Putting purpose first – 10 functional forest types for New Zealand

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Figure 1: Productive plantation

Abstract

New Zealand needs to look after its existing forests and develop new ones if we are to respond to the multiple challenges of climate change, biodiversity and environmental degradation, and the need to shift to a zero or low carbon economy. This paper introduces a new framework of functional forests to enable us to have wider discussions on the purpose of our forests and how they may be developed over time. The framework is based on a continuum of level of human disturbance or naturalness, underpinned by an ecosystem services framework. The intent is to broaden debate past the dichotomies of 'exotic plantations versus natural conservation forests' and 'native versus exotic species'. The functional forests will have species and management regimes tailored to sites and landowner preferences, putting function or purpose first.

Introduction

Key challenges currently confronting New Zealand are climate change, water quality, economic growth, and individual, whānau and community wellbeing. Trees and forests are all closely tied to these challenges and are themselves affected by climate change – increased temperatures and atmospheric carbon dioxide (CO_2) levels, increasing storm impacts, droughts, pests and diseases.

There has been much recent discussion in the media about trees and forests, and much of this has focused on carbon and climate goals and the effect of large-scale plantings on communities. Some has focused on the value of indigenous species versus pines (exotics). A third thread has focused on the adverse environmental impacts of clear-fell harvesting of pines. Generally, the focus is on the negative. However, there are many positives and the role of trees and forests in confronting our key challenges needs careful thought and changes in perception.

With the undoubted role of trees and forests in helping New Zealand meet its climate obligations and other challenges, there has not been a better time to look at how forests fit within this country's future landscapes or to have discussions on what we would like New Zealand to look like in the future and where trees fit. We are going to need more trees and forests.

The simple and widely-held dichotomous view of this country's forest as productive exotic plantations and natural forests is an issue (Figure 1). New Zealand is unique in its split between privately-owned exotic plantations for timber and fibre production and natural forests managed in the public estate for conservation values. There was an excellent reason for this – taking the harvest pressure off our rapidly shrinking natural forest resource with consequent loss of our unique biodiversity. New Zealand has always had a bio-based economy and we depend on forestry, agriculture and horticultural products for international exports, and our conservation estate to support a very significant international tourism industry. Our society depends on them. However, we need to move past this dichotomy and open up a wider discussion that considers the function of our trees and forests more widely. Production and conservation are too simplistic.

Current land use

An analysis of the most recent landcover database (LCDB5) launched in January 2020 (Manaaki Whenua Landcare Research, 2020) shows us the current land use mix. For the purposes of this paper, we focused on the forests and agricultural lands (exotic and indigenous forests, high and low-producing grasslands and shrub and scrub landcover). We also explored the distribution of exotic forests by land use capability (LUC) (Manaaki Whenua Landcare Research, 2020) and Erosion Susceptibility Classification (MPI, 2016), these being two commonly discussed areas of interest. Analysis was done using ArcGIS Pro (ESRI, 2021).

Forests make up 31% of New Zealand's land area, low and high-producing grasslands 38%, and scrub and shrub 10% (Table 1). Focusing on exotic forests we find 80% are in LUC 6 to 8, with most of the remainder in classes 3 to 5 (Table 2). With respect to erosion susceptibility class, 24% are in the high to very high class with the remainder low to moderate (Table 3).

Table 1: Indigenous, exotic forest, high and low-producing grassland, and scrub and shrub area in NZ from LCDB5 analysis

Land use	Area (ha)	% of NZ land area
Indigenous forest	6,307,010	23%
Exotic forest	2,037,710	8%
High-producing grassland	8,639,543	32%
Low-producing grassland	1,721,966	6%
Indigenous scrub/shrub	2,407,537	9%
Exotic scrub/shrub	239,817	1%

Table 2: Area and percent of exotic forest by LUC class (noting that class 8 is considered unsuitable for productive use)

LUC	Area (ha)	Percent
1	1,661	0.1%
2	13,711	0.7%
3	94,132	4.6%
4	295,985	14.6%
5	14,304	0.7%
6	972,069	47.8%
7	607,032	29.9%
8	34,079	1.7%

Table 3: Area and percent of exotic forest by ESC class

ESC	Area	Percent
Low	783,564	39%
Moderate	768,195	38%
High	345,188	17%
Very high	136,332	7%

Developing a framework for defining functional forests

The LCDB shows us location, area and land use type, but not function. We are becoming more interested in why the forests are where they are and what their function is, and also what forests we might establish in the future and for what purpose. The two functions of timber and fibre production and conservation dominate today, but there are other functions we can consider. Carbon forests for climate mitigation is probably the third most recognised function, but there are more. Identifying these functions and considering them in terms of opportunities is a first step to moving beyond the timber versus conservation paradigm.

Ecosystem services framework

Forests are a highly multifunctional land use, providing many products, goods and services. These ecosystem services can be categorised into supporting, provisioning, regulating, and social and cultural, as shown in Figure 2. These services all contribute to overall human wellbeing in a variety of ways, and also have very significant environmental benefits.

These ecosystem services are provided to varying degrees by all our forests and include timber, fibre, energy, chemicals, food, medicines/rongoa, carbon storage, erosion control, water flow regulation, clean water, recreation, human health and wellbeing, spiritual and cultural values, biodiversity conservation, climate regulation and aesthetics. All forests provide a mix of services and in New Zealand we have worked on biodiversity, carbon, erosion control, nutrient regulation, recreation and timber (Yao et al., 2021).

Using the framework will allow us to design and manage forests for specific purposes or functions. Obviously, we have been most successful at designing and managing planted forests for timber production, as evidenced by the more than $6 billion export industry, but much less focus has been put on designing forests for other purposes or functions. This is a big opportunity for New Zealand.

Definition of functional forests

Using the ecosystem services framework in the context of our national environment we have developed a suite of 10 functional forest types that are relevant/most important for the New Zealand context.

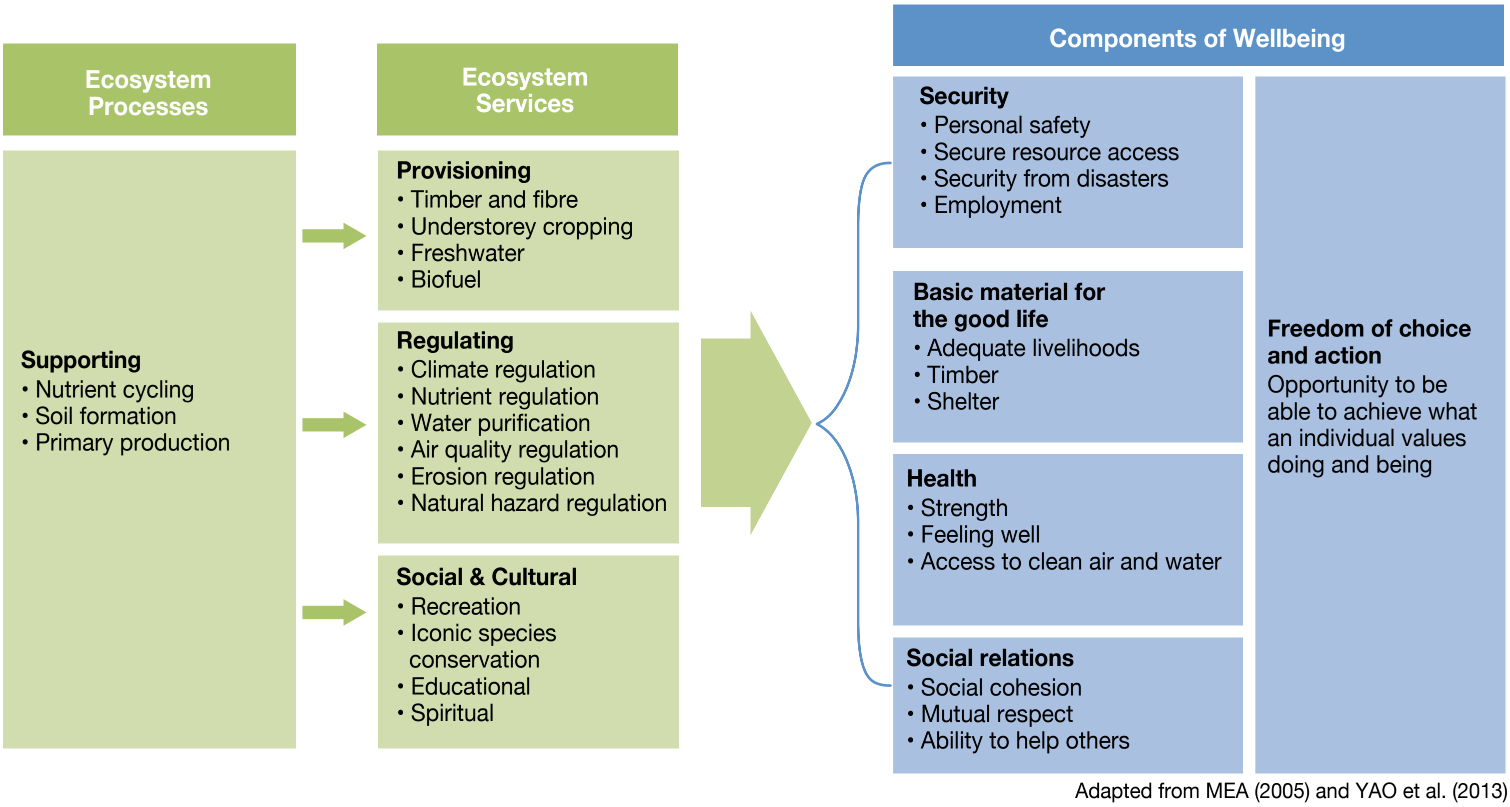

Figure 2: Forest Ecosystem Services Framework (from Yao et al., 2013)

These are:

- Biodiversity conservation and restoration forests
- Timber and fibre forests
- Energy and bio-based chemical forests
- Water regulation forests
- Nutrient control or regulation forests
- Erosion control forests
- Food and nutraceutical forests
- Health and wellbeing forests
- Climate regulation forests – urban forests
- Climate mitigation forests – carbon forests.

Some of these functions are well known and well established (e.g. timber and fibre, carbon forests, erosion control), others much less so (e.g. health and wellbeing, climate regulation).

All forests, whether indigenous or exotic, natural or planted, can provide these functions and these functions may be provided singly or in combination in a forest. Each functional type will require a different management approach. Species selection, silvicultural regimes and siting will all have to be considered and developed to best fit the function. Species selection is important for function. A paper by Smaill et al. (2014) evaluated a range of species for functional traits, such as rooting density for erosion control and carbon sequestration rates. This demonstrated that different species were best suited to different functions. Complexity will increase if the forest is being designed for multiple functions. Significant new work will be required to develop regimes for the range of functions identified.

To further broaden the discussion of forests in New Zealand we have adapted the United Nations Food and Agriculture Organisation (UN FAO) forestry classification (Figure 3). The framework is internationally applied and is a foundation for the five-yearly Global Forest Resources Assessment (UN FAO, 2020).

The classification is organised on a continuum of the level of human intervention, or degree of naturalness, and has seven categories from primary forests where there are no signs of human activity, through to trees outside forests where the trees occur in agricultural or urban landscapes and the level of human intervention is at its highest. Each category has a description.

Primary forests are those that are untouched by human hand and would include those forests, for example, in South Westland with no harvesting history (Figure 4). However, the indirect human hand of anthropogenic climate change will be affecting them, as will the impact of introduced pests, such as possums. Most of our natural forests would fit solidly into the **modified natural forest** category due to their history of timber extraction. In the public conservation estate, this timber extraction ceased finally in the early 1990s and the forests are re-growing. Small areas of privately-owned natural forest are still being harvested under sustainable management plans where only a small proportion (10%) of the annual growth can be harvested.

Semi-natural forests are those where natural regeneration of species originally occurring in the forest is assisted by human interventions (such as weed control) or pest management (such as control of grazing animals). This is a rare type of forest currently in New

Zealand, although there is interest. Even more unusual and rare here are semi-natural forests where there is active planting of seedlings to either improve growth or change forest quality.

The **planted forest** type most common in New Zealand is plantations. These plantations are generally managed for economic returns from timber and fibre and tend to be exotic species, although interest in indigenous species is increasing. The dominant New Zealand type is therefore **productive plantations**. However, forests have been planted in the past for their protective function. In the early days of the NZ Forest Service, **protection plantation forests** were a prominent category with several forests established, usually for erosion control (Figure 5). An example of this is Mangātu Forest in the Te Tairāwhiti|Gisborne District. Other examples of these can be found on erosion-susceptible slopes in both the North and South Islands. However, with the sale of the state's plantations in the late 1980s, the dominant function has shifted to productive as new owners require an economic return from the trees they purchased.

The seventh category is **trees outside forests** – these are plantings that do not meet the international definition of a forest (>1 ha in area, able to achieve a height greater than 5 m, and with a tree canopy occupying more than 30% of the planted area). These plantings tend to be trees planted as an integral part of agricultural systems – so-called agroforestry systems. The most commonly recognised example of these in New Zealand would be spaced poplar plantings for control of soil erosion on steep agricultural lands. Windbreaks and shelterbelts also fall into this category, as do trees along the banks of waterways and water bodies, and trees in urban settings.

We mapped forests to the FAO categories using LCDB5 and other data sources (GFRA data, Te Uru Rākau, Poplar and Willow Trust) (Table 4). We used GFRA 2020 data for primary forest area and subtracted this from total indigenous forest area in LCDB5 to split indigenous forests into primary and modified natural forests. We could not find a source of data for semi-natural forests, although there is likely to be some activity in this category in the privately-owned indigenous forests.

We estimated protection plantation area from a combination of Erosion Control Forestry Programme, Afforestation Grant Scheme and One Billion Trees programme data, plus the deciduous hardwoods category in LCDB5, noting that there is no single data source for the area of poplars and willows planted for protection. This protection-production is an underestimate as it does not include the area planted under the Sustainable Land Use Initiative (SLUI). We approximated the trees outside forests area by calculating the area of exotic forests in LCDB5 of less than 1 ha, giving a small area of 13,864 ha, not including urban trees. We modified the FAO definition to trees and stands of less than 1 ha to align with the New Zealand Emissions Trading Scheme (NZ ETS) area definitions.

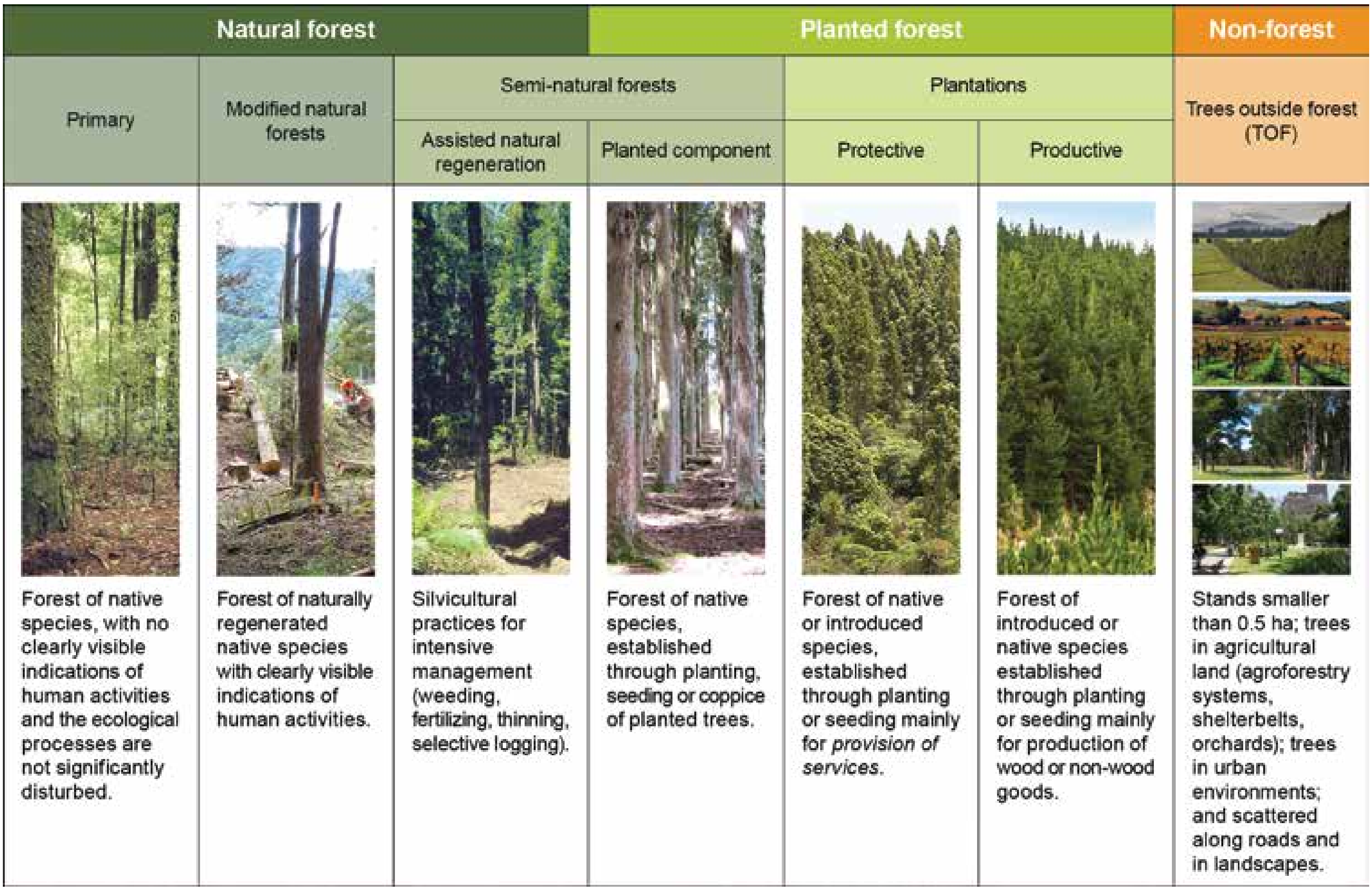

Figure 3: UN FAO forest types

Table 4: Areas of forest under each UN FAO forest category

UN FAO Forest Category	Area (ha)
Primary	1,971,000
Modified natural forest	4,389,910
Semi-natural forest (assisted regeneration)	No data
Semi-natural forest (planted)	No data
Protection plantation	161,699
Production plantation	2,023,955
Trees outside forests	13,864

In summary, as expected the two dominant categories in New Zealand currently are a combination of **primary and modified natural forests** (mainly in the Department of Conservation estate) and **productive plantations** (the commercial exotic forestry sector).

Future functional forests

We mapped the 10 functional forest types to the most relevant FAO and ecosystem services classes (Table 5). This shows biodiversity and health and wellbeing functions linking to natural and semi-natural forests and trees outside forests (Figure 6). New protection plantations will provide forest with regulating functions – water, nutrients, erosion and carbon. New and existing production plantations provide provisioning services – timber and fibre, energy and chemicals, and food and nutraceuticals. Urban trees fit within the trees outside forests and provide climate regulation functions.

If we consider New Zealand in the context of these types of forests and their function, we can gain a broader perspective of how things could look in the future and a more nuanced partitioning of the landscape into different types of forest.

To respond to the challenges outlined earlier, forests will have to play a greater role in New Zealand's future. We need to restore our environment, future-proof our landscapes against climate change, conserve and restore our biodiversity, and move to a low/zero-carbon economy. We will have to create new forests, and also enhance the functions of existing forests.

Enhancing the function of existing forests

With our indigenous forests, it may be possible to enhance the rate of carbon sequestration in some areas and thus mitigate some of New Zealand's greenhouse gas (GHG) emissions. As part of a study for Beef + Lamb New Zealand, Norton and Pannell (2018) identified 2.8 million ha of indigenous vegetation on private lands, with 1.4 million ha (or 13% of the area of sheep and beef farms) being native forest. They suggested that with active management these forests could provide a range of functions, such as enhanced biodiversity and potentially increased rates of carbon sequestration. The recently completed Tōtara Industry Pilot Project (TIP, 2020) undertaken in Northland showed that there is a significant resource of naturally regenerated tōtara, which (if managed well and harvested) could provide up to 3,000 m^3/year of high-value native timber (Scion, 2020a). Harvesting this volume would potentially allow us to reduce imports of other high-value timbers and to expand our semi-natural forests.

On public lands, pest control within indigenous forests also has the potential to enhance biodiversity and possibly carbon stocks. However, a study by Carswell et al. (2012) concluded that such benefits may only occur over a very long period. This work was expanded by Dymond et al. (2013) to identify areas to prioritise for indigenous forest restoration. The work to quantify the added benefits continues with recent work on carbon stocks and biodiversity conservation in indigenous vegetation on agricultural lands (Case & Ryan, 2020; Pannell et al.; 2021, Norton et al., 2020) and ongoing work through the Ministry for the Environment to better understand carbon stocks and fluxes (MfE, 2020).

The potential for enhanced functions within our exotic plantations may be greater than in the indigenous forests. Recent work by the Ministry of Business, Innovation and Employment (MBIE) and the Forest Growers Levy Trust Programme 'Growing Confidence in Forestry's Future' (Scion, 2013) has shown that the forests are not growing to their full potential, and there is an opportunity to enhance both timber and fibre production and carbon stocks through more intensive management. Several forestry

Table 5: 10 functional forest types and their primary ecosystem services

Forest function	Most relevant FAO forest types	Primary ecosystem service	Future
Biodiversity conservation and restoration	Natural, semi-natural	Social and cultural	Enhance
Timber and fibre production	Production plantation	Provisioning	Enhance
Energy and bio-based chemical production	Production plantation	Provisioning	New forests
Water regulation	Protection plantation	Regulating	New forests
Nutrient control or regulation	Protection plantation	Regulating	New forests
Erosion control	Protection plantation, trees outside forests	Regulating	New forests
Food and pharmaceutical production	Production plantation	Provisioning	New forests
Health and wellbeing	Natural, trees outside forests	Social and cultural	Enhance
Climate regulation – urban	Trees outside forests	Social and cultural	Enhance
Climate mitigation – carbon	Protection plantation, semi-natural	Regulating	New forests

companies are now applying recent research results to achieve such benefits, for instance, Timberlands Ltd has a strategic goal to double their average growth rate by 2050 (Forest Growers Levy Trust, 2020). This would also increase their standing carbon stocks significantly.

Such enhancements might, however, adversely affect other functions (such as biodiversity or catchment water yield). There is also the opportunity to enhance the environmental protection of forests planted on highly erodible slopes by either not harvesting and retiring the land, modifying the harvesting regimes, or redesigning the forests to establish new permanent riparian buffers of native vegetation to protect land downstream of the forests from debris flows as recently announced by Aratu Forests (Scoop, 2021).

Establishing new forests

Numerous studies have identified the potential area available for the establishment of new forests in New Zealand. These estimates have ranged up to 2.9 million ha (e.g. Watt et al., 2011) and are mainly located on pastoral agricultural land. It is likely new forests will mostly be established for climate mitigation (carbon), erosion control, nutrient and water regulation and possibly energy and chemicals. Other new forests may also be established for biodiversity values, food and nutraceuticals, health and wellbeing and climate regulation.

Erosion control: Climate impacts are increasing, and we are expecting more extreme and more frequent storm events. New Zealand has some of the highest soil erosion rates in the world. Once lost, topsoil can take centuries to rebuild. We therefore must plan for new forests for erosion control. We will need to protect our most erosion-susceptible sites and also consider other sites. The national ESC indicates there are 164,872 ha of grassland in the very high ESC class and 599,0874 in the high class. This totals 763,946 ha, or 7% of the grassland area. To be most effective in erosion control we need to consider the type of forest that would best suit. Permanent forest cover might be best, or a regime with very low impact harvesting.

The Climate Change Commission suggests native species, but these come with significant establishment challenges on very erodible sites. In addition to the severely erodible sites, consideration must be given to less erodible sites and the potential expansion of the spaced planting programmes on pastures using poplars and willows. These spaced plantings on pastures also have the added benefit of providing shade for animal welfare and fodder under drought conditions.

Nutrient control or regulation: Most of New Zealand's rivers are polluted, with nitrogen and phosphorus the main culprits. Trees have two roles to play in mitigating this – one is through riparian plantings that reduce nutrient movement into waterways, especially phosphorus. We calculated from LCDB5 and NIWA's River Environment Classification (REC) (NIWA, 2021) that there are 156,404 km of waterways within low and high-producing grasslands. If these all had a 10 m

Figure 4: Primary natural forest

buffer of trees planted on each bank this would equate to 312,808 ha of new forest that would also contribute to carbon sequestration and, depending on what species were planted, biodiversity values both on land and within the waterway.

The second role trees can play is phytoremediation, which is stripping nutrients out of the soil using short-rotation cropping with trees. Phytoremediation could be used in a fallowing system for land with a history of high nitrogen and phosphorus inputs. Soil cadmium can also be high from superphosphate application. Multiple cropping of short-rotation poplars and willows is also an option to lower cadmium levels (Robinson et al., 2000).

Water regulation: This is an emerging area, with increasing interest in both regulation of water flows by forests to future-proof against increased storm events, but also to manage overall water yields from forests and availability of water to downstream land users. The smoothing effect of forests on storm rainfall peaks is well known (MfE, 2008), but the perceived benefits may be outweighed by concerns about adverse effects of planted forests on catchment water yields. This concern may lead to increased regulation of where a new forest can be established. This is an area of increasing research focus (Scion, 2020b) as landscape-scale climate adaptation plans become more important.

Energy and biochemicals: Bioenergy feedstocks are normally seen as a by-product of existing timber and fibre forests, with the collection of residues for use in energy plants. However, there are issues with the collection and transport of material from remote sites. Dedicated new bioenergy forests may be a more effective route for the production of feedstocks, potentially with shorter rotations and on higher-quality land than current exotic plantations. Scion's Biofuels roadmap (Scion, 2018) identified that an area of forest the size of Taranaki (~725,000 ha) harvested on a 28-year rotation would provide 30% of New Zealand's current liquid biofuels need. There are a few examples of the nascent biochemical opportunity, with Douglas-fir essential oil extraction from wilding conifers in the South Island (Estate Aromatics, 2018), and high-pressure reactive extrusion technologies that turn wood residues into biochemicals that are being trialled at Scion (2018).

Food and nutraceuticals: These could be new specialist forests or modifications to existing forests to enable understorey cropping of, for example, ginseng. Food forests are currently mainly an urban concept with some interest in nut crops, for instance, new Chilean hazelnut plantings in the Bay of Plenty (Holt et al., 2019). Areas established are likely to be small, but the crops could be of high value. Multi-tiered silvopastoral/agroforestry systems and associated value chains are common internationally and are worth exploring further in New Zealand.

Climate mitigation – carbon: New Zealand has committed under the Paris Agreement to decrease its GHG emissions by 30% below 2005 levels by 2030 (MfE, 2018). In 2018, the Government launched the One Billion Trees programme aimed at offsetting emissions through carbon sequestration in new forests. Additionally, the ETS encourages tree planting for carbon sequestration. Most recently, the Climate Change Commission (2020) released draft advice on emissions reductions. In that advice, they recommended up to 780,000 ha of new carbon forests. These initiatives will contribute strongly to developing a low carbon economy. The question is what type of forest – fast-growing exotic plantations will store carbon more rapidly and in a shorter period than indigenous species. So, we would need a larger area of new forest using indigenous species to store the same amount of carbon as with faster growth exotics. From a pure carbon perspective, fast-growing plantations seem the best and most effective approach. Also, consideration of where these forests might be located is very important.

Climate regulation – urban environments: By area, urban trees are tiny compared with other functional forest types in New Zealand, but they have a very significant potential climate regulation function. Shade provides temperature regulation within the urban environment and soft surfaces help lessen water run-off peaks. New urban design is including more and more trees for their environmental functions. They also have a significant impact on human wellbeing, both physiologically and psychologically (Salmond et al., 2016).

The future

If New Zealand is to achieve its climate goals, improve its environmental quality, protect and enhance its biodiversity, and grow its economy, we will need more trees and forests. We can have these, as well as other land uses, woven into the landscape. However, the scale of expansion will need to be large and there are potential barriers to achieving such expansion.

In an environment of rapid change, people can worry about proposed changes and often prefer stability and the status quo. The unknown or different can be scary. We have seen these concerns raised in rural communities when increased tree planting and forest establishment is proposed. One example of this is worry about blanket planting of pine trees, and potential adverse economic and community impacts. This has led to campaigns, such as 50 Shades of Green (2020), and their calls for limits to tree planting on higher agricultural productivity lands. Their campaign is not against trees per se, but one type of forestry.

This is interesting as there did not seem to be the same concern in the mid-1990s when there was a planting boom with new investments in forests, mainly through retirement funds. In the 1990s, the annual area planted peaked at around 90,000 ha. It is possible that social media use has increased the profile and awareness of these concerns.

A further concern is on community impacts – effects on school rolls, local employment, declining rural populations, plus issues such as traffic nuisance. Again, I do not remember this coming up in the 1990s. Recent studies should have allayed some of the concerns though they still rumble on. An economic analysis of forestry and sheep and beef land use for Te Uru Rākau by PWC (2020) showed that the economic and employment intensity of forestry was higher on a per hectare basis and that the areas of both land uses were

Figure 5: Protection plantation

Figure 6: Assisted natural regeneration forest

significantly different. However, permanent carbon forestry – plant and leave had a much lower employment level than normal rotational radiata regimes. They also demonstrated that integrating plantation forestry into sheep and beef operations gave better value chain impact per 1,000 ha than sheep and beef alone.

These concerns are valid and must be addressed as we consider what New Zealand might look like with more trees and forests. We must consider the purpose of the planting, but also any potential impacts – environmental, social and economic. Generally, tree planting is environmentally beneficial, but economically it will be displacing another land use. The common assumption is agricultural returns on-farm will decrease. However, some recent studies and expert opinion suggest that 5–15% of a farm may be planted into trees without a significant impact on agricultural returns, and often with a long-term additional economic benefit. This equates to between 517,881 ha and 1,553,644 ha in total. The percentage possible will depend on a specific farm.

If the opportunities for new forests are generally on agricultural land, then the trees will mostly be established by individual landowners based on their values and preferences. There is a need for commonly understood and used facts to underpin decisions, for example, how much carbon is in a native forest as opposed to a planted forest, the effect that planting of trees will have on local employment, or the possible forest options that are available on a given type of land. This information is often unavailable, hard to find, or can be of dubious provenance. Discussion and communication around perceptions, understanding and purpose and value of new forests will be critical, supported by a sound and commonly-used evidence base. Using a broader framework of functional forests should help this dialogue, considering the purpose of forests, and their wide range of potential benefits to landowners and the wider community.

Conclusion

To sum up, developing a new forest or enhancing an existing forest requires a clear definition of purpose followed by the development of the appropriate forest type and management regime to suit that purpose. It also needs an in-depth analysis of potential unintended consequences at the local regional and national scale to avoid future issues, such as environmental damage or community impacts. Trees and forests have a very significant amount to offer New Zealand. There are many areas where more trees would be beneficial for many reasons and many ways we can expand our thinking beyond the 'commercial plantations, locked-up conservation forests' dichotomy. We should explore a range of future scenarios for our forests using the 10 functional forest types as the framework. These scenarios will then give us a great foundation for discussion and ultimately the design of future landscapes.

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