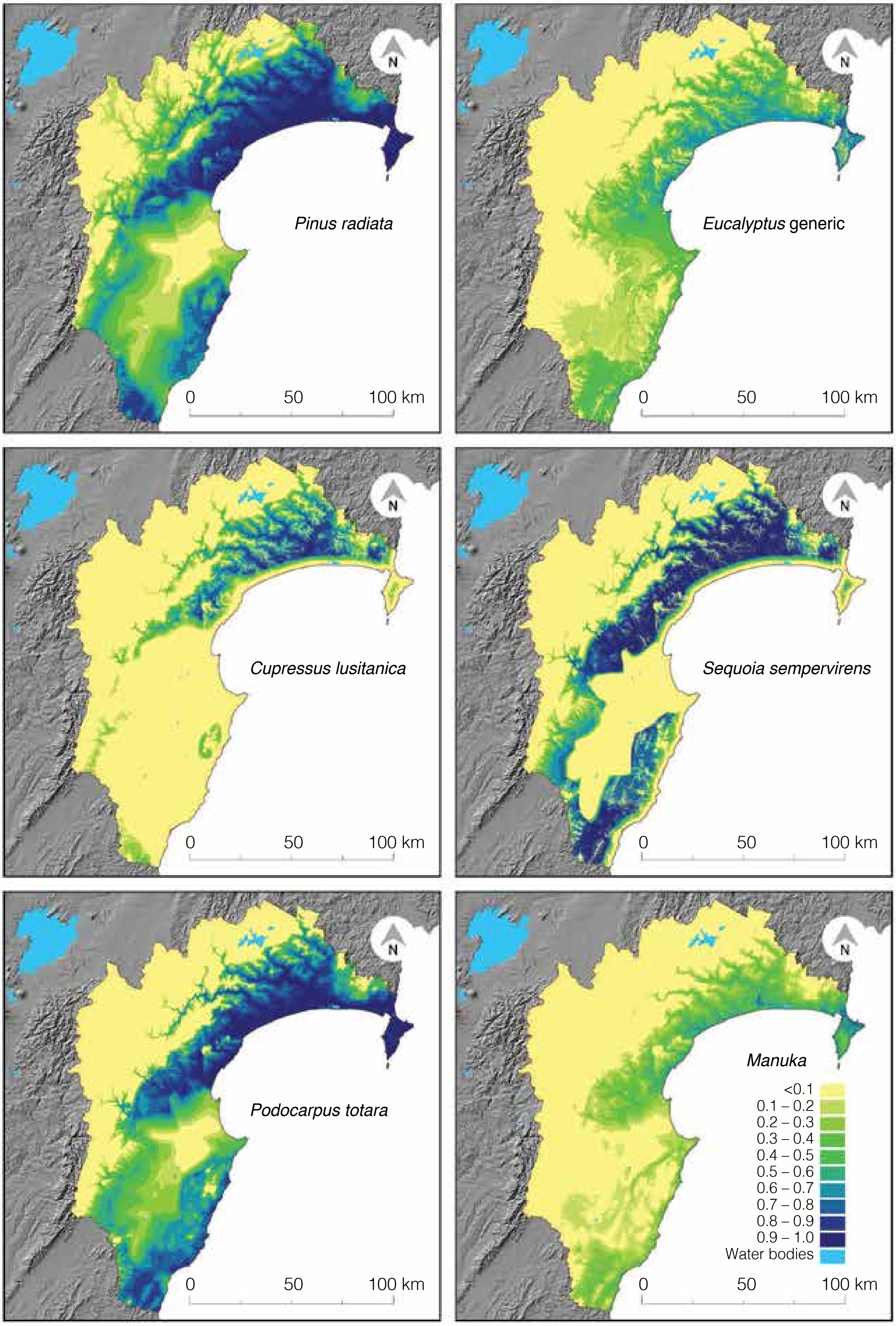

Figure 1: Tree species site suitability for *Pinus radiata*, *Eucalyptus* spp, *Cupressus lusitanica*, *Sequoia sempervirens*, *Podocarpus totara* and *Leptospermum scoparium*. The scale is applicable to all maps and shows site suitability from unsuitable (<0.1) to optimal (1.0)

for radiata pine, coast redwood, *Cupressus lusitanica*, a *Eucalyptus* generic scenario, tōtara and mānuka. This approach not only gives us a useful prediction of where a species can be planted, survive, and grow from low to high productivities (i.e. low to high suitability), but also provides an estimation of suitability between species. The modelling framework is dynamic and can be easily updated as the thinking changes around what constitutes tree species characteristics that affect site suitability. The tree species site suitability maps can also be redeveloped as new information becomes available. This includes, for example, the collection of more observations to represent the full environmental regimes of potential growth sites for different tree species.

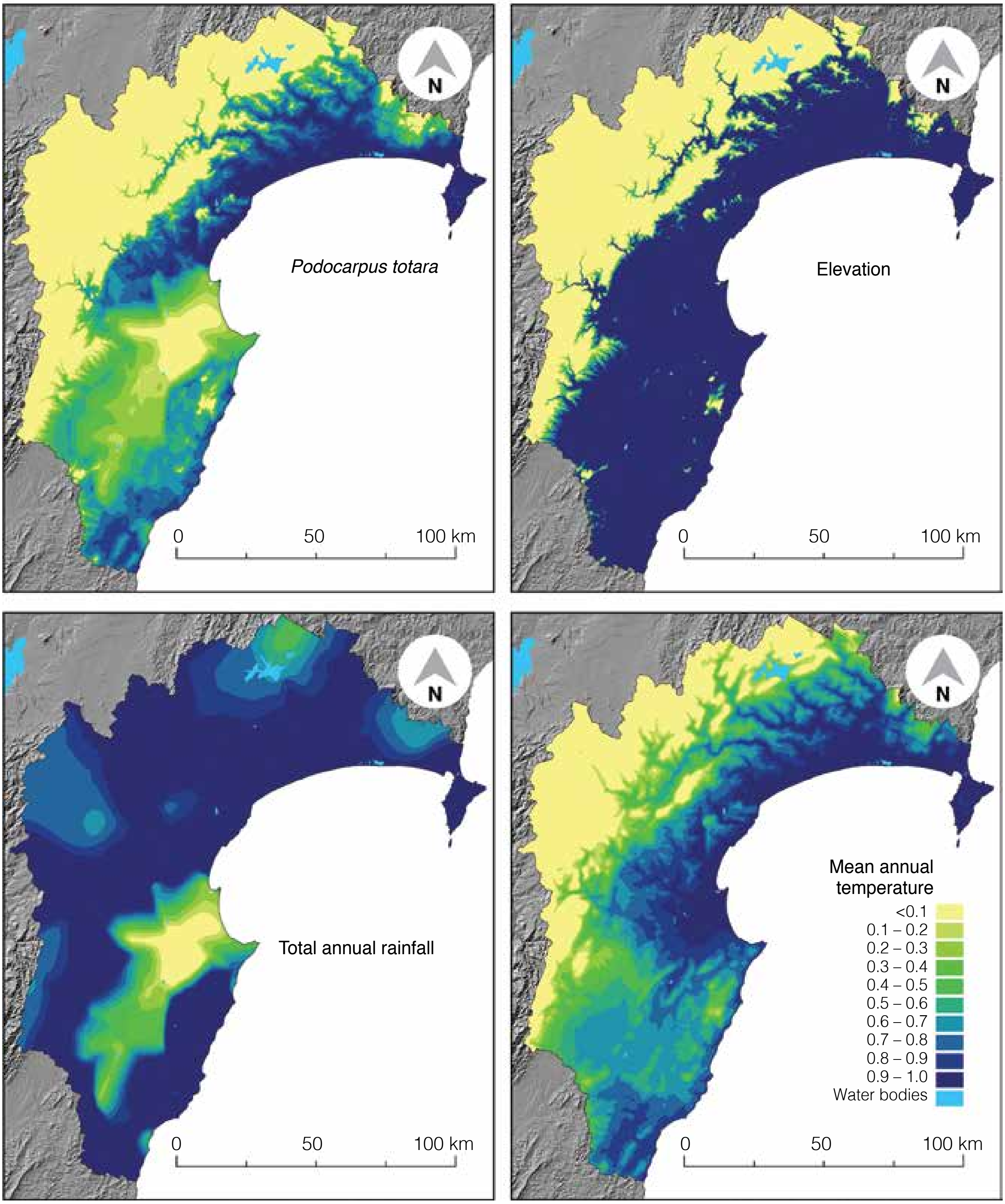

Figure 2: *Podocarpus totara* site suitability characteristic maps for elevation, total annual rainfall, and mean annual temperature across Hawke's Bay. The scale is applicable to all maps and shows site suitability from unsuitable (<0.1) to optimal (1.0)

The fuzzy membership approach assumes we have selected the best upper and lower limits, and the optimal response curve to represent each of the tree species. By choosing limits that are logical, and applying these consistently across all the tree species characteristics, we hope to have provided a level playing field across all the tree species we have modelled.

Productivity and/or a site index could be added to the modelling system in the future. They were not included in this work as values were not available for all species considered in this project and their use may have introduced bias. Further, productivity encompasses many of the characteristics used in the current modelling, and the national spatial datasets used in the development of productivity surfaces are from the same sources and have similar uncertainties.

Looking at the radiata pine productivity (standing volume) or site index (tree height) (Palmer et al., 2009) across Hawke's Bay, radiata pine is reasonably tolerant of high elevation and cooler sites compared to *S. sempervirens* (Palmer et al., 2012) and *C. lusitanica* (Watt et al., 2009), which is very similar to the site suitability maps developed. Also, in keeping with site suitability maps, radiata pine volume and tree height are substantially higher in the northern regions and along the coastal Hawke's Bay regions.

Making comparisons between species at a given location should be approached with care. We believe that separating the data into unsuitable, poor, medium, high and optimal would provide a practical (coarse) interval of comparison. In reality, there is currently no method of validating these results except by expert knowledge. Even with expert knowledge, we seldom find an abundance of tree species growing across the region, let alone a range of species planted at the same locations. From this perspective, using empirical data from PSP locations across New Zealand provides insights that are not otherwise available.

Conclusions

We have developed the tree species site suitability maps to provide a high-level view of where in the landscape a species could be established and grow. An estimate of site suitability, where a tree species finds site characteristics unsuitable (zero) through to optimal (one) across the landscape, can be modelled using fuzzy logic. The site suitability maps are dynamic and can be updated and improved as new information or knowledge becomes available.

Elevation, rainfall and temperature are the main contributors across all the tree species site suitability maps developed here. Overall, the modelling suggests that radiata pine is the most versatile, closely followed by tōtara, albeit at lower elevations. Coast redwood and cypress species are more suited to lower elevations, with redwoods more suited to the southern regions of Hawke's Bay. Neither species are suited to coastal regions due to intolerance to sea spray. The *Eucalyptus* generic scenario and mānuka occupy similar environmental envelopes and site characteristics.

Most species could be grown on highly erosion-prone sites. However, site fertility will be a major consideration for many of the species. In using these broad-level tree species site suitability data, it would be useful to consider each of the characteristic layers independently, to highlight limitations and optimal conditions.

Our tree species site suitability maps provide information across productive agriculture areas where trees are unlikely to be established because of the high cost of land. Conversely, information is provided on areas were the landscapes are eroded, with skeletal soils that would suit the establishment of trees. In these marginal land areas the retirement of the land for reducing erosion and gaining other ecosystem services benefits would be beneficial.

The information provided here can help stakeholders in the decision-making process around the establishment of trees. The next stage of the process would be to engage a forest specialist who can walk across the landscape and assess the terrain, and its climate, and provide the fine-level detail that is required for the establishment and management of trees. It is hoped this work will encourage discussion and conversation about the right species in the right place in the landscape.

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Cost to post-1989 participants registered in the ETS under the stock change accounting method and regulations

Robert Hughes and Paul Molloy

Abstract

The stated purpose of the Climate Change Response Act 2002 is to support and encourage efforts to reduce greenhouse gas (GHG) emissions. Despite this, the current application of the stock change accounting method on the harvest of forest is to the economic detriment of existing post-1989 ETS participants, and the negative impact increases with length of registration and an increase in the price of carbon. This is because it places the entire burden of the reduction in carbon stock on harvesting on the participant with no offsetting benefit, and this is compounded by a rigid Carbon Accounting Area (CAA) specification that is impractical for good forest management. As a transitional arrangement the rigid CAA should be relaxed by applying the practices that allow for the flexible removal of land from a CAA. As this would account for emissions using the land area harvested it is a cost-effective method of operating within a single CAA. It is recommended that the change to a Flexi-CAA approach be made immediately for participants under the stock change accounting method, and backdated for those who filed returns for the second mandatory emission return (MER) period.

Introduction

This paper deals with the burden imposed on forest owners participating in the Emissions Trading Scheme (ETS), with compliant forests planted post-1989 and registered in the ETS on or before 2018. These forests are mainly small-scale (less than 1,000 ha) and make the most significant contribution in offsetting New Zealand's gross emissions (NZ Productivity Commission (NZPC), 2018, 31). In their review of the contribution of forestry to reducing New Zealand's emissions, the NZ Productivity Commission noted the high administrative costs imposed on forest owners by the ETS (NZPC, 2018, 330).

This paper explains the burden placed on participants on harvest, and for some participants this is a significant financial burden. We conclude with the finding that the current form of the ETS has some significant inconsistencies that can cause significant financial harm to forest owners, which will impact future owners' behaviour. This issue is not discussed in the Ministry for Primary Industry (MPI) review of the ETS forestry accounting proposals (MPI, 2019a), the consultation document on the proposed changes to the Climate Change (Forestry Sector) Regulations 2008 (the Regulations) or in the text of the Climate Change Response (Emissions Trading Reform) Amendment Bill. The Government has indicated that issues facing current participants will be revised in 2021 (Te Uru Rākau, 2019, 4). We argue that *transitional arrangements* are urgently needed to minimise harm to forestry before decisions are made on the entry of existing participants into the average accounting method. First, however, we will discuss the Climate Change Response Act 2002 (the Act) and the Regulations 2008 that give rise to this situation.

Post-1989 forests and the stock change accounting method

Participating land is recorded in the ETS as Carbon Accounting Areas (CAAs). This is a fixed geographical/spatial unit defined by the participant on registering the land in the ETS, and can only be changed by removal of the CAA completely and re-entry as a new CAA, or by removal of land from the CAA. Either option requires some repayment of allocated units. Within a CAA there can be a mix of species and age classes. It is important to understand this administrative unit is unrelated to forest management boundaries due to silvicultural treatment, practical logging settings, market conditions or environmental considerations that occur after registration. There could be several decades between initial registration and harvesting.

The inflexible nature of the fixed CAA, given the practical need by participants to change areas over time, is a common problem for existing participants who entered young or immature stands into the ETS. The problems caused by an inflexible CAA will only become worse as the administration of the ETS becomes more complex. The oldest post-1989 eligible stands at commencement of the ETS in 2008 were 18 years old, arguably still 10 years from harvest. In our experience, most participants at that stage had no appreciation of the pending complications arising at harvest or the limitations and financial burden of the fixed CAA unit. This particularly applies to participants who have re-mapped CAAs and wish to add or remove an area, or to the large number who have transferred ownership pre- or post-harvest.

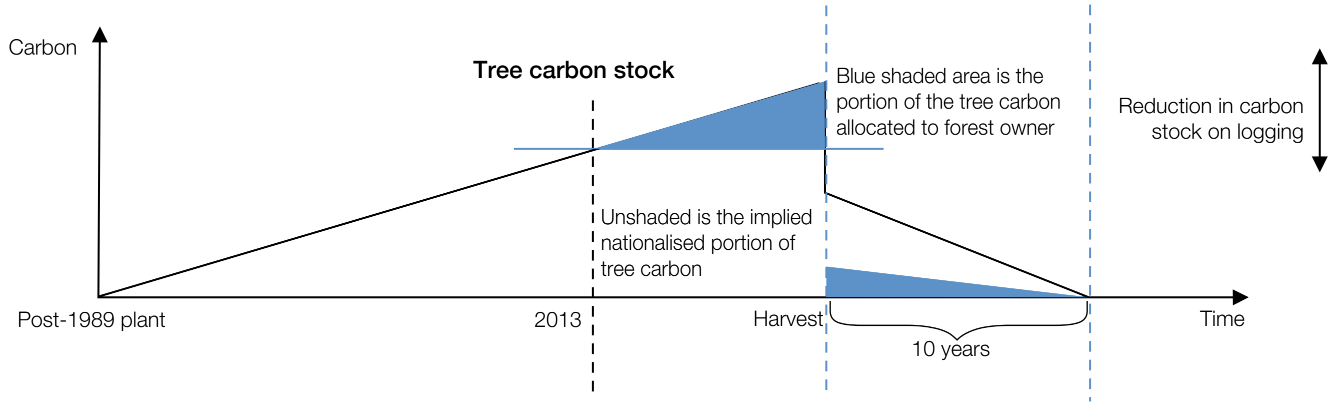

Figure 1: Simplified single age class forest carbon stock and annual change in carbon, with allocation of units to participant from 1 January 2013

Compounding this, under strict rules participants may be subject to pedantic monitoring of CAAs by MPI where new imagery provides greater mapping accuracy than existed 10 years ago. This particularly applies to Field Measurement Approach participants who may have much greater data collection costs resulting from rules which require new sets of plots to be allocated following any change in CAA area. Recently, MPI advised they will be auditing all participants before the end of Commitment Period 3 (CP3) ending 31 December 2022, and the burden of mapping accuracy and consequences on carbon accounting rests solely with the participant. Forest growth since 2008, and better aerial and satellite imagery, will result in boundary discrepancies for possibly every participant! Boundary changes always produce a negative result and liability for the participant to surrender carbon units.

Participants must account for the change in carbon stock in a CAA (section 62 of the Act) when filing voluntary or mandatory returns. Under the existing accounting method, the calculation requires consideration of the change in carbon stock in a CAA over the period covered by the return, and for the decay of any residuals from the first crop. Participants are likely to be aware that at harvest, under section 190 of the Act: 'a participant … is not liable to surrender more units in relation to any carbon accounting area … than the unit balance of that … carbon accounting area.'

Participants may not fully recognise that at harvest, the obligations on a CAA extend to the *full life-cycle* of the crop as a result of the removal of carbon through logs and decaying residues. That is, the participant has had the benefit of carbon allocations from sequestration from registration in the ETS, but has the liability for harvest residue from the date of planting. The cap on liability to surrender units is therefore a smokescreen and grossly penalises existing participants. The true liability is significantly more as participants have accountability for all below-ground carbon, so that is a liability exceeding the cap.

The calculation of the change in carbon stock is set out in sections 20 and 21 of the Regulations. It is important to note that while much of the explanation of the benefits of the proposed averaging method used for post-2019 planting is based on the life-cycle of the forest (MPI, 2019a, 19; Te Uru Rākau, 2019, 10–11), this concept is absent in the regulations that apply to existing participants. They must account for discrete five-yearly changes. The presumption is therefore that forestry participants are 'emitters' – who for some return periods are sequestrating carbon.

Figure 1 provides a simplified depiction for a single age forest of the carbon stock of a first rotation in which the annual tree growth is constant. At harvest, logs are removed from the forest, and the remaining residuals decay at a constant rate over the next 10 years – this is the decay profile used in the Regulations (section 21(3)). The carbon from the date of planting to the participant entry into the ETS is unavailable to the participant. The carbon stock is in effect 'nationalised' by the state. Nonetheless, the Regulations make the participant responsible for the full reduction in carbon stock at harvesting in a Mandatory Emission Return (MER) period (see Figure 1). The 'repayment' of the emissions follows the residual decay profile, even though the number of units surrendered is capped at the number allocated.

As an example, where the forest is registered as a single CAA, the proportion of nationalised and participant allocated carbon stock by date of planting on entry into the ETS in 2013 and harvested at age 28 is shown in Figure 2 (see footnote to figure for assumptions). The figure shows that for a forest planted in 1990, 82% of the carbon is nationalised, with the remaining 18% allocated to the participant. The proportion allocated to participants rises steadily for younger forests. For forests planted before 1997, most of the carbon is nationalised.

This profile also shows the pre-registration emissions imposed on the participant. A participant with 1990 forest entering the ETS in 2013 would be faced with 456% (82%/18%x100) more emissions than occurred during their time of registration. This is the ratio of the nationalised-to-participant proportion of carbon expressed as a percentage, and as seen in Figure 2 this ratio decreases with the reduction in age of forest entering the ETS.

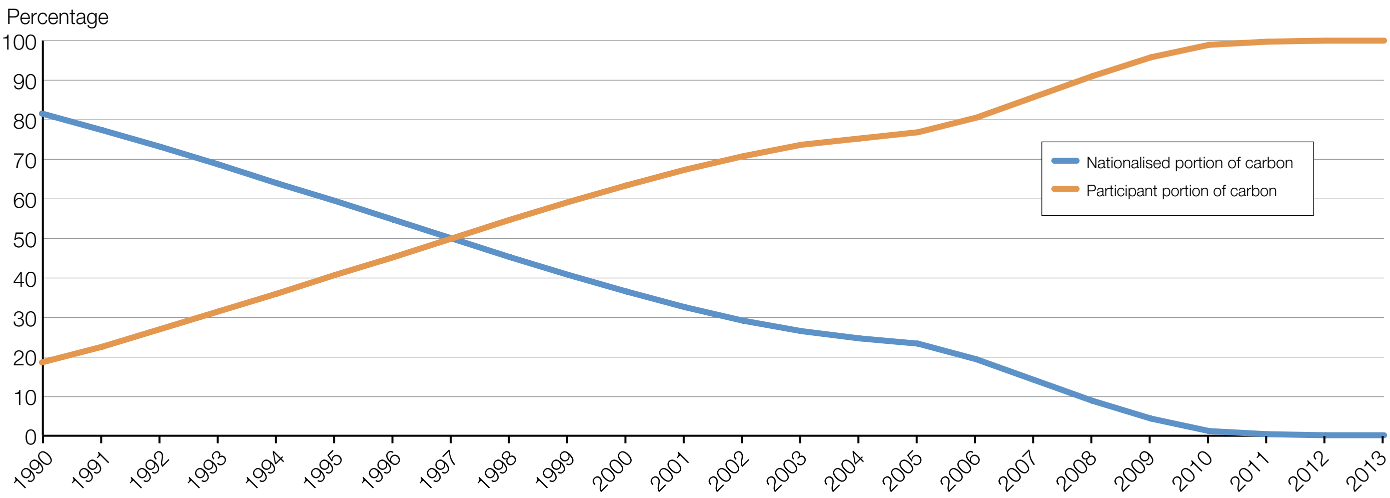

Figure 2: Proportion of carbon nationalised by planting date with 2013 entry into the ETS (per ha)*

* 1 ha *Pinus radiata* harvested at age 28 years old, using Schedule 6 growth tables for Hawke's Bay/Southern North Island and entered into the ETS in 2013 as a single CAA, and with carbon valued at $25/tonne

The difference that timing makes

The Act clearly distinguishes between pre-1990 and post-1989 forests. Post-1989 forests contribute to the reduction of greenhouse gases (GHGs) under the Act. As Figure 1 shows, over their life-cycle, forests planted post-1989 always store carbon. For administrative purposes, commitment periods are usually for five years with the first commencing January 2008. Participants must submit MERs at the end of each commitment period. There are three implications of this regime:

- Forest owners have no claim on the sequestrated carbon from prior commitment periods – these are always claimed by the state
- The full burden on the reduction in carbon stock is assigned to one commitment period. There is no sharing of the carbon stock reduction between the claimants of the carbon – the participant always bears the cost
- Funding the state's share of first rotation residuals is a first charge deduction from the allocated units and from the number of units that can be claimed by the participant on the second rotation crop.

For the participant, this regime provides two contradictory messages. On the one hand their investment has contributed to efforts to reduce GHGs, while on the other they are emitters who must pay the full cost of the emissions calculated in a MER period.

The requirements under section 189 of the Act relate to the whole carbon stock from the date of planting and continue to the harvest and decay of residuals, and on to the planting and growth of the second crop. The impact of these requirements on the CAA is that for the first nine years after harvest the participant must forgo units to fund the state's share of the carbon stock in the residuals, as shown in Figure 2. An example of this calculation is given in Table 1, which shows that for a 300 ha forest entered as a single CAA in 2013 (with 100 ha logged in 2017), despite allocations of units for the first four years all allocated units must be returned in the fifth year. This is an odd result, given there exists a standing forest in 2018 of 200 ha that has sequestrated 30,400 tonnes of carbon over the five-year period.

Table 1: Example calculation of carbon stock change over the 2013–2017 mandatory return period*

Return	Year	Area (ha)	Plant (year)	Harvest (year)	Age	Tree stock	Residual stock	Total	Change	VER	Balance
Voluntary	2013	300	1990		23	195,000		195,000	9,900	9,900	9,900
Voluntary	2014	300	1990		24	204,300		204,300	9,300	9,300	19,200
Voluntary	2015	300	1990		25	213,600		213,600	9,300	9,300	28,500
Voluntary	2016	300	1990		26	222,300		222,300	8,700	8,700	37,200
Mandatory	**2017**					**153,800**	**30,330**	**184,130**	**38,170**	**37,200**	**–**
		200	1990		27	153,800					
		100	1990	2017	27		30,330				

* 300 ha *Pinus radiata* planted in 1993, using Schedule 6 growth tables for Hawke's Bay/Southern North Island, and having entered the ETS in 2013 as a single CAA

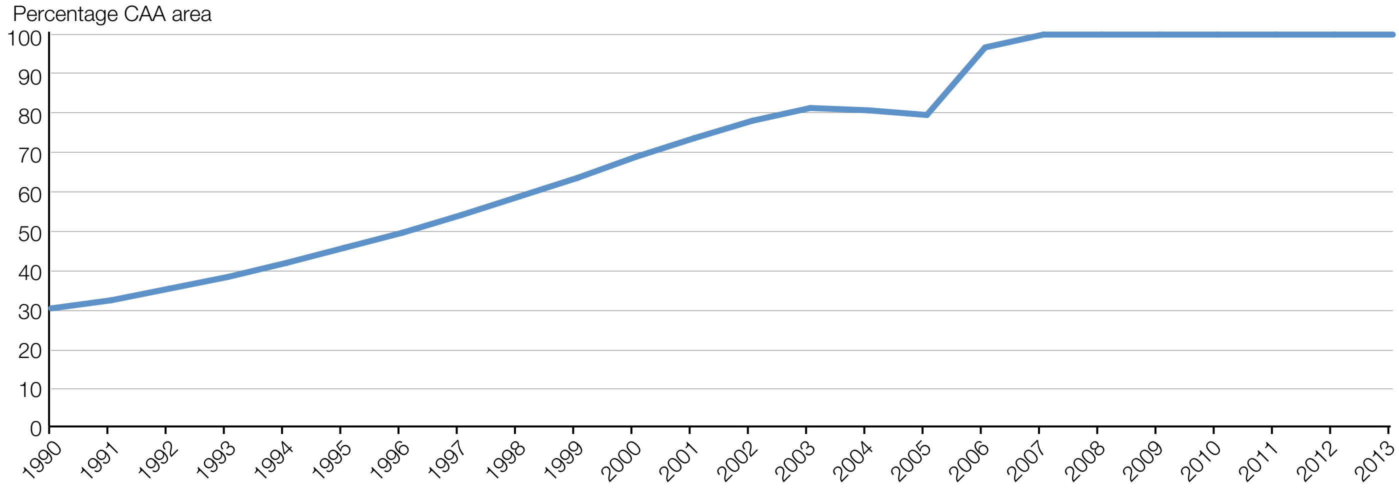

Figure 3: Percentage of a CAA that would result in all units allocated over the 2013–2017 mandatory return period having to be returned

There are two reasons for this result:

- A rigid CAA definition that does not permit the harvested land and its liabilities to be separated from the growing forest that continues to remove carbon
- The stock change accounting method, which delinks the five-year MER period from the growth cycle of the forest.

Inconsistency of a rigid CAA specification with purpose of Act

The purpose of the Act, as it is to be amended by the Climate Change Response (Zero Carbon) Amendment Bill, is the operation and administration of a GHG ETS to give effect to clear and stable climate change policies that 'contribute to the global effort under the Paris Agreement to limit the global average temperature increase to 1.5° Celsius above pre-industrial levels' (section 3(1) of the Act)). The conclusion, imposed by the CAA definition, that the forest in 2018 has sequestrated no carbon is inconsistent with the fact that there is a 200 ha standing forest. This conclusion under the Regulations, that because a CAA is registered as a larger CAA (rather than many small CAAs) no carbon is sequestrated, disincentivises investment in forestry. It also signals to participants that their efforts have contributed nothing to removing carbon from the atmosphere, which is an affront to participants who have made a major contribution to the reduction of New Zealand's GHGs to date.

Figure 3 shows how perverse the Regulations are. The vertical axis gives the percentage of the area in a CAA that, if logged in 2017, would result in the entire unit allocation to the CAA for 2013–2017 having to be returned. The horizontal axis is the year of planting. The graph shows that harvesting 40% of a 1994 planting would result in the surrender of all the allocated units. The clear conclusion is that the rigid specification a CAA makes no allowance for the practical considerations of logging or the commercial and environmental realities of managing a forest. Instead, it assumes the ability to predict the future and the preparedness to incur additional costs from accounting for many small CAAs.

Aligning the MER with the forest sequestration cycle

There is also the issue of the state's share of the carbon in the removed forest. The Regulations require that 'a … participant must calculate the emissions or removals from each carbon accounting area … by determining the carbon stock change in the carbon accounting area …' (section 20(1)A of the Act). The operation of this requirement is shown in Figure 4. The example used is a 300 ha forest planted in 1990 (and harvested 1/3rd in 2017, 1/3rd in 2022 and the remainder in 2025) that enters the ETS in 2013 and submits annual returns for the next five MER periods.

Figure 4 shows the units allocated each year. With a rigid CAA specification of the type being applied by Te Uru Rākau in its calculation of voluntary and mandatory returns, referred to as the Rigid-CAA method in this paper, NZUs are allocated in the first four years then surrendered in the fifth year (this is the profile in Table 1). A few units are allocated in the second mandatory return period to 2022. No more units are allocated until 2033 (in the fifth MER), despite having growing forest for the first three MER periods. Units are allocated for the fifth MER as all remnants of the first crop have decayed.

A very different profile is obtained by making the CAA specification flexible to accommodate emerging economic and forest management considerations. This is particularly useful and equitable when land is removed from a CAA or when boundaries or species change post-harvest of the first crop. With a flexible CAA, the accounting for emissions is confined to the harvested land, referred to in the rest of the paper as the Flexi-CAA method.

Figure 4 shows the unit balance calculated under this method. Clearly seen is the familiar saw tooth profile as forest is harvested. The shaded area shows that the difference between the unit balances calculated using the Rigid-CAA and Flexi-CAA methods is the impact of

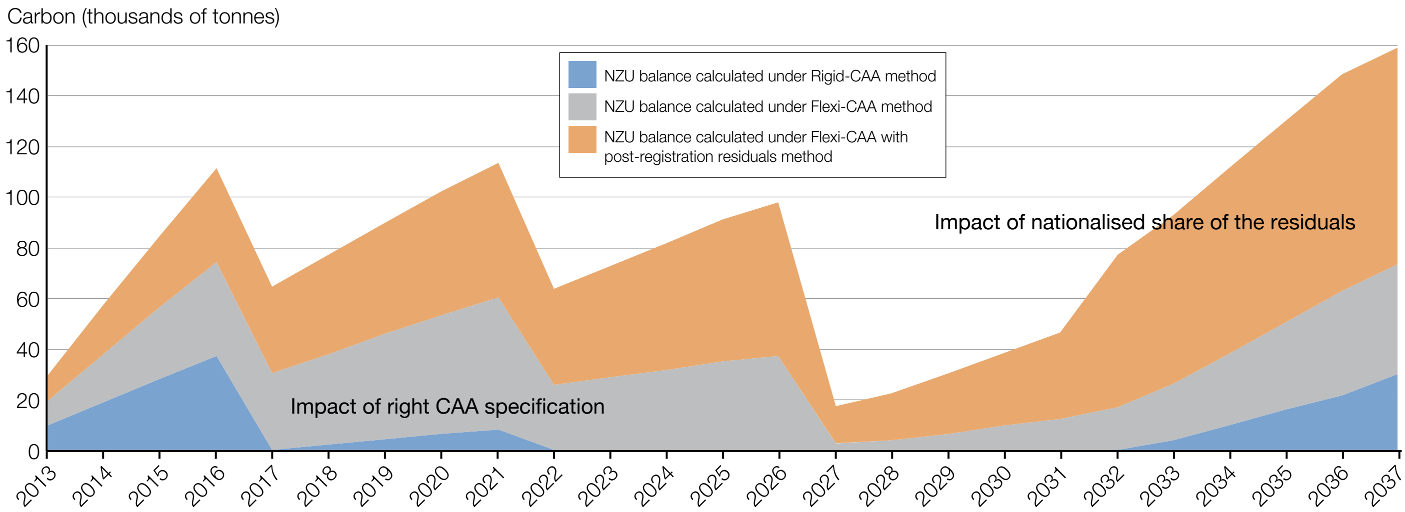

Figure 4: NZU balance calculated using the Rigid-CAA, Flexi-CAA and Flexi-CAA with post-registration residuals method

the rigid CAA specification requiring allocated units to cover liability for a part of the CAA.

Figure 4 also shows the impact of the nationalised share of the residuals on the allocation of units. This is calculated as for the Flexi-CAA method, except the participant accounts only for the residuals in proportion to the time in the ETS. This share of residuals is shown as the shaded triangle in Figure 1 (this method in which the participant shares in the decay of residuals according to the proportion of carbon allocated to the participant is referred to as the Flexi-CAA with post-registration residuals method). The balance of units available to the participant under this method is higher. Of the three methods, this one provides incentives consistent with the purpose of the Act. It does this because by allocating the residuals to the party that gains the benefit of the carbon, and aligns the MER with the time of entry into the ETS in the post-1989 forest life-cycle. The allocation of residuals to the party that benefits from the carbon is an important step in addressing the disincentives provided by the current method of allocating the whole liability for emission on harvest to the participant.

The difference between the three methods in accounting for the carbon content of the forest is shown in Figure 5. The figure shows NZU balances calculated using the three methods as a percentage of forest carbon stock. Over the 25 years covered by the graph, there is a poor alignment between the units allocated under the Rigid-CAA and Flexi-CAA methods and the carbon stock of the forest. Over the period, there is an improving alignment between Flexi-CAA with post-registration residuals method with carbon stock of the forest as the share of the nationalised units in the carbon stock diminishing with the second rotation crop. It is important to note that, for example, even after 25 years of having registered a single CAA there is poor alignment between the units allocated using the Rigid-CAA and Flexi-CAA methods and the carbon stock of the forest.

The burden placed on the participant

Net present value (NPV) is frequently used to assess the relative attractiveness of alternatives. We have previously estimated the cost of participating in the ETS at $3,150 per annum (Hughes & Molloy, 2017). With a 5% annual discount rate for the following calculations,

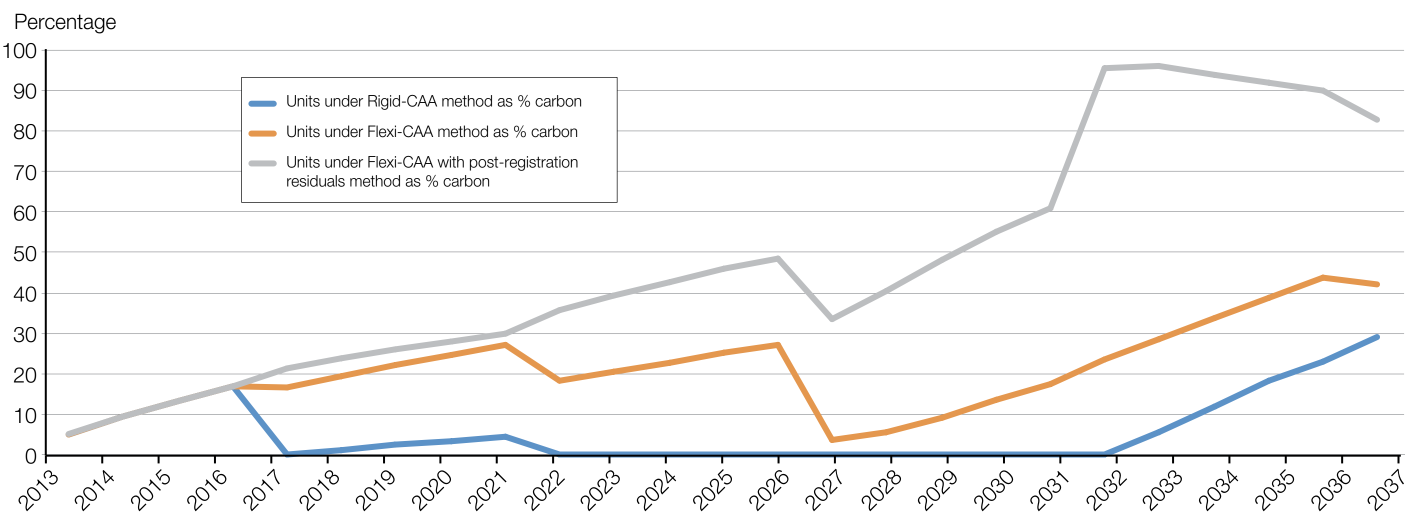

Figure 5: NZU balance as percentage of forest carbon stock calculated using the three methods

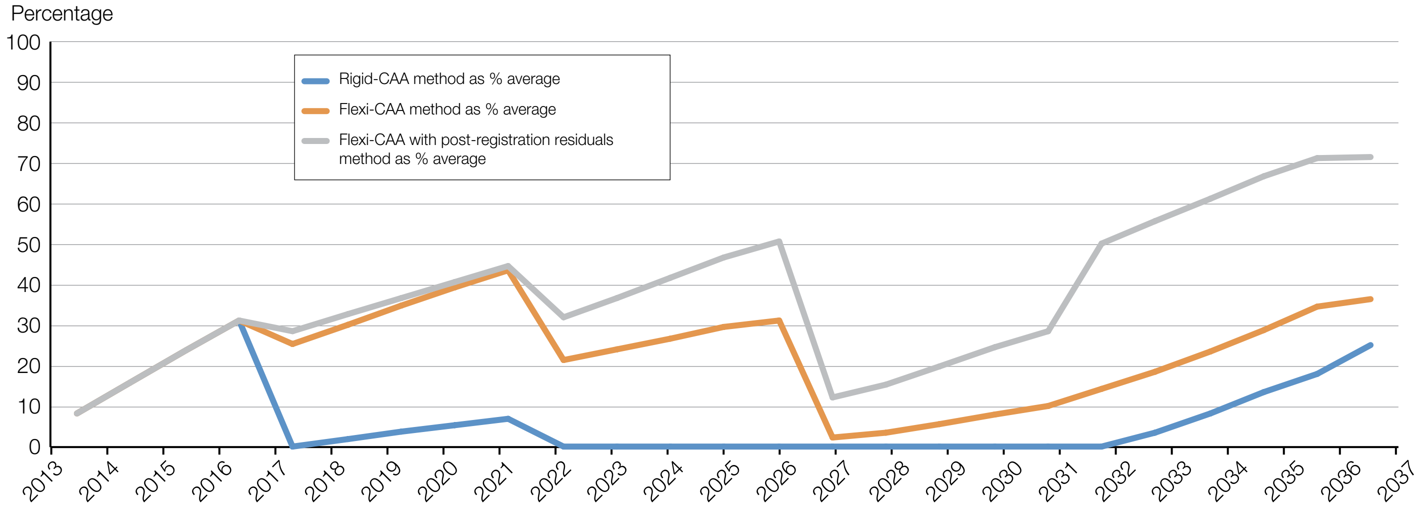

Figure 6: Units allocated by the three methods as a percentage of the average forest carbon with 28-year rotation

and continuing with the example given above and assuming a carbon price of $25/tonne, the NPV of the NZUs allocated under the Rigid-CAA method is $338/ha from those participating in the ETS.

Considering the hazards involved in entering the ETS, the inevitable conclusion is that participating in the ETS provides little improvement to the cash flow profile of investing in forestry. The NPV of the Flexi-CAA method is $1,407/ha. In contrast, over this same period the present value under the Flexi-CAA with post-registration residuals method is $2,317/ha. This method makes participation in the ETS a valuable contribution to improving the economic returns on forestry. These returns increase with an increase in the price of carbon.

Given the intent of the Government to move towards the averaging method, the application of the Rigid-CAA and even the Flexi-CAA methods seems to be retrograde. Figure 6 shows the units allocated by the three methods as a percentage of the average forest carbon with a 28-year rotation. Over the 25 years covered in the graph, only the Flexi-CAA with post-registration residuals method gets close (at 71%) to the average carbon stock of the forest.

Implications for participants

The Rigid-CAA method gives the state two bites at the sequestrated carbon in a post-1989 forest: first, the unclaimed units on the first rotation; and second, the claim on the nationalised share of the residuals for the second rotation. The inescapable conclusion is that the current arrangements provide a strong disincentive to participants in the ETS, and the disincentive increases with the age of the forest. Note that these comments apply to existing participants and the first rotation where forest owners have limited benefit and significant liability. Late entrants with new plantings obtain proportionally more benefit, even under the current accounting method. This has implications for land value.

Figure 7 shows the cost of residuals imposed by the Rigid-CAA method on participants by year of planting with entry into the ETS on 1 January 2013 and harvest at age 28. This cost is $7,095 for forest planted in 1990 reducing to $3,177 for forest planted in 2000 where carbon is priced at $25/tonne. The situation is even more unattractive at higher carbon prices (e.g. the corresponding values where carbon is priced at $35/tonne are $9,934 for 1990 forest and $4,447 for 2000 forest). To put these costs into perspective, forest land is typically valued in the range of $3,000 to $7,000/ha. Given that the bulk of post-1989 forests are planted prior to 2000, most of this land on harvest is severely impaired by entry into the ETS.

The impairments imposed by the Rigid-CAA method have significant ramifications for land value and future land sales. To give an idea about the way that it impacts on freehold rights, Table 2 shows the implications on the ability to sell land. Low interest (below say 5% per annum) with low impairment has little impact on land value. At a high level, with high interest rates (say more that 10% per annum) the strategy is to sell early to minimise loss (as assessed in present value terms). A quite different strategy applies where the land is highly impaired. In broad terms it means where interest rates are low (holding until residuals are zero before selling becomes optimal), and at high interest rates, it changes to hold to minimise the loss on sale. The inevitable conclusion is that to shed the impediments on the options to sell or change land use, participants must deregister. This finding has implications for the sale and purchase of cut-over forest land, and whether it continues as forest land.

Table 2: How entering the ETS under Rigid-CAA method impacts the ability to sell land

Impairment on land	Interest rate	
	Low	**High**
Low	Sell close to land value	Sell early to minimise loss
High	Hold until residuals are zero	Hold to minimise loss

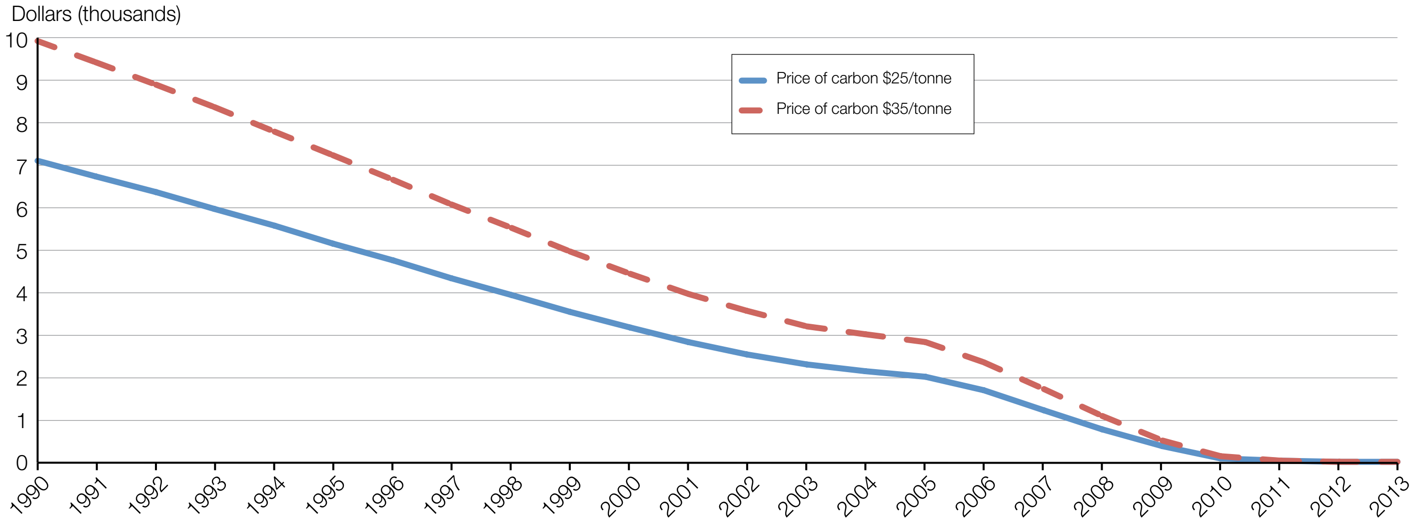

Figure 7: Cost of residuals imposed by the Rigid-CAA method on participants by year of planting with entry into the ETS in 2013 and harvest at age 28 ($/ha) where carbon is priced at $25 and 35/tonne

The harvest residue liability from first rotation may be equivalent to normal forest land value, which is a huge disincentive to sale. It encourages the purchase of clean alternate qualifying land, particularly hill country farmland. The NPV of a combination of a potential One Billion Tree subsidy and liability-free carbon on new land is a market indicator that renders post-harvest cut-over relatively worthless, and is a trigger for land use change from agriculture. That may be a problem for many participants whose ownership is by limited qualifying company or partnership from the 1990s planting boom and who wish to exit post-harvest.

Risk profile for participants

The ETS has been supported by, and has relied on, the initial pioneers and investors in the small-scale forest industry. Yet they are the ones at a serious disadvantage. They have been forsaken by flawed legislation, government inaction, and by proposed changes that favour new entrants. Delays in implementing proposed changes have caused uncertainty, confusion and lack of confidence, and fail to reward existing participants. New entrants under the new accounting method are gifted 18 years worth of 'free' carbon, whereas existing participants under existing accounting are gifted 18 years worth of carbon liability.

Participants have an adverse risk profile, compounded by a carbon pricing model and a market that is very difficult to predict. The price is more strongly influenced by government policy and climate change initiatives than supply and demand (i.e. carbon pricing is not subject to normal market forces).

There is too much downside with not enough upside. For example, a significant number of participants who deregistered when the opportunity was available in the second commitment period have not re-registered as the perceived costs outweigh the benefits. This is for forest owners with experience in the ETS.

To illustrate the inconsistencies in the ETS as they apply to existing participants, with compliant forests planted post-1989 and registered in the ETS on or before 2018, we have used *Pinus radiata* with the growth profile as set out in Schedule 6 for Hawke's Bay/ Southern North Island. Forests with faster growth rates, and therefore the best-performing forests, will be more severely impacted and vice versa. It is beyond the scope of this paper to estimate the scale of this problem, but suffice to say we are aware that many forest owners face the impacts we describe in this paper.

Conclusion

This paper looks at the cost imposed by Te Uru Rākau's application of the Regulations by fixed specification of the CAA, and a MER period unaligned with the forest life-cycle. We argue that the current application is inconsistent with the purpose of the Act, and does not facilitate a transition to the averaging method. Te Uru Rākau already has practices that allow for the flexible removal of land from a CAA and this could be applied to enable a cost-effective method of operating within a single CAA.

The problem described in this paper does not exist under the averaging method. Given the significance of the financial burden being placed on some forest owners, forcing existing participants to wait until 2021 for some unknown action (Te Uru Rākau, 2019, 4) is comparable to Nero fiddling while Rome burns. We recommend that as an interim step Te Uru Rākau apply the Flexi-CAA with post-registration residuals method for both voluntary and mandatory returns. This change should be made immediately and made available to participants who have filed 2017 mandatory returns.

The current application of the Regulations has some significant inconsistencies, provides ambiguous incentives to continue to invest in forestry, and does not provide a transition path to the averaging method. Allowing this situation to continue only signals to current and future participants that 'you can't trust the Government on forestry policy.' The Government has also announced transitional measures for agriculture outside of the ETS. Clearly the ETS is not working for all emitters. A total rewrite of the Act and Regulations is required to accommodate the characteristics of biological systems, rather than assuming they are a form of an inanimate manufacturing system. Alternative proposals will dilute the ETS as the absolute answer to carbon neutrality. Failure to account for the unique characteristics of forestry management will diminish the significant contribution forestry is making to New Zealand's actions to remain within the '1.5° Celsius' target.

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Right tree, right place, right purpose – but what is 'right'?

Mark Bloomberg

'Right tree, right place, right purpose' is the slogan of Te Uru Rākau's One Billion Trees programme (1BT). It seems sensible, if not axiomatic – but in practice this slogan may not be easy to apply. Let's start with how we define the term 'right'. Like many words in the English language, it can be used in multiple ways. It can be an adverb, adjective, noun or verb, and has several meanings when used as any of these parts of speech. In 'Right tree', it is used as an adjective. *The New Zealand Oxford Dictionary* offers five different definitions of 'right' as an adjective, but the two main ones are: (1) '(of conduct etc.) just, morally or socially correct', or (2) 'true, correct; not mistaken.'

From the Te Uru Rākau website, it seems 'right' will be assessed in both these senses. For example, under the heading of 'Right place' the website states (italics added for emphasis): 'We want to see trees integrated into the landscape to complement and diversify our existing land uses, rather than see large-scale land conversion to forestry. *We also want trees planted to be suitable for the site and their intended use. To do this we need to align tree planting with local land-use and planting priorities and strategies.'*

So, we need to make correct decisions about tree planting that are based on technical and economic knowledge – they must be 'suitable for the site and their intended use.' But we also need to account for the priorities of local communities, including a preference for small-scale forestry. Note that while the priorities of local communities are explicitly mentioned in Te Uru Rākau's explanation of the 'Right tree' slogan, national priorities are not. Yet the key driver for 1BT is the need to plant new forests to facilitate New Zealand's transition to a zero carbon economy by 2050. Without this underlying need, would there even be a 1BT programme?

What this means is that there is an inherent contradiction in the 'Right tree' slogan. While local priorities are important, New Zealand's targets for carbon sequestration are unlikely to be achieved without large-scale land conversion to fast-growth plantation forests. Small-scale plantings with indigenous or slow-growing exotic tree species are unlikely to sequester enough carbon in the 30 years between now and 2050. This contradiction between national and local afforestation priorities has happened before. New Zealand planted most of its plantation forests during three 'planting boom' periods – during the 1920s, 1970–80s and 1990s. The drivers for these booms were a combination of government policy and investor appetite. The Government wanted more plantation forests to meet goals for national economic development. Private investors, both corporate and individual, saw forestry as a profitable investment. In each of these planting booms, large-scale afforestation with a few proven fast-growth species was the rule. This was driven by expediency and economics – once acquired, land needed to be planted completely and rapidly to meet investor expectations or government planting targets. And the planted trees had to grow reliably and quickly, with a good chance of maturing into a valuable timber resource.

In contrast, particularly in the second and third planting booms, many communities were opposed to the purchasing of farms for conversion to large-scale fast-growth plantations. This opposition often manifested in rules in local government plans that restricted the location and extent of new plantation forests – first under the Town and Country Planning Act 1977 and later under the Resource Management Act 1991 (RMA). In cases where indigenous forests were converted to plantation forests, political activism was the preferred response of environmentalists, although they later came to see local plans under the RMA as another way to limit plantation forests on lands with conservation value.

So, this conflict between large-scale tree plantings (to meet government or commercial objectives) and local priorities is nothing new. All the 'Right tree' slogan does is restate the same conflict we have failed to come to terms with for half a century now – how to be 'right' in the objective, technical sense (i.e. efficiently meeting targets for national development or carbon sequestration), and at the same time 'right' in the sense of being morally and socially correct. The Government is trying to address this. For example, government-funded tree plantings under the 1BT must meet criteria such as giving priority to small-scale plantings within existing farming operations. But of the 149 million trees planted so far under the 1BT, only 17% have been directly funded by the Government. The rest will have been planted (or replanted) by commercial foresters.

Further, it seems likely that most of the new commercial plantings will involve whole-farm conversion to a forest. In a recent report, Te Uru Rākau noted that 'Market drivers, especially the economic prospects for commercial forestry, high log price and high carbon price, are likely to be the key drivers of whole-farm conversion rather than the One Billion Trees grant funding.' As with previous planting booms, the Government appears happy to accept and even facilitate large-scale plantation forests to meet national objectives such as carbon sequestration. While there is some intervention using direct government funding to promote small-scale forests, once again communities' views on 'Right tree, right place, right purpose' will most likely be advanced through local plans under the RMA – with lobbying and other direct action by activists where the opposition to large-scale plantation forestry is strongest. The more things change, the more they stay the same.

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