The role of data, models and tools in support of afforestation

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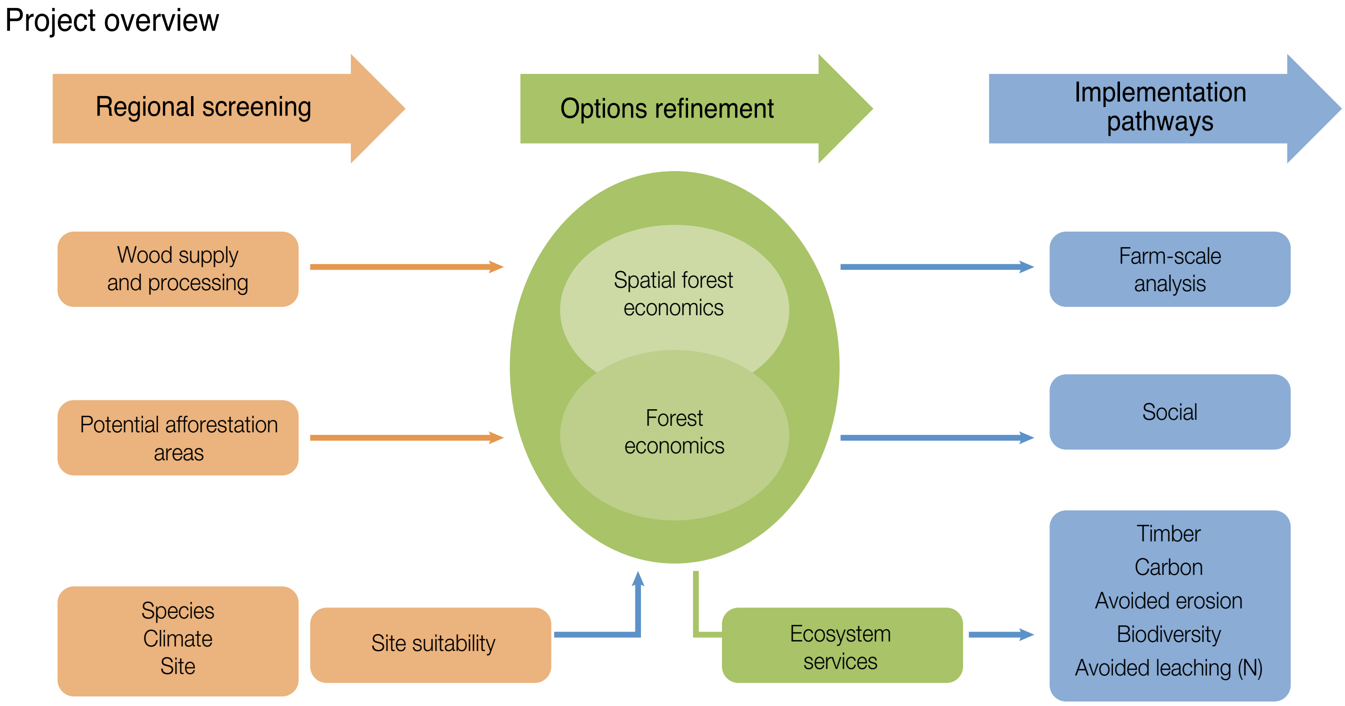

Figure 1: An overview of the 'Planting Eroding Hill Country in the Hawke's Bay Region: Right Tree, Right Place, Right Purpose' project

Abstract

In the Hawke's Bay region erosion and sediment loss is a major environmental issue. A recent project looking at the potential for afforestation to control erosion has identified a range of tree species, forestry regimes, the potential economic and environmental returns of afforestation across the region, as well as comparing the economics of afforestation with agriculture. The regional resources developed as part of the project will enable objective discussions and decision-making in what is becoming an emotive and subjective social arena. Data and modelling tools and software were fundamental to the success of the project. Advances in data technology will allow even better afforestation potential analysis at much finer scale. These new technologies and ways to monitor the land and its productivity are increasingly making sustainable, complementary land management (which unites farming, plantation forestry, permanent forests and other land uses) a reality.

Introduction

Researchers from Scion (along with forestry and agricultural consultants and funding from Te Uru Rākau) have used broad-scale spatial information across a range of tree species and forest systems, as well as forest economics and social analysis, to explore planting the right tree in the right place and for the right purpose across the Hawke's Bay landscape. In this case, the primary purpose of afforestation is to reduce or mitigate erosion. Around 12% of the Hawke's Bay region has a high susceptibility to erosion. The Hawke's Bay Regional Investment Company (HBRIC) and the Hawke's Bay Regional Council (HBRC) want to explore opportunities for using afforestation to reduce erosion and provide both economic and environmental land-use solutions. See inset about the HBRC's work in this area (written by Chief Executive James Palmer) at the end of this paper on page 8.

The structure of the project was designed to provide a sound platform for future decision-making. Regional screening (Figure 1) investigates the possible (practical) options for afforestation and was reported in the May 2020 issue of the *New Zealand Journal of Forestry*.

Implementation pathways

Human and social aspects are important considerations when trying to encourage forestry options. Indeed, for the establishment of forests across landscapes identified as the most vulnerable to erosion to occur, landowners need to be convinced of the economic, environmental and social benefits that afforestation will bring. Forestry consultants, PF Olsen, have modelled the financial implications of afforestation using different tree species and alternative forestry management regimes for the Hawke's Bay. Agricultural consultants, AgFirst Hawke's Bay, have demonstrated a tipping point between forestry and pastoral land use where forestry options can make better financial sense under the right conditions.

Detailed assessments at the farm level need to take place if a complementary approach between forestry and farming is to be considered. The approach could be where less-productive land is assessed for afforestation, while higher quality land is managed more intensively, together increasing overall returns. Landowner attitudes towards afforestation have been explored by business consultants, Fresh Perspective Insight. They believe that every landowner's situation is unique and needs careful consideration to address and encourage the drivers to afforestation and overcome barriers such as lack of experience and uncertainty around financial risk.

The work has also shown that the HBRC and HBRIC and landowners need more information and knowledge to support their decisions around afforestation. This is information that can be used to compare agricultural and forestry outcomes, to support landowners considering afforestation, and to provide incentives. This can be achieved in part by empowering landowners with the tools to help with decisions, but also through educating and employing rural professionals to work through details with landowners on the hows (where and what to plant) and whys (range of benefits) of forestry.

Data key to supporting individual solutions

The information that individual landowners and regional bodies need to make decisions often depends on software and tools for modelling available data. The models and software used are continually being refined and the amount of data related to terrain, land use, tree species and genetics, for example, is growing rapidly. Combined, improved models and data will contribute to better decision-making and improved economic, environmental and social outcomes.

A wealth of spatial data is available for modelling forests, many of which are in the public domain, but also some that are privately owned. Table 1 lists the spatial layers that are frequently used in the modelling and mapping of land uses including forestry.

Table 1: Selected spatial layers frequently used in the modelling and mapping of forestry and afforestation

Spatial layers	Units	Abbreviation	Reference
Climate			
Air temperature (mean annual)	°C	T_{mean}	Wratt et al. (2006)
Air temperature (Dec & Jan)	°C	T_{DecJan}	Wratt et al. (2006)
Degree ground frost (Oct)	days	DGF	Leathwick et al. (1998)
Rainfall (total annual)	mm	Rain	Wratt et al. (2006)
Rainfall days (Dec & Jan)	days year^{-1}	Rain days	Wratt et al. (2006)
Landscape and topographic			
Aspect	°	Asp	Palmer et al. (2009)
Distance from coast	km	CoastDist	Palmer et al. (2020)
Distance from mills	km	MillDist	Yao et al. (2016)
Distance from ports	km	PortDist	Yao et al. (2016)
Elevation	m	Elev	Barringer et al. (2002)
Hauler and ground-based	–	HaulGround	Yao et al. (2016)
Impedance	$	Imp	Yao et al. (2016)
Land Cover Database	–	LCDB	MfE (2020)
Land Use Capability	–	LUC	Lynn et al. (2009)
LUCAS	–	LUCAS	MfE (2020)
Roads	–	Roads	LINZ
SedNetNZ	t km^{-2} yr^{-1}	SedNetNZ	Dymond et al. (2010)
Slope	°	Slope	Palmer et al. (2009)
Wind effect (SAGA)	–	Wind exposure	SAGA-GIS.org
Productivity			
300 Index	m^3 ha^{-1} yr^{-1}	300Index	Palmer et al. (2009a)
Soil water			
Profile available water content	mm	PAW	Newsome et al. (2008)

Models and tools

Making use of these data required integrated modelling systems and tools. In this project we used a number of them to undertake the regional analysis and finer scale case study analysis at the property level.

Forest productivity and economic modelling requires forest regime and productivity data, and also costs and revenues to enable economic analysis. Radiata pine has the best supporting data and tools such as Forecaster are normally used for regime analysis. In the case of this project, where much less information and data was available for species other than radiata, Excel-based models were developed.

The Forest Investment Framework (FIF) integrates data from many sources to quantify the broader value of planted forests. FIF was used in the Hawke's Bay right tree, right place, right purpose project by Yao and Palmer (2020) to estimate the non-market value of benefits such as avoided erosion and reduced nutrient leaching. Being able to account for the multiple values of an ecosystem that are realised not only by landowners and/or managers, but also by the general public, helps bodies such as the HBRC with decision-making. They are now armed with the information and understanding to formulate and support programmes that promote economically viable, ecologically sound and socially just initiatives as part of sustainable land management.

WoodScape, a techno-economic model, was used to assess wood-processing capabilities in the Hawke's Bay (Hall & Harnett, 2020). They found there was scope for increasing processing, leading to employment creation and an increased gross domestic product (GDP). Techno-economic modelling can be taken further by looking at how a whole value chain might be optimised. Scion used this approach in their Biofuels Roadmap study (Scion, 2018) considering variables such as land use capability, where biomass could be grown, the siting of existing and new forests, feedstock transportation and technologies to produce biofuels. A process of mixing, matching and analysing then modelled various scenarios to find optimised combinations.

Farmax (www.farmax.co.nz) is a decision support tool for farmers that allows them to create a farm system model and test different scenarios to see how changes to the farm will affect biological and financial feasibility. In this project we used it to develop on-farm case studies and explore the opportunities for trees, and the tipping point between pastoral systems and production or retirement forestry, by linking to separate forestry models.

A taste of the data-rich future

Perhaps most exciting and interesting to farmers and foresters is the new data being collected remotely by laser scanners, still and video cameras, and spectral sensors mounted on unmanned aerial vehicles (UAVs), aircraft or even satellites. With decreasing cost, improving resolution and more frequent scanning, obtaining the data for precision land management is becoming a reality.

The highly detailed terrain maps that can be created using laser scanning will allow landowners to identify smaller, more vulnerable areas that need to be managed closely, and assist in decision-making around permanent (riparian) plantings, for example, or plantation forestry, or a combination. Identifying the right place to plant trees to prevent vulnerable land from further degradation is at the heart of the Hawke's Bay afforestation on erodible landscapes project.

Forest owners and managers are also taking advantage of this technology. Not only can remote laser scanning be used to create digital terrain maps of forested landscape, individual trees can also be picked out and characterised. This opens up the possibility of using a tree's appearance (phenotype), which is influenced by both its genes and its growing environment, to identify trees with optimal genetics for different niches in the landscape. For example, while most trees will grow well on warm fertile sites, being able to select trees that thrive despite a southerly aspect or being planted in a damp gully or on a dry, cold site, can speed up genetic improvement programmes and increase overall forest productivity by ensuring the right genetics are planted at the right micro-site (Dungey et al., 2018). Figure 2 shows a tree that has been laser-scanned from above, then below. Each image is missing detail, but by combining the two the full tree can be visualised.

Remotely-sensed measurements collected at mid- and end-of-rotation can be used to construct 3D representations of forests to accurately predict key variables such as top height, stem density, basal area and total stem volume (Puliti et al., 2020). Having an accurate inventory of both tree volumes and tree

Figure 2: Laser scanning results for an individual tree. (Left) scanned from above; (middle) scanned from below; (right) composite image

grades allows forest owners and managers to value their forests, and decide prior to harvesting which products (end use) the trees may be most suited for.

The technology can go further. Laser scanning below the canopy can also allow the vertical structure of a forest to be represented and characteristics such as internode distances and tree sweep can be estimated (Figure 3). This technology has the potential to provide processors with an exact tree stem shape and form before milling, allowing optimisation of milling operations. Overall, trees can be harvested, processed and marketed to reduce waste and maximise returns.

Discussion and conclusion

Reliable and detailed data, and tools to translate the data into information, are essential to support the landowners who will be planting trees on vulnerable landscapes with the goal of reducing erosion. Each landowner's situation is unique in terms of their financial situation, land use capability classes, and their aspirations and attitudes. However, the majority want to protect their land for future generations and make their operations more resilient and sustainable. To do this they need to assess the performance of their land to within-paddock detail and consider other land-use options such as forestry that could, for example, complement pastoral farming and increase overall returns. They also need to recognise that afforestation can provide wider environmental and social benefits, as well as economic.

More data is also needed on tree species. Radiata pine dominates plantation forestry in New Zealand, and it is the current focus of increasing forest productivity. While other species can compete favourably, their performance is not always consistent. However, applying new data collection and analysis technology to these species will also lead to improved productivity though better site selection and genetic improvement. Targeting selected alternative species will also allow effort to be focused on market development, collaboration, and developing scale and infrastructure.

Other benefits of afforestation are often ignored when making decisions about what to plant and where. The economic tool FIF can be used to better account for the full value of planted forests in land-use policy. Being able to put a value on benefits that do not have market values, such as avoided erosion or water quality, helps stakeholders understand and compare the true costs of different land uses and move towards sustainable land management practices.

The HBRC and HBRIC have an opportunity to support and leverage existing industry and infrastructure. This includes using specific interventions and investment strategies to influence landowners' decisions

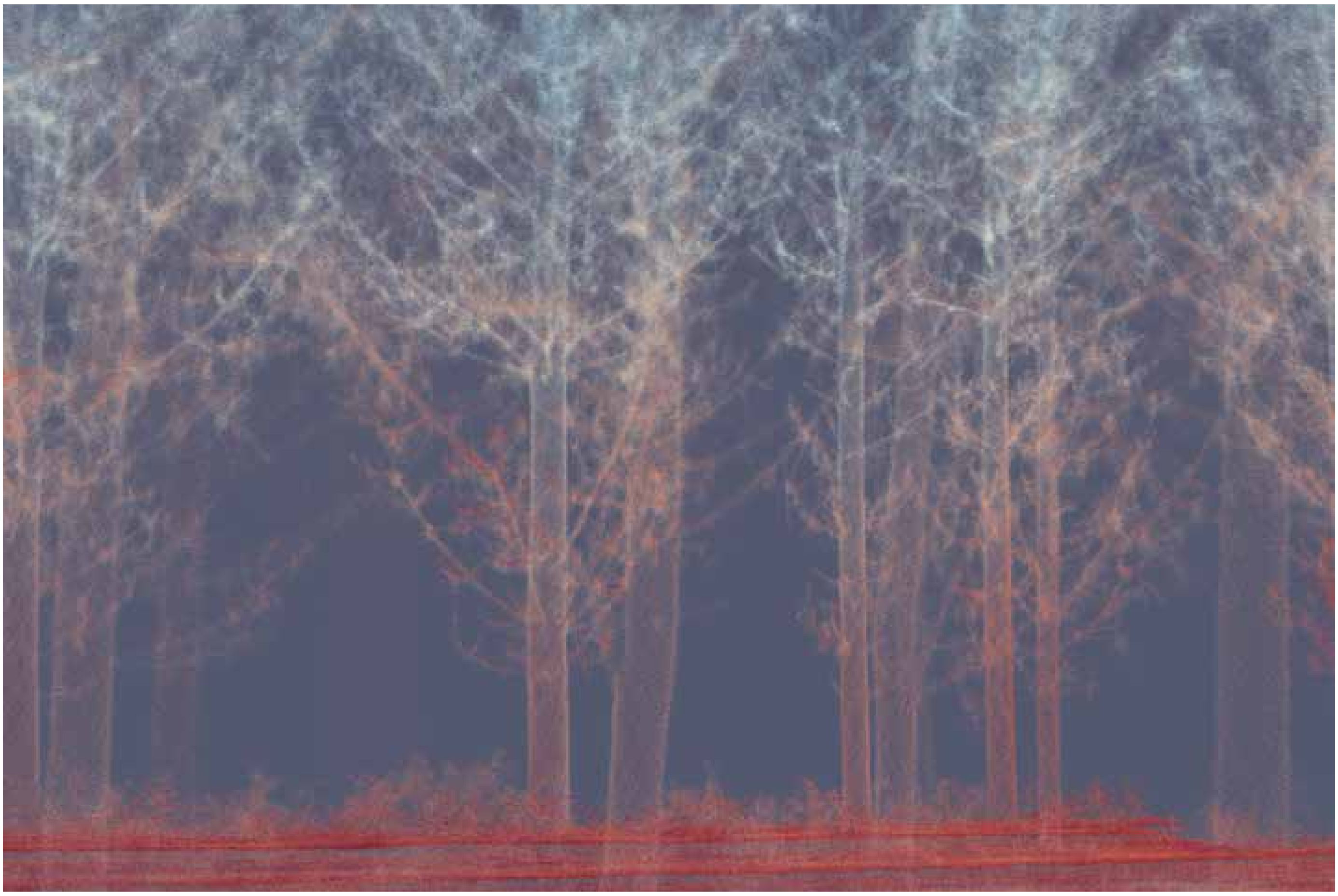

Figure 3: 3D representation of radiata pine trees obtained by below-canopy laser scanning

to choose native as well as exotic forest species to deliver environmental benefits and satisfy landowners' preferences. Another possible role for regional bodies is developing internal forestry expertise and resources for landowners unsure of how to get into forestry.

Data collection and analysis has underpinned this entire project, and some of the new data science and technologies that have been described here are already helping foresters increase the productivity of their forests. The ability to get remotely-sensed data that is frequently updated, detailed and accurate from remote, hard to access country, is cheaper and safer than having boots on the ground. Foresters will be able to monitor forest health and growth rates, for example, and make early interventions to boost productivity. Accurate pre-harvest inventories of volume and form will also boost productivity by enabling optimised processing and waste reduction.

The HBRIC and HBRC and landowners can now identify areas that are vulnerable to erosion, which forestry species and regimes could be appropriate, the economic (timber and carbon) value of afforestation plus the value of preventing erosion and other environmental benefits, and how the wood could be processed to increase returns and jobs. New technologies and ways to monitor the land and its productivity are increasingly making sustainable, complementary land management (which unites farming, plantation forestry, permanent forests and other land uses) a reality. The result will be a robust and resilient landscape increasing the wellbeing of all New Zealanders.

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HBRC pulling all the levers to reverse catastrophic erosion damage

Hawke's Bay is at a critical turning point where we must act with urgency and plant trees on such a scale so as to reverse the catastrophic damage to our environment over the past 100 years. Our landscapes are barren – the casualty of mass clearing by pioneering settlers to create farms, who could not have foreseen the full environmental implications of their actions. You don't need to go very far down a rural road in this region before seeing gaping, scarred and eroded hills.

We estimate around 12% (or 250–380,000 ha) of our region is highly vulnerable to soil erosion. Every year, thousands of tonnes worth of potentially productive soil dislodge and fall into our waterways, threatening our ecologically important estuarine and coastal habitats. On a stormy day, you can see the pervasive sedimentation of our waterways, from our streams and rivers to the coast, where our seas turn brown.

The story of how we got here is similar to other regions, and rural areas around the world, marked by deforestation, the development of pastoral farming and loss of biodiversity. In 1938, a storm hammered the East Coast, which resulted in massive sediment loss from the hills north-west of Napier, drowning the valley floors and burying homes in silt to the rooftops. This resulted in the 1941 Soil Conservation and Rivers Control Act, which started the soil conversation programme and established catchment boards – the early genesis of our regional councils.

Following that event, the Hawke's Bay Catchment Board (now the Hawke's Bay Regional Council) established the Tangoio soil conservation reserve and reduced soil erosion in one of the most affected parts of the region. Fast-forward to today, and despite 80 years of valiant soil conservation work the region still faces wide-scale erosion damage. Given climate change is coming at us like a freight train, we need to act with urgency.

We know planting trees is the single most effective short-term action to restore erosion-prone areas, slow climate change, and the most cost-effective mechanism to improve water quality and biodiversity. We want to develop our existing partnerships with landowners to plant trees, and accelerate this planting programme at sufficient pace and scale to meet freshwater quality objectives and ensure climate resilient landscapes.

The quality and quantity of our soil is critical to the overall health of our land and wider environment, storing water, carbon and nutrients, growing food, breaking down contaminants and hosting species. The data-driven Right Tree, Right Place (RTRP) programme project reinforced that owners of the land need to see the social, environmental and financial benefits of afforestation and how it might impact local communities. It provided context on regional afforestation options in Hawke's Bay. The project showed us a detailed technical and spatial analysis of what tree species might be planted where, wood processing opportunities, an assessment of ecosystem services, farmer perspectives on afforestation and farm case studies.

We will use the insights gained from the RTRP project to partner with landowners to optimise the mix between permanent forest and tree crops and pastoral farming, to knit together a more diverse patchwork of land use with greater resilience and ecological integrity and function.

The regional council recognises the sediment and water quality challenges associated with plantation forestry as well, and that binary choices between landscape-scale pastoral farming and plantation forestry are an impediment to optimised land use. Most of all, the project reinforced for us the importance of partnership with our farming community.

While there may be broad themes applicable across farms with similar characteristics and soil types, each farm is unique. Each farmer has their own vision and aspirations for their land.

The RTRP programme needs to be co-designed with farmers as early as possible. The most likely area for a co-design trial for large-scale implementation would be in the Wairoa area. Catchment management advisors will be key to that, as they hold the relationships with farmers and local knowledge.

Our strategic goal is that all highly erodible land in the region is under tree cover by 2050, through acceleration of riparian planting and fencing in priority catchments and financial incentivisation of the treatment of erosion-prone land.

We are exploring funding mechanisms and landowner engagement programmes to bring the environmental and economic issues, and subsequent options, to landowners. In partnership with our community, we can ensure the right tree is placed in the right place for the right purpose. In doing so we can dramatically improve water quality and biodiversity, farm system resilience and diversification of income, and make a tangible difference to climate change adaptation and mitigation. Eighty-two years on from that storm in Northern Hawke's Bay the imperative to act is greater than ever before.

James Palmer

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Member of Forestry Ministerial Advisory Group