Review of literature on the development of climatic and socio-economic scenarios for New Zealand forestry

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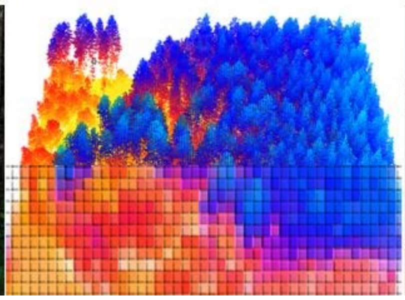


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EXECUTIVE SUMMARY

This report introduces and summarises the main factors influencing New Zealand's forestry through the course of this century. We focus first on the projected impacts of climate change on forestry before outlining the major socio-economic drivers and their current characterisation into shared socio-economic pathways. We also identify some of the major domestic influences on forestry in New Zealand.

The biophysical analysis indicates that projected productivity increases for radiata pine from changing climatic conditions are slight, without considering CO2 fertilisation. With CO2 fertilisation, productivity gains are projected to increase by 19% by 2040 and 37% by 2090, however other risks may counteract these gains.

Different global socio-economic pathways will present very different futures for New Zealand's forestry. While there is limited scope to influence these pathways directly, domestic policy choices will have important impacts on rates of afforestation and land use choices.

This information will be used in subsequent research to develop scenarios or use in quantitative modelling.

INTRODUCTION

The aim of this programme of work is to develop a ‘predictive pipeline’, incorporating biophysical and socio-economic scenarios of climate change at global, national and regional levels, in order to provide foresight to the forest sector in New Zealand (NZ).

What will the future look like for forestry in NZ, particularly under a changing climate? While it is of course impossible to predict the future, we can identify a range of factors that are likely to influence the sector. In this report, we bring together the main climate-related drivers of change affecting NZ’s forestry sector over the coming decades. We summarise the major sources of information here as a foundation, with the next stages of the research focused on distilling these diverse sources into a set of NZ forestry-specific scenarios.

The Intergovernmental Panel on Climate Change (IPCC)’s framing of risk, (also used by New Zealand’s first national climate change risk assessment) can be a helpful way to approach the drivers and processes leading to climate-related risk in the forestry sector. This is illustrated in Figure *1*, and shows clearly the role of climate related processes resulting in climate hazards, the socio-economic processes that influence exposure and vulnerability, as well as the emissions that drive the climate, all together culminating in the risk.

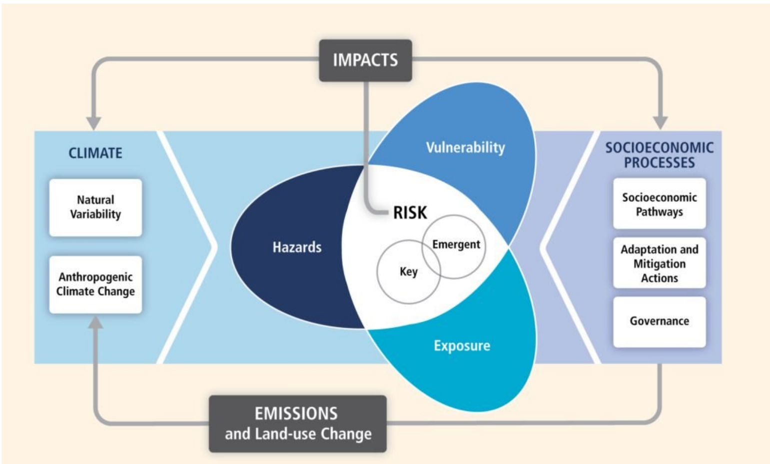

Figure 1: IPCC Framing of Climate change risk. Climate change produces hazards, whereas socio-economic processes affect exposure and vulnerability. Together they create risk. Source IPCC AR 5 Chapter 19.

Considerable work has already gone into projecting the impacts of climate change on forestry. These are summarised in Section 0. The projections of future climate change are developed under a range of representations of future global greenhouse gas (GHG) emissions, known as Representative Concentration Pathways (RCPs). A range of futures are considered under RCPs as we cannot predict how the world will act in terms of reducing emissions. RCPs are summarised in section 2.

The future of forestry will also be determined by other factors, including social and economic changes as well as domestic and global policies. The international climate community developed a series of possible socio-economic pathways in 2015, known as the Shared Socioeconomic Pathways (SSPs) (O’Neill et al. 2014, 2017). These present alternative development pathways at the global scale, and they are discussed in section 3, in particularly the implications of different global pathways for NZ forestry.

In section 4 we discuss the domestic policy drivers that will influence the future of forestry in NZ, and in section 5 we discuss global changes and disruptions that may also affect forestry. Finally, we discuss the next stages of this research, particularly how these different drivers and pathways can be incorporated into quantitative frameworks to inform future modelling.

Climate projections for New Zealand forestry

The impacts of climate change NZ forestry are summarised in this section, based on existing published research in NZ.

Representative Concentration Pathways and Global Climate Models

Previous assessments of changes to New Zealand forestry in New Zealand where made using the SRES climate scenarios from the IPCC Fourth Assessment report (AR4). Although the Fourth and Fifth Assessment scenarios do not correspond directly to each other, CO_2 concentrations under the Fifth Assessment RCP4.5 and RCP8.5 are very similar to those of the Fourth Assessment SRES B1 and A1FI, respectively, which may allow some results comparison. A mixture of the SRES and RCP projections are used in this report, RCPs are used for the fire section and Figure 3 and SRES elsewhere.

Representative Concentration Pathways (RCPs) were developed for the Intergovernmental Panel on Climate Change (IPCC)'s Fifth Assessment Report (AR5) (van Vuuren et al. 2011). Researchers developed four scenarios of future concentrations of GHGs and climate warming by 2100. The RCPs are designed to be used as inputs into climate models. The RCPs are named according to the radiative forcing target level for 2100, and include a stabilisation scenario (RCP2.6), two medium stabilisation scenarios RCP4.5/RCP6) and a very high baseline emission scenario (RCP8.5) (*ibid*).

Their approximate total radiative forcing at 2100 relative to 1750 identifies these pathways are:

2.6 W m^{-2} for RCP2.6
4.5 W m^{-2} for RCP4.5
6.0 W m^{-2} for RCP6.0
8.5 W m^{-2} for RCP8.5.

Detailed projections on a 5 kilometre-grid covering New Zealand are produced by downscaling output from IPCC Fifth Assessment global climate models (GCMs). Dynamical downscaling is applied to a subset of six GCMs to produce projections for a large number of weather variables. The six GCMs selected have simulations for all four RCPs, and validate well in the New Zealand region in their historical simulations. They are HadGEM2-ES, CESM1-CAM5, NorESM1-M, GFDL-CM3, GISS-E2-R, and BCC-CSM1.1. Data from these GCM projections are bias corrected to minimum and maximum temperature and precipitation, and downscaled using local topography and wind direction.

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Projected climate change impacts on New Zealand's forests

Overall, analysis shows productivity gains for *Pinus radiata* from the direct effects of climate change that ranged from relatively minor to substantial depending on the response to increasing CO_2. Under the assumption of constant CO_2, and averaged across the whole of New Zealand, productivity for *P. radiata* plantation forests was projected to be virtually unchanged for both 2040 and 2090. On the other hand, if one assumes that this species fully responds to increasing CO_2, projections showed productivity increases across almost all plantations, with average increases of 19 and 37% by 2040 and 2090, respectively. Even if the potential CO_2 response is only partly realised, the simulations suggest that the direct effects of climate change are likely to favourably affect forest productivity.

Damage from abiotic factors, and in particular wind, however, is likely to increase in the future. This increase in the risk of wind damage under future climate is greatest in unthinned stands that are grown for maximum biomass production and carbon storage. For this silvicultural regime the mean annual probability of damage by 2090, assuming no further increases in wind speed, was more than triple the value at 1990 for the same stand age. The average season length with 'very high and extreme' fire risk increased on average by 71% by 2040, and 83% by 2090.

Changes in trade and increased global travel are likely to influence the origin of future incursions of invasive pests, with invasions from regions in eastern Asia likely to constitute a growing risk. Future risk from the two most damaging needle cast diseases, within New Zealand were not projected to change much under climate change. Although New Zealand does not currently have any damaging forest insect species, population levels and resulting damage are likely to increase in the future as warmer temperatures accelerate insect development and increase the susceptibility of host plants to attack. Climate change may result in increased competition within plantations from aggressive woody tree species such as *Acacia* and *Eucalyptus spp*., as the climate becomes increasingly similar to the current-day climate of Australia, where these species have originated from. Weed species are likely to become more competitive under climate change as their growth rates are likely to increase at a greater rate than that of plantation species.

These effects are discussed in detail in the subsequent sections.

Productivity effects

Projected productivity increases for radiata pine (*Pinus radiata D. Don*), the main commercial forest species in New Zealand, are slight due to changing climatic conditions. However, including photosynthetic effects from increasing CO_2, productivity gains across New Zealand averaged 19 per cent by 2040 and 37 per cent by 2090. This increased productivity results in marked increases in wind risk due to trees becoming taller and more slender. The average season length with 'very high and extreme' climatic fire risk increases by 71 per cent up to 2040 and by 83 per cent up to 2090. Currently, the most significant biotic disturbances in New Zealand plantations come from two needle cast diseases, for which climate projections show slight increases or decreases depending on the disease and region. Although insect pests currently cause little damage to New Zealand plantations, damage may increase in the future with projected increases in population and host susceptibility. It has not been possible to fully account for the effects of any new introductions of pests and pathogens and evidence from other countries with a significant resource of planted forests suggest this should not be underestimated. Potentially invasive weedy and damaging tree species are likely to expand their range under climate change and compete more strongly with plantations.

New Zealand's mean annual temperature at low elevation sites ranges from 8°C in the south to 16°C in the north, with colder conditions at higher elevations, especially in the South Island (Figure 2a). Variation between summer and winter temperature is generally relatively small, especially in coastal regions. Consequently, there are currently few periods with extremely hot or cold conditions in the low to moderate elevation areas of New Zealand where plantation forests are grown.

Precipitation within most of New Zealand ranges from 500−2,000 mm yr -1. Mountain chains extending the length of New Zealand provide a barrier to the prevailing westerly winds, dividing the country into markedly different climatic regions. The west coast of the South Island is the wettest area of New Zealand, with a number of locations receiving over 5,000 mm yr^{-1} whereas the area to the east of the mountains, just over 100 km away, is the driest, with annual precipitation reaching minima of 500 mm yr^{-1}.

New Zealand's exotic plantation estate is distributed throughout most of the country, with the largest areas in the central North Island. Substantial areas of plantation are also found in the far north and east coast of the North Island, the upper South Island and various locations along the east coast of the South Island, especially in the far south (Figure 2c).

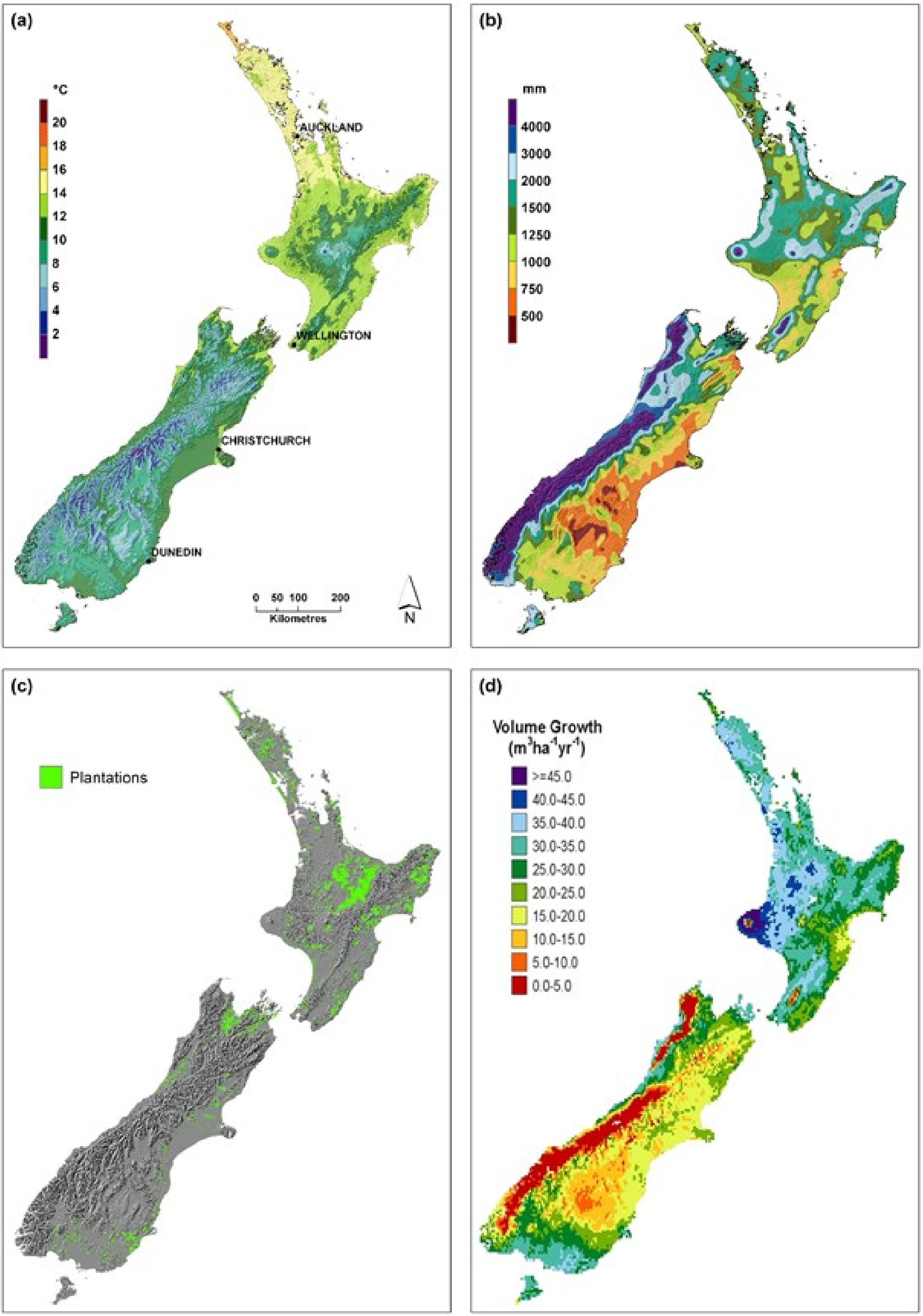


Figure 2 New Zealand maps of current (a) mean annual temperature and (b) mean annual rainfall (after Wratt et al. (2006)), (c) the current location of plantation forests and (d) modelled wood productivity (as volume growth) of P. radiata under current

Modelling forest productivity

The process-based model CenW version 4.0 (Kirschbaum, 1999) was used to project productivity of *P. radiata* across New Zealand under current and future climates (Kirschbaum & Watt, 2011, Kirschbaum et al., 2012). CenW has been developed primarily for climate-change investigations and incorporates the key processes and feedbacks between plants and their environment that can operate on timescales ranging from daily (for water relations) to decadal or longer (for soil organic matter feedbacks and wood growth). Kirschbaum & Watt (2011) demonstrated that CenW can successfully model stand productivity of *P. radiata* under current climatic conditions within New Zealand, providing confidence that the model incorporates the key processes underpinning productivity.

CenW was parameterised for current climatic conditions using growth data from permanent sample plots covering almost the complete environmental range across which *P. radiata* is grown within New Zealand. These data consisted of 101 sites with 1,297 individual observations of height and/or basal area from which diameters and volumes were calculated. Using the parameter values determined by Kirschbaum & Watt (2011), there was excellent correspondence between model predictions and measurements of a range of tree dimensions.
Simulations were run under both current and future climatic conditions using projections from the 12 GCMs and the three emission scenarios described previously. Future climate scenario outputs were used in CenW with both constant and increasing CO_2 to isolate tree responses to changing climatic conditions and elevated CO_2. The results presented hereafter are the averages from the 12 GCMs unless otherwise stated.

Under baseline climatic conditions, there was wide regional variation in predicted stem volume growth (Figure 2d). Values were highest in the warm and moderately wet northern and western areas of the North Island, reaching maximum growth rates of > 40 m3 ha^{-1} yr^{-1} in the fertile Taranaki region. Productivity was considerably lower within the South Island, partly attributable to cooler temperatures that were generally sub-optimal. Reduced productivity was also attributable to excessively high rainfall (> 3000 mm yr-1) on the west of the main axial ranges, and relatively low rainfall (< 750 mm $year^{-1}$) on the eastern side. In contrast, in far southern regions, where there is moderate rainfall (Figure. 2b) and little seasonal water deficit, productivity was predicted to be higher than in regions with greater rainfall extremes, but still considerably lower than in the North Island, owing to the much lower temperatures.

Neglecting future increases in CO_2 isolates the effect of expected climatic changes on future volume productivity. Projections to 2090 showed reduced productivity in northern and low-elevation regions and increased productivity in southern and upland regions (Figure 3), likely due to shifts in temperature towards the optimum range for *P. radiata*, which Kirschbaum & Watt (2011) found to be 12 – 15°C. These changes in climatic conditions resulted in growth gains for about half of all plantations (Kirschbaum et al., 2012), with mean changes in volume productivity within plantation forests averaging +3% by 2090.

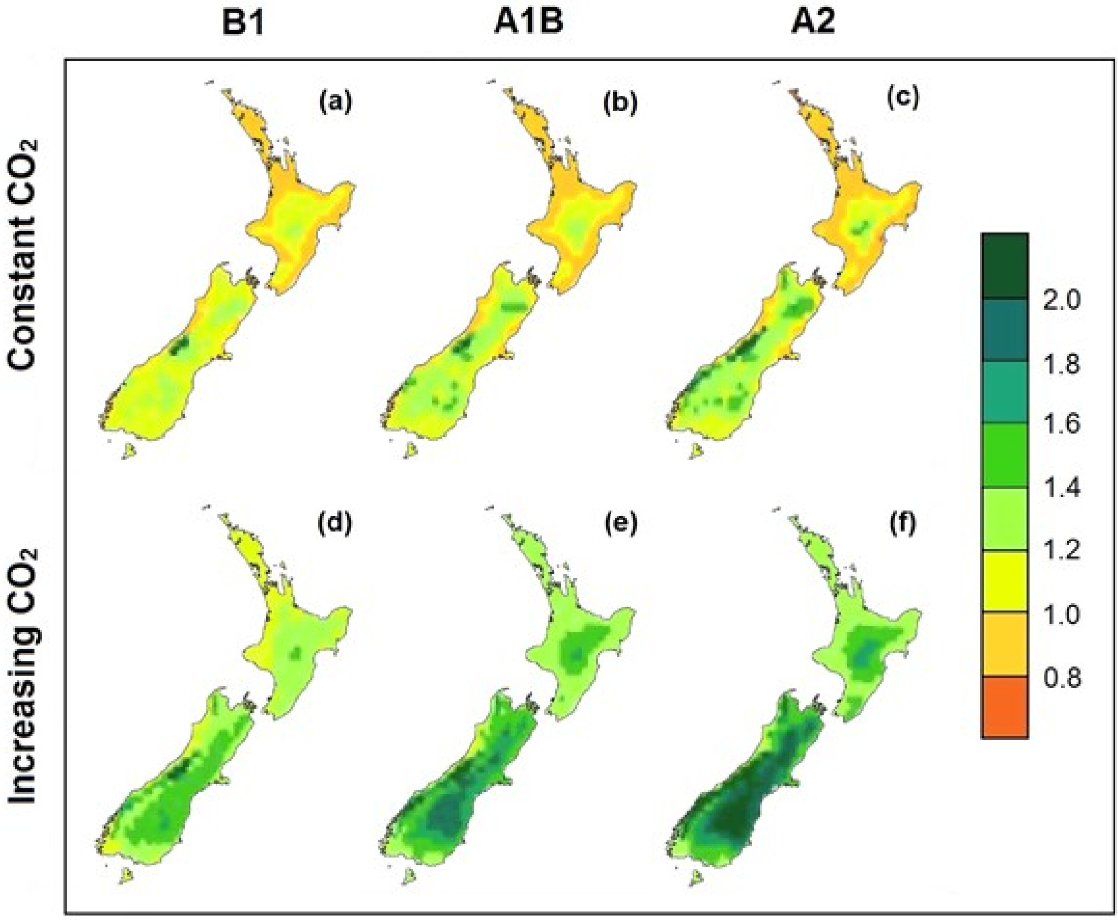


Figure 3 Mean volume productivity ratio in 2090 compared to current productivity with constant (top row) and increasing CO_2 (bottom row) under the B1 (a, d), A1B (b, e), and A2 (c, f) emission scenarios.

Abiotic impacts

Wind damage

The risk of wind damage was quantified using the approach described in Moore & Watt (2015). They investigated both the direct effects of increasing wind speeds and the indirect effects of changes in stand structure, which affects the underlying susceptibility to wind damage. These impacts were investigated using representative growth rates and climatic conditions for seven bio-geo-climatic zones for *P. radiata* in New Zealand (Goulding, 1994). Site productivity metrics for these zones were used to predict the stand structure (diameter, height, volume and spacing), for three contrasting silvicultural regimes (pruned, un-pruned and carbon) under current and future climatic conditions. This information was then input into a mechanistic wind damage model, ForestGALES (Gardiner et al., 2000), in order to predict the critical wind speed required to damage the mean tree within a stand. The average annual probability that these critical wind speeds were exceeded was estimated from frequency distributions of extreme wind speeds calculated from time series of observations from long-term meteorological stations in each zone. Although there is still considerable uncertainty around New Zealand's future extreme wind climate, analysis carried out by Mullan et al. (2011) has indicated that extreme wind speeds are only likely to increase by between 1 and 5% under the A1B scenario (predicted increases under other future scenarios were not available). We accounted for these potential increases through increasing the mode of the extreme wind speed distribution by 5% for all simulated time periods (Quine & Gardiner (2002)).

For a 30-year-old stand, i.e. at typical harvest age, the risk of wind damage was relatively low under the baseline climate. Under this baseline, AEP ranged from 0.094 for the unpruned regime to 0.166 for the carbon regime. Projections to 2040 for the pruned regime show that AEP was less than 0.2 for all scenarios apart from the A2 emission scenario with the CO_2 held constant at 1990 levels where the AEP was 0.286. Projections to 2090 showed that the AEP increased on average by 0.066, and for four of the six scenarios, the AEP was greater than 0.2). The risk of wind damage for the unpruned regime was very similar to the risk for pruned stands in both 1990 and 2040. However, for projections to 2090, the risk of wind damage for the unpruned regime was substantially higher than for the pruned regime due to the higher ratio of height to diameter for this regime. These increases were particularly marked for emission scenarios that assumed a full response to increasing CO_2. The risk of wind damage was markedly higher for the carbon regime than for the other two regimes due to the higher height to diameter ratio of trees. The carbon regime had very high sensitivity to increasing CO_2. For projections made to 2090, scenarios that assumed a full response to increasing CO_2 had an AEP that was on average 0.33 higher than those that assumed no response and the AEP of these three scenarios ranged from 0.639 for the B1 to 0.922 for the A2 emission scenario.

Table 1. Annual exceedance probability (AEP) of wind damage in 30-year old stands as a function of simulation year, emission scenario, and CO_2 concentration for three silvicultural regimes. Values shown represent the means across seven bio-geo-climatic

Year	Emission scenario	Inc. CO_2	Silvicultural regime: Pruned	Unpruned	Carbon
1990			0.110	0.094	0.166
2040	B1	N	0.152	0.141	0.262
2040	A1B	N	0.164	0.155	0.291
2040	A2	N	0.286	0.154	0.286
2040	B1	Y	0.150	0.172	0.419
2040	A1B	Y	0.164	0.201	0.507
2040	A2	Y	0.164	0.197	0.495
2090	B1	N	0.186	0.182	0.344
2090	A1B	N	0.238	0.242	0.443
2090	A2	N	0.272	0.278	0.483
2090	B1	Y	0.191	0.256	0.639
2090	A1B	Y	0.267	0.423	0.850
2090	A2	Y	0.321	0.522	0.922

The relative contributions of different factors on AEP at 2040 and 2090 were determined using the methods described in Melia et al. (2015) and Hawkins & Sutton (2009), (2011)). Figure 4 shows that currently, most of the variation in AEP is attributable to location, with stand age and silvicultural regime also being important. Under future climates, mean values of AEP for a 30-year-old stand ranged from 0.18 to 0.79 across locations (data not shown). Stand age accounted for 27% of the variance in AEP under future climates. The change in mean AEP as stand age increased from 20 to 30 years ranged from 0.09 to 0.33 in 2040 and from 0.12 to 0.49 in 2090.

The impacts of silvicultural regime were relatively important accounting for 19% of the variance in AEP under future climates. Mean AEP ranged from 0.21 under the pruned regime to 0.24 under the unpruned regime and 0.50 under the carbon regime (Table 1). The growth response to increasing CO_2 had relatively little impact on AEP in 2040 but did have a greater impact in 2090 at which time it was equal in importance to silvicultural regime. Both emissions uncertainty and increasing wind speed had very little effect on AEP, relative to other factors, and together constituted less than 4% of the total variance during both 2040 and 2090 (Figure 4).

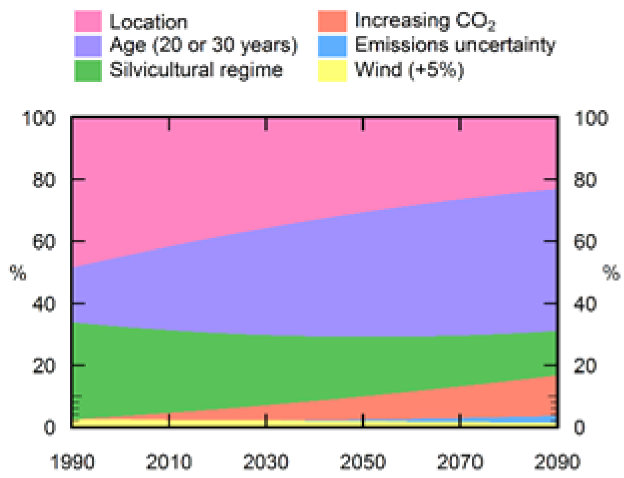


Figure 4 Relative contribution of location, stand age, silvicultural regime, increasing CO_2, emissions scenario and windspeed to annual exceedance probability (AEP). Values of relative importance used in the figure were extracted from Table 2 and relative importance was interpolated between years using second-degree polynomials.

Wildfire Risk

Wildfire is a climate hazard. Wildfire risk is measured by the fire weather index (FWI) / daily severity rating (DSR) on daily time scales, and seasonally as the seasonal severity rating (SSR). Projecting wildfire risk is a function of temperature, precipitation, relative humidity and wind speed – these are used to calculate the dryness and availability of the land surface fire fuel and the spread and ferocity a fire would burn at given these weather conditions. Higher FWI / DSR values indicate a more intense fire development and higher SSR numbers indicate a greater risk. It is important to note that wildfire is an extreme event in a climatological sense and can be ignited by non-climate drivers, these metrics also do not take into account the specific land surface types and their flammability.

On average all climatological measures of wildfire risk will increase for all of New Zealand during the remainder of the 21st century. On average the four main drivers of wildfire are all expected to change to promote an increase in wildfire risk: increased temperature, decreased relative humidity, increased wind speed, and decreased rainfall. Relative humidity and temperature are the best indicators of climatological wildfire risk, while wind speed and precipitation stoke or quench the risk on the daily time scale.

The SSR is highest in the east coast of the north island (Gisborne, Hawke's Bay, and Wellington), inland areas of Otago and south Canterbury (Central Otago, Queenstown-Lakes and Mackenzie), and northern parts of Marlborough. The SSR is lowest in locations of elevation greater than about 800m, the entire of the West Coast region, as well as Southland and coastal Otago.

The fire season length can be defined as the number of day exceeding a particular DSR. Regionally the fire risk is projected to increase by about 10% per decade for all measures including season length. The cities and towns with the highest risk include Lower Hutt, Blenheim, Wellington, and Hastings. For example these locations have a 'moderately vigorous surface fire' season length currently of 14-20 days which will increase by 10-15% by mid-century.

If global average mean temperatures are mitigated in line with the Paris agreement (as modelled by RCP2.6), then wildfire danger will peak and stabilise mid-century. The statistically extreme and sporadic nature of wildfires far outweighs the climate change signal at the local scale; for example, the Port Hills in Christchurch is far more likely to see temperature records broken years than it is to experience a wildfire worse than the 2017 wildfire in the next 30 years?.

Biotic impacts

Distribution of pests

One of the most important changes likely to result from climate change is a shift in suitable habitats for certain pests, which is mainly caused by changing temperatures. Temperature influences thresholds for pest growth and survival through events such as frost frequency and the requirement for reproduction as determined through accumulation of thermal units. A benchmark for the effects of temperature on changes in distribution is provided by the relationship of temperature with elevation and latitude (Linacre, 1992). Each 1 ºC increase in global temperature corresponds to a potential increase of ca.170 m in a species' elevational distribution and a latitudinal shift of ca. 160 km. Average warming over the past century has been about 0.85ºC (IPCC, 2013), with 2015 having been the first year with temperatures more than 1ºC above pre-industrial temperatures (Hawkins et al., 2017). Global meta-analyses have documented significant range-boundary changes for 279 species, which on average have shifted poleward by 40 km over an average timespan of 66 years (Parmesan & Yohe, 2003). This shift is considerably less than the expected shift in climatic zones described above over this time period which most likely reflects the delayed response of species distributions to climatic changes.

Geographic source of future pests

The main pathways for the arrival of pests and pathogens are associated with international trade. This section reviews recent changes in trade patterns and considers future trends based on trade agreements and expert opinion. New Zealand-specific import data were obtained from Statistics New Zealand (2017) and for data going back to 1988, from Statistics NZ Infoshare (2017).

Since the 1980s, imports have increased from the established trading countries of Australia, Europe, the USA, and Japan. However, the most significant change has been the dramatic rise of China as the dominant importer to New Zealand (Figure 5). In 1988, only 1% of New Zealand's imports originated in China, but in 2016 these imports represented more than 16%.

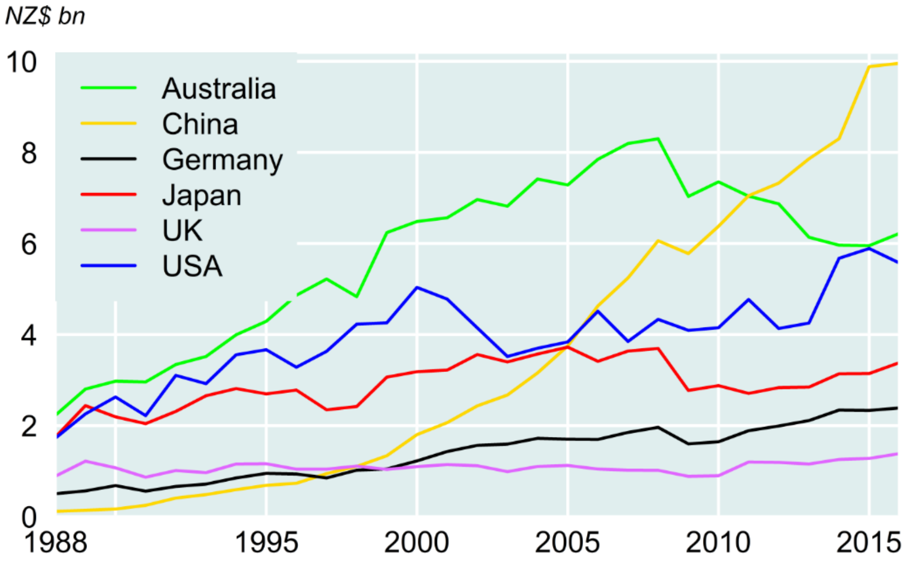


Figure 5 Imports from New Zealand's main trading partners, 1988-2016 (Statistics New Zealand, 2017).

Changes in the origins of imported goods and passengers would be expected to result in changes in the profile of pest threats. In fact, this has already been observed in several regions. For example, in North America and Europe there has been an increase in insect pest and pathogen incursions originating from northeast Asia (Brockerhoff & Liebhold, 2017). Historically, the majority of forest insects invading North America originated from Europe but in the last two decades, northeast Asian species, including some high-impact invaders, such as the Asian Longhorned beetle (detected in 1998) and Emerald Ash Borer (detected in 2002), have become more prominent (Aukema et al., 2010).

Based on import trends and bilateral/multilateral trade agreements, one can assume that New Zealand's imports from east Asia will continue to increase. New Zealand's traditional trading partners in Europe, and North America are likely to remain important sources of imports, even though their relative share may decrease, and Australia is likely to remain a key source of imports owing to its physical proximity. While trade may arguably present the greatest risk of introducing unwanted pests and diseases, the increasing number of international passenger arrivals to New Zealand is likely to present another important pathway for possible pest incursion.

The volume of imports and the number of international visitors may be primary drivers of pest propagule pressure, but several other factors will also affect future biosecurity risks. For example, rapidly growing trade with new trading partners may have a disproportionate effect on biosecurity risks because they may host pests that have not previously had access to New Zealand's borders. Many of the most invasive species from New Zealand's long-standing trading partners will have either already been established in New Zealand or have had effective border protection measures put in place to exclude specific species or to mitigate specific entry pathways. This is not necessarily the case for entry of pests from newer non-traditional trading partners, though many pests may be excluded by generic measures to prevent pest entry. The greatest threat may be from new 'hitchhiker' species that are difficult to manage because they are not necessarily associated with particular pathways in a predictable way (Toy & Newfield, 2010).

Climatic similarities between New Zealand and the potential incursion species' native habitat will also be important for the ability of pests and plant weeds to establish and develop pest potential in New Zealand. In this respect the southeast Asian countries will probably pose smaller risks due to their fundamentally different climatic zones. However, pests from temperate and some subtropical regions are of greater concern. Climate matching of current and future climates suggests that parts of northeast Asia, southern South America, western Europe, and southern Africa, as well as cooler (e.g., montane) regions in subtropical countries may represent sources of species of growing biosecurity concern (Bertheau et al., 2010, Kriticos, 2012, Peacock & Worner, 2006, Ridley et al., 2000). The native floras of southern South America and Australia and adjacent islands share many plant families and genera with New Zealand which means that they are likely to harbour many insects that pose a threat to New Zealand's native trees (including those tree species that are being considered for plantation forestry). For example, Nothofagaceae and Podocarpaceae occur mainly in parts of Australia, New Caledonia, New Guinea, Chile, Argentina, and New Zealand. Increasing imports from these countries, together with a warming climate in New Zealand, would increase the likelihood of arrival and establishment of such pests (Brockerhoff et al., 2010).

Damage from tree pathogens

Damage from foliar pathogens is currently the most costly natural disturbance to New Zealand plantation forests (Watt et al., 2008). *Dothistroma septosporum*, which causes dothistroma needle blight, is currently the most damaging forest pathogen to *P. radiata* plantations. More recently, *Phytophthora pluvialis* (Reeser et al., 2013) which is associated with red needle cast, was detected in 2008 and has the potential to cause significant damage within plantations (Scott & Williams, 2014). *Cyclaneusma minus* which results in cyclaneusma needle cast is also important but of lesser concern. Other pine pathogens currently within New Zealand may cause sporadic or localised damage but their national impact is insignificant (Watt et al., 2008).

The approach used to determine damage from *D. septosporum* and *C. minus* has been described in detail previously (Watt et al., 2011a, Watt et al., 2011b, Watt et al., 2012a, Watt et al., 2012b), and is briefly summarised below. Disease incidence and severity data were collected from plantations throughout New Zealand over a 45-year period for dothistroma needle blight and over a 34-year period for cyclaneusma needle cast. Disease severity, Ssev, was determined at the stand level by multiplying the percentage of trees in the stand affected by mean severity (percentage of needles affected) on affected trees (scale = 0 – 100). Growth reduction generally occurs when disease severity exceeds 20%, and expressed as national averages Ssev values of 2 to 10% (Table 2) may not appear serious. However, stands and individual trees growing in disease prone regions will have values at which significant growth loss occurs. Multiple regression models of Ssev were developed for both diseases from meteorological data, described above, using the methods described fully in Watt et al. (2011b, 2012b).

Within the major plantation areas in the North Island, simulations showed that the severity of dothistroma needle blight and cyclaneusma needle cast are likely to decline throughout the 21st century; however, increases in disease severity were predicted for large areas of the South Island (Table 2). However, with the exception of the west coast of the South Island, the actual predicted severity remains relatively low compared to the damaging levels currently found within the North Island. Although high disease severity is predicted within the west coast of the South Island under both projection periods, it causes little concern in the national context because this area currently constitutes only 1.8% of the total New Zealand plantation area (Watt et al., 2011a, Watt et al., 2012a).

There are also a number of other pathogens that could cause considerable damage to the plantation forests should they establish within New Zealand. Pitch canker is a devastating disease of *Pinus spp*., and *P. radiata* is known to be highly susceptible to the disease (Ganley et al., 2011). Projections using process-based distribution models show that the potential New Zealand distribution for this disease could expand from coastal areas of the North Island under baseline climate to almost all of the North Island and eastern parts of the South Island under future climate by 2080 (Ganley et al., 2011).

Table 2. Variation in mean predicted stand severity, Ssev, of cyclaneusma needle cast and dothistroma needle blight for New Zealand under current climate and the B1, A1B and A2 emission scenarios, projected for 2040 and 2090 within the North (NI) and South (SI) Islands.

Year	Cyclaneusma		Dothistroma	
	NI	SI	NI	SI
Baseline	6.4	2.17	10.9	4.26
2040	6.17	3.79	9.68	5.31
2090	5.63	5.56	7.34	6.95

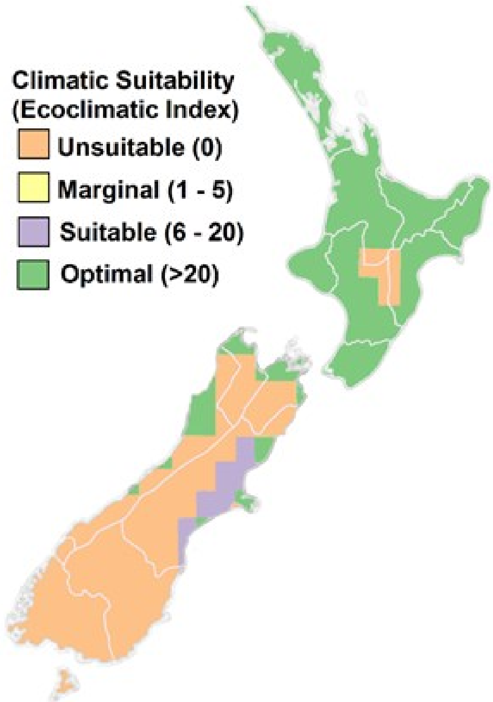


Figure 6 Ptich canker Ecoclimatic Index for 2080 derived from NCAR-CCSM for the A1B emissions scenario. Based on Ganley et al. (2011)

Red needle cast caused by Phytophthora pluvialis causes periodic episodes of defoliation in New Zealand's *P. radiata* plantations, particularly in locations exposed to frequent wet days and fog over the cooler months. *Phytophthora pinifolia* causes similar problems in Chile (Durán et al., 2008) and could be problematic in New Zealand if it were introduced. Perhaps of greater threat are those pathogens that are new to science (e.g. *P. pluvialis* was unknown when the pathogen was first isolated from diseased *P. radiata* foliage in 2008), or those that behave in unexpected ways in a new environment. For instance, *Neonectria fuckeliana* (C. Booth) Castl. & Rossman, in the

Northern Hemisphere was a well-known wound-invading fungus that was found only on spruce and fir and caused little or no damage. When it first established in the Southern Hemisphere on *P. radiata* it caused severe damage to some plantations in the lower half of the South Island (Crane et al., 2009) until a successful control strategy was developed.

Damage from tree-feeding insects

Although climate change effects on tree-feeding insects are relatively well-known in several countries, and have been the subject of a considerable research effort, little research on this topic has been carried out in New Zealand. However, several general reviews specific to New Zealand exist, and one specific study on effects by a potentially invasive defoliator was undertaken (Kriticos et al., 2013).

Climate change can affect problems related to insect pests through several mechanisms including (i) changes in the severity of damage by native or non-native insects due to changes in climatic suitability, or host tree susceptibility (Battisti et al., 2005, Marini et al., 2012), (ii) changes in the likelihood of establishment of invasive species that are not yet present in New Zealand (Kriticos et al., 2013, Sutherst et al., 2007), and (iii) indirect consequences through interactions with other disturbance factors, such as increases in fire hazards due to tree mortality or pest susceptibility of stands through increasing wind damage (Hickey et al., 2012, Jenkins et al., 2012, Stinson et al., 2011).

Currently, only a few insect pests affect plantation forests of P. *radiata* in New Zealand. As there are no native Pinaceae in New Zealand, most insects feeding on these trees are non-native species that were introduced accidentally (but see Berndt et al. (2004) on a native defoliator that has adapted to feeding on pines). Fortunately, most of these species cause little or no damage. An exception is the woodwasp Sirex noctilio that was a concern in the past, but is now largely controlled through the introduction of biological control agents and changes in forest management that reduce stand susceptibility to *S. noctilio* (Bain et al., 2012). However, the pest status of some of these species could change as a result of climate change, and in other countries, there are many pests of conifers that could represent serious threats to plantation forests in New Zealand if they should ever become established in the country (Brockerhoff & Bulman, 2014). These threats could potentially become even more severe in the future.

There are hundreds of damaging pests associated with conifers that are not yet present in New Zealand (Brockerhoff & Bulman, 2014). For example, the Eurasian nun moth, *Lymantria monacha*, and the European pine processionary moth, *Thaumetopoea pityocampa*, would probably cause considerable defoliation if they became established in New Zealand (Kriticos et al., 2013, Withers & Keena, 2001). A climate-matching study has indicated that there are also a number of North American bark beetles attacking pines that represent a threat to New Zealand's plantation forests, including Dendroctonus valens and Ips calligraphus (Lantschner et al., 2017).

Most of the regions in New Zealand where conifer plantation forests occur are expected to be climatically suitable for the pine processionary moth, and estimates of its impacts on pine productivity suggest that significant growth losses would occur if it were introduced (Kriticos et al., 2013). In Europe, the main limiting factor for most insect pests is cold stress (Kriticos et al., 2013, Robinet et al., 2007). Hence, for many species, climate change is expected to increase the area with suitable climate (Robinet et al., 2007). The situation in New Zealand is likely to be similar. This effect of climate change on climatic suitability is likely to have more far-reaching implications for species from warmer (e.g., subtropical) regions which currently are unlikely to become established in New Zealand given its mainly temperate climate. Several studies have suggested that climate change will increase the risk of establishment of species from warm-temperate or subtropical regions (Kriticos, 2012, Peacock & Worner, 2006).

Climate change may also affect the severity of damage from existing insect pests because warmer temperatures can be expected to accelerate insect development and therefore lead to an increase in population levels, especially in species that can complete more than one generation per year. An example of such a species is the Monterey pine aphid, *Essigella californica* (Watson et al., 2008). Although this aphid is presently not considered damaging in New Zealand, in parts of Australia with a warmer climate (i.e., warmer than New Zealand's current climate), E*. californica* can cause considerable defoliation of pines (May & Carlyle, 2003).

In other parts of the world, warming has been shown to increase population levels and damage caused by the mountain pine beetle and other bark beetles (Bentz et al., 2016, Bentz & Jönsson, 2015, Hicke et al., 2006, Marini et al., 2012). Warming can thus lead to an expansion of areas affected by tree feeding insects (Battisti et al., 2005, Marini et al., 2012). The unprecedented spread of the mountain pine beetle into the boreal forest east of the Rocky Mountains, as a result of climate change, is of particular concern because it could cause substantial mortality of jack pine, *Pinus banksiana*, and other eastern pines (Cullingham et al., 2011). Furthermore, warmer temperatures, especially if associated with greater frequency of drought conditions, can increase the susceptibility of trees to attack and damage from bark beetles or wood borers such as *S. noctilio* (Carnegie and Bashford, 2012). Both warming and increasing drought incidence can lead to an expansion of areas affected by tree feeding insects (Battisti et al., 2005, Marini et al., 2012). Although there have been no observations, yet, of increases in any identified insect pest in plantation forests in New Zealand that could have been linked to climate change, this is likely to occur in the future.

Competition with weeds

The future prevalence of weed problems is likely to be related to (i) the future distribution, growth and competitive strength of the currently problematic weeds, and (ii) the potential of weeds that are either currently already present in New Zealand, but not yet widely distributed, or that could enter the country to become problem weeds, especially under changed climatic conditions.

The weed species that compete most strongly with *P. radiata* within New Zealand are tall woody weeds. Within this group, gorse (*Ulex europaeus*), Scotch broom (*Cytisus scoparius*), bracken (*Pteridium esculentum*), blackberry (*Rubus fruticosus*) and wilding conifers (*Pinus spp*. and *Pseudotsuga menziesii*) are the most competitive and invasive (Watt et al., 2008). In addition, buddleja (*Buddleja davidii*), Acacia spp. and pampas (*Cortaderia spp.*) are problematic weeds in some specific regions within New Zealand. Tall shrubby species reduce plantation growth more than short species such as grasses and herbaceous species as they compete more vigorously for both water and light and are not as effectively shaded out by trees as they grow taller (Richardson et al., 1999, Watt, 2003).

Little research has investigated the future distribution of the most problematic weed species in New Zealand under climate change. Potter et al. (2009) found that changes in climate will have little effect on the potential distribution of broom, with all regions remaining suitable for the species. In contrast, it is expected that under future climate change, buddleja may expand its range within the southeast of New Zealand (Kriticos et al., 2011, Watt et al., 2010).

Expansion of 'sleeper weeds' is likely to pose a future threat to plantation forests. Sleeper weeds are weeds that are present in New Zealand, but whose distribution or vigour is limited under current climatic conditions. For instance, the exotic tree *Melaleuca quinquenervia*, which is currently established in Auckland and Northland, could become quite invasive if the species' thermal requirement for reproduction within northern areas of New Zealand is surpassed in the future (Watt et al., 2009). Range expansion of this species could have significant consequences as *M. quinquenervia* has been found to be extremely difficult to control in exotic locations, such as Florida (Austin, 1978, Woodall, 1983).

Kudzu (*Pueraria montana*) is a perennial, semi-woody, climbing leguminous vine, which is extremely invasive and damaging in the southeastern United States (Britton et al., 2002). It has recently been found in northern New Zealand. Although we do not currently have an estimate of the potential distribution of this species, the distribution where it is invasive in the United States is quite similar to that of *M. quinquenervia*. Kudzu has migrated northwards in the continental United

States from its distribution during the 1990s (Council, 2007), a shift which is in line with previous model predictions (Sasek & Strain, 1990) and thought to be associated with an increase in minimum winter temperatures (Ziska et al., 2011). This change demonstrates the responsiveness of the weed to climatic conditions and highlights that the potential for range expansion under climate change should not be underestimated.

There is a risk that currently established exotic woody tree species native to Australia may become more dominant competitors in New Zealand under a warmer climate. Both Acacia and Eucalyptus spp. can have very high growth rates and rapidly occupy disturbed sites, vigorously competing with planted *P. radiata* seedlings (Turvey et al., 1983). As tree species, they can compete further into the rotation than even tall weed species (Hunt et al., 2006), which are predominantly shrubs. Some species have the ability to resprout after their stems have been severed which makes them hard to control. Seed germination is also often stimulated by fire. With a likely increases in fire frequency and severity, it will make sites more predisposed to invasion by these species. Some Acacia species are already a localised problem in northern and eastern parts of the country (Watt et al., 2008).

Climate change is also likely to affect growth rates of weeds through changes in CO_2, root-zone water storage, temperature and changing length of the growing season. If relative growth of both trees and weeds increases at the same rate then competition levels may not significantly change. However, in agricultural settings there is evidence that weeds exhibit a stronger positive response to CO_2 than crop plants which is likely to cause a greater reduction in crop yields (Ziska, 2011, Ziska et al., 2011). The basis for this increased competitive behaviour of weeds is unclear but may be related to the vigorous and generally indeterminate growth habit of weeds and greater genetic and phenotypic plasticity associated with wild species (Ziska & McConnell, 2015). As the growth response of different weeds to climate change has been shown to vary widely (Sheppard & Stanley, 2014) increases in CO_2 have been shown to preferentially select for invasive species within plant communities (Ziska & McConnell, 2015).

The effects of climate change present global plantation forests with many challenges but also new opportunities. This study quantifies the increases in productivity expected due to climate change. Changes in the wind climate have implications for silvicultural practices, while increased wild-fire risk will spread to both areas of plantation forestry and large population centres. The future impact from biotic factors are complex and often species dependant, but this summary highlights the major threat species and notes the highest-risk source locations.

Socio-economic processes

Shared Socio-economic Pathways

Shared Socio-economic Pathways (SSPs) were developed by the international community as reference pathways “describing plausible alternative trends in the evolution of society and ecosystems over a century timescale” (O’Neill et al. 2014 p.1-2). SSPs allow risk to be evaluated, but also can be used to identify processes that can be modified or new processes that mitigate risk.

SSPs describe five potential future development paths at global scales without reference to climate change related policies – which are added though a process of identifying shared policy assumptions (SPA) (Kriegler et al. 2013). SSPs can be used to test the ability of strategies and adaptation plans to reduce vulnerability and increase resilience to climatic and socio-economic changes and can be used to develop effective integrated mitigation and adaptation solutions, transformative strategies and transition pathways.

The socio-economic drivers of climate change are given in Table *3*, and will affect the timing and amount of GHGs released into the atmosphere (IPCC AR5); and will affect the impacts that climate change will have on people and affect the ability of societies to manage and mitigate GHG emissions (Adger et al., 2007), plotted in Figure *7*.

Table 3 Socio-economic elements considered in the SSPs (O'Neill et al. 2014)

Category	Scenario element
Demographics	Population total and age structure Urban vs. rural populations, and urban forms Other location information, such as coastal vs. inland
Economic development	Global and regional GDP, or trends in productivity Regional, national, and sub-national distribution of GDP, including economic catch-up by developing countries Sectoral structure of national economies: the share of agriculture, and agricultural land productivity Share of population in extreme poverty Nature of international trade
Welfare	Human development Educational attainment Health, including access to public health and health care infrastructure
Environmental and ecological factors	Air, water, soil quality Ecosystem functioning
Resources	Fossil fuel resources and renewable energy potentials Other key resources, such as phosphates, fresh water etc.
Institutions and governance	Existence, type and effectiveness of national/regional/global institutions Degree of participation Rule of law
Technological development	Type (e.g. slow, rapid, transformational) and direction (e.g. environmental, efficiency, productivity improving) of technological progress Diffusion of innovation in particular sectors, e.g. energy supply, distribution and demand, industry, transport, agriculture
Broader societal factors	Attitudes to environment/sustainability/equity and world views Life styles (including diets) Societal tension and conflict levels
Policies	Non-climate policies including development policies, technology policies, urban planning and transportation policies, energy security policies, and environmental policies to protect air, soil and water quality. It is possible that SSP's could be specified partly in terms of policy objectives, such as strong welfare-improving goals, rather than specific policy targets or measures

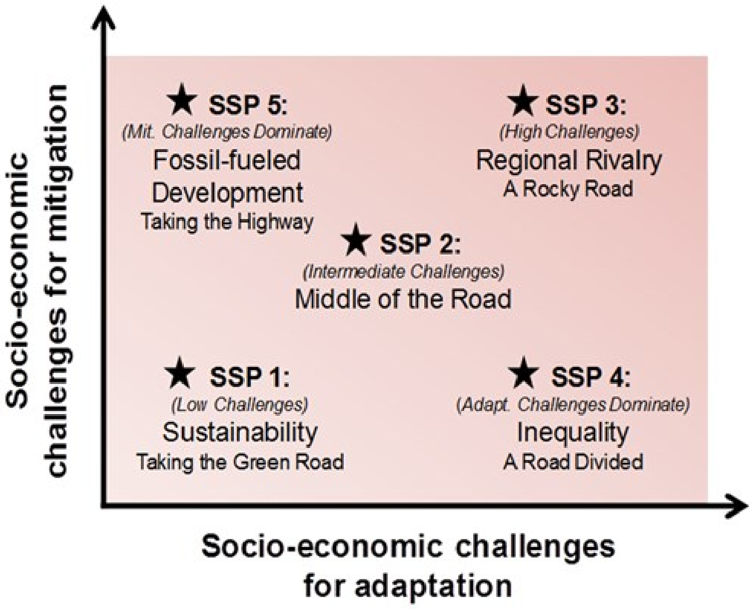


Figure 7: Global SSPs (O'Neil et al, 2014)

Forestry Futures under different SSPs

The key factors from the SSPs that affect forestry are population, trade (forest products), land use regulation, pressure on forest area, consumption (forest products), forest productivity and forest product utilisation efficiencies.

SSP1 – Sustainability

SSP 1 is a world that is sustainability driven, with respect for environmental boundaries, and triple bottom line accounting. The SSP 1 marker scenario (van Vuuren et al, 2017) is a coherent story line for sustainable development, addressing reasonably ambitious improvement in resource efficiency, human development, and preferences regarding consumption and production systems within energy- and land-system. The scenario assumes that due to the developments in technology and governance there are no or limited barriers to effective mitigation and adaptation. SSP 1 emphasises the use of environmentally friendly technologies, a transition to less resource intensive lifestyles; an increasing global GDP coupled with a decline in population post 2050. Technology improvement and efficacies drive down cost of technologies such as PV and electric batteries.

Forestry in an SSP 1 NZ world is expected to benefit all primary sectors, with enhanced and collaborative trade, environment and sustainability foci developing circular economic thinking and 'green' substitution of (e.g.) wood for concrete; a reduction in environment impacts of harvesting, improvements in ecosystem services. The increase in technological developments in genetic stock, management and processing all contribute to improved utilisation, and forests are used for other bio-based products, such as bio-plastics and fuels.

SSP2 – Middle of the Road

SSP2 is described as an intermediate case between SSP1 and SSP3.

SSP3 – Regional Rivalry

SSP 3 describes a world of fragmentation, resulting in low economic growth and low technology development, so when combined with an increasing population, means that mitigation and adaptation are difficult (van Vuuren, 2017). In the absence to climate policy and factors that tend to reduce the ability of society to mitigate climate change (Fujimori et al. 2016), emissions are high in

SSP3 and lead to a warming of 4°C above pre-Industrial temperatures by 2100 (Van Vuuren et al., 2017, Fujimori et al. 2016). SSP 3 is a world of regional rivalry (O'Neil, 2017).

Countries develop policies that are identity based and focused on national security. The lack of international collaboration on climate change, and weakened international organisations limits economic growth, especially in developing countries; provides for low investment in education and low technological development. Hence, economic growth is resource intensive with low increases in energy efficiency and agricultural production efficiencies, or growth can be pursued through increasing land in production, increasing deforestation. The drive for more growth also depreciates environment policies and protection and perversely limits investment in resource efficiencies limiting improvement in agriculture system efficiencies. Trade barriers are strengthened, with a reliance on in-country resources.

SSP 3 is a high fossil fuel dependant world, and sees more coal used and with carbon intensity increasing (whereas with SSP 1, and the increase in renewables, it deceased). SSP 3 has low renewable energy share (~20%, 2100) due to poor / slow technology development and increased costs. SSP 3 does not have specific energy access policies as in SSP 1, hence the transition away from traditional energy sources is slower.
As in SSP 1, land use is driven by food demand, with the trends in population and welfare increasing food demand. SSP 3 has slightly higher animal production consumption, but with lower incomes the per capita consumption is lower. Yield improvements are limited (considerably less that SSP 1) due to low technology developments resulting in increased competition for land. Feed crops for ruminant systems (and monogastric) is much (2x) higher in SSP 3 than SSP 1, further increasing pressure on land available for production.

Forestry in NZ in an SSP 3 world is expected be very constrained. Land will be prioritised for the sectors that provide high returns to private owners. There is limited regulation of land use, and of environmental impacts. The world is competitive; with potential constraints on market access can be, with artificial barriers and tariffs created to ensure dominance of overseas markets' local forestry. *P. radiata* use does not move beyond its current usage, with limited substitution of concrete etc. Technology developments are country's intellectual property (IP), access to international IP is limited and political, hence a reliance on local developments. This world is typically a high temperature world, with resultant increase in biotic and abiotic impacts on forests.

<u>SSP4 – Inequality</u>

The SSP 4 world is one characterised by global and within nations inequality. From the global narrative (O'Neil, et al 2015) inequality and stratification between haves and have-nots, it is entrenched through high levels of unequal investment in human capital, increased disparities in economic opportunities and political power.

Society is divided into those who are: well educated, internationally connected, and who drive and develop knowledge and have access to capital, or those who are low income, poorly educated working in labour intensive and low technology economies. Power is held by the elite even in democratic societies where the 'poor' have limited representation nor the capacity to achieve it. Globally, 'extreme poverty, income inequality, and lack of opportunity lead to environment ills especially for the poor' (Calvin, et al 2017). As there is wealth and power in the elite segment, they are able to invest in mitigation, and technologies 'should the will to do so materialise' (p. 285.). Poverty, and lack of access to technologies makes it hard for the 'poor' to adapt to climate change. The marker scenario paper does not discuss the SSP implications for adaptation deferring that discussion to a future, currently unpublished paper.

The marker scenario shows that for high- and middle-income regions (HIR, MIR) population decreases. HIRs become more prosperous. The opposite is for low-income regions. This with population growth, but with no means for increasing income. These differences between the different strata will drive different demands for food, energy as well as how demand is met.

How this plays out for NZ depends on whether the regions are benefiting from a world that requires food, providing economic returns to agriculture, or whether economic growth and trade is dominated by cities. Forestry in a SSP 4 NZ world is expected to be regulated (as opposed to LDC countries where there will be limited regulation). NZ belongs to the global elite and as this world does mitigate strongly, forestry will prosper based in its mitigation role. Adaptation is difficult, hence there will be financial impacts for forests especially under medium increases in temperature.

We would expect to see technologically-led improvements on all aspects of forestry and processing, and in a CO_2 regulated world, there will be demand for biofuel and bioplastics. International mitigation collaboration is high particularly in HICs, and this collaboration may flow across into trade negotiations. Initially, there will be large scale LIC tropic deforestation in pursuit of increased food production and security which may impact trade. Inequality within NZ may lead to forests being largely owned by large corporates (as with other primary sectors), as they will have access to IP, capital, and will have political influence.

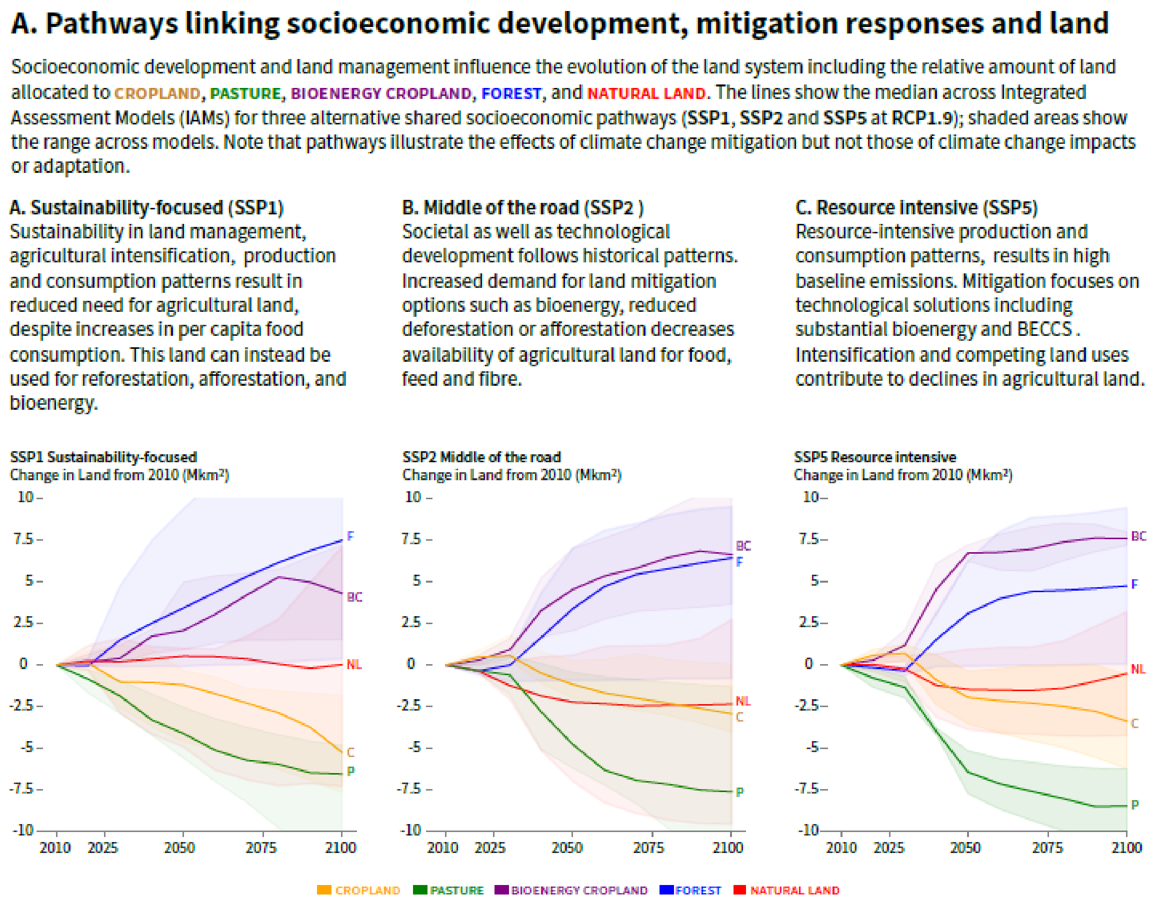
SSP5 – Fossil-fueled development

SSP 5 is a world that is energy and resource intensive, derived from very high fossil fuel usage, with high food usage and a tripling of energy requirements. Under this scenario CO_2 will increase with a resultant challenge for mitigation. Population will increase and then decline, there is rapid human development and a growth in income convergence, coupled with an inclusive and globalised economy. The high challenge to adaptation means that adaptive capacity is high and continues to grow.
This world, somewhat similar to the world over the last 30-50 years, includes international collaborations, trade dominated economies, and some focus on sustainable development. Dependant on attitudes to climate change mitigation, and appropriate technologies, there could be limited CO_2 increases – the NZ CCII programme sketched narratives for worlds that have low global warming (RCP 2.6) all the way to medium high (RCP 6.0). Adaptation and mitigation are driven by technological solutions or afforestation and policy – emission payments - to some degree.

Forestry in an SSP 5 NZ world is based on neo-liberal market economics. There is no international agreement on mitigation (even though it is seen as desirable), hence forests are mined for their economic benefit, and technology improvements are strongly pursued with increased productivity. There is a highly competitive trading environment that pushes for further production efficiencies and product improvements but allows for country product specialisations. The whole environment encourages investment in education and research, society wide and within the sector. Forestry is seen as a key economic sector in NZ. The practise of adaptation to climate change risk is established, and along with a wish for mitigation, providing some impetus for environmental protections that minimise damage in forestry and across sectors, but are held in tension with any trade-offs in economic development (Daigneault et al (2018), Daigneault (2018); Dunningham (2020, in prep)).

The IPCC Special Report on Climate Change and Land (SRCCL) (IPCC 2019) identifies the implications of three different SSPs on global land use, illustrated in Figure 8. These figures are useful to highlight the implications of the SSPs for global land use, although the NZ context may be somewhat different. Because of the sustainability focus in SSP1, there is less pressure on the land for food and widespread bioenergy production, hence the land can be used for afforestation. Forest land shows gradual and sustained increases out to the end of the century. SSP5 on the other hand, shows an initial decline in forest land, followed by an increase but with a lower proportion of land in forests at the end of the century. Land for bioenergy (which may include types of forestry) increases sharply as a mitigation option, taking land from other uses. SSP2 presents a middle of the road picture.

Figure 8 Pathways linking socioeconomic development, mitigation responses and land (IPCC 2019)



Domestic policy drivers

Implications for forestry will be influenced by a range of relevant policy outcomes linked to the direct impacts of carbon values in the emissions trading scheme (ETS), with more widely, initiatives coupled to international pledges for carbon emissions. Further policy incentives to promote afforestation, improve water quality, develop a circular bioeconomy and implement regional economic stimulus are also expected to positively influence outlooks for forestry over coming decades. Additionally, changes to land use through differing forest management and ownership outcomes, relating to the outcome of Treaty settlements are also likely. Many of these policy drivers will improve opportunities for forestry, particularly if diversification of management techniques and species portfolios are also implemented.

Emissions trading and carbon

An on-farm emissions accounting system will be gradually applied to all farms by 2025 (He Waka Eke Noa 2019). This roll-out process suggests that an on-farm emissions pricing scheme is in development and may be deployed by 2030. Emissions prices will be applied per unit of CO_2, or CO_2 equivalent for methane and nitrous oxide emissions. With the fixed-price carbon trading option to be increased to around NZ$30 per tonne, a rate of around NZ$50 per tonne is likely by 2030, which will be contained a government reserve trigger pricing policy. This economic scenario for carbon emissions will provide a strong disincentive, particularly for the higher-emitting forms of agriculture, while also strongly incentivising afforestation.

An expected increase in carbon prices will deliver strong incentives for afforestation, both involving exotic plantation forestry and indigenous species. This presents an opportunity for commercial forestry. The impacts from on-farm emissions costs would affect the profitability of agricultural sectors, particularly impacting pastoral grazing industries and dairy. These outcomes may see some farms becoming unprofitable, with a net impact that farmers sell-up and additional land becomes available for afforestation. Alternatively, some farmers may choose to offset emissions costs by planting and restoring habitat, including forests, taking advantage of incentives currently under development that will also account for carbon sequestration rates on-farm. These finer-scale accounting approaches may deliver value and recognition for the sequestration services delivered by habitat restoration and other smaller-scale (<1 ha) afforestation projects in capturing carbon, if methods and policies that effectively recognise the carbon stored can be developed. This shift may present a potential opportunity for some new smaller-scale forestry operations to be developed, including innovative arrangements for growing and potentially harvesting trees, including indigenous species. Increased afforestation nationwide is an expected outcome of farmers wanting to make their farms carbon neutral.

Domestic climate policy and the circular bioeconomy

In order to meet NZ's Paris Agreement commitments, NZ has committed to reduce GHG emissions by 30% from 2005 levels by 2030, and has gone further in domestic policy through the Climate Change (Zero Carbon) Amendment Act. Although biofuels currently make up less than 0.1% of the total liquid fuel consumed in NZ, their increasing use is an important component of the national strategy to meet these targets**.** Currently, most bioethanol in NZ is currently produced from waste milk whey, however, strong incentives exist to increase the use of forestry residues as a feedstock for biofuel production in order to meet our emissions reduction targets. Sources of forestry biomass for biofuel feedstock include willow and poplars, together with waste material from harvesting and processing of timber. This presents an opportunity for the forestry sector to diversify and utilise new timber species, together with develop new value chains for waste recovery and utilisation. Additional momentum exists with nurturing a wider circular bioeconomy for NZ. Although no explicit policy drivers yet exist to promote the bioeconomy (Wreford et al. 2019), for the immediate future the government expects that private investment will support this. Recent analysis work on the bioeconomy by MPI indicates a strong impetus at government level in developing policies to promote the infrastructure, knowledge and value chains that will support this. Forestry has an opportunity to significantly contribute to the bioeconomy by delivering the raw materials and feedstock needed for the novel processes that will underpin this. This presents an opportunity for diversifying the forestry portfolio.

Afforestation policies

The One Billion Trees (1BT) Policy will provide an opportunity for country-wide regeneration involving a range of forested landscapes, with the potential to develop new forest systems that will deliver multiple beneficial outcomes for landowners and society. From a forestry perspective, 1BT provides an opportunity to promote afforestation, while capturing carbon, and potentially encouraging diverse species mixes in forestry. There is some potential for native species as a newly-developing industry. In theory, 1BT especially encourages the planting of native species, as grants provided for this have a value more than twice that for exotic species. These measures could underpin delivery of a diversified species tree stock for plantation forestry, which would potentially enhance resilience to adverse climatic or disease outcomes in the future. One difficulty in this lies with resolving a set of viable conditions that allow a forestry industry with indigenous species to take place. These include addressing public perceptions around using these species commercially. The 1BT policy has also lead to some negative public perceptions about afforestation, with interpretations from some sectors that this policy is preferentially beneficial for exotic plantation forestry. An outcome of this is that future policies that attempt to build on 1BT to promote afforestation (post-2030) could be met with public resistance. It may be possible to counter this, by diversifying the range of species used in plantation forest stock, including the emergence of an indigenous plantation forestry industry, to generate more favourable social perceptions around this.

Treaty settlement impacts

Treaty settlement claims will continue to see land assets returned to Maori landowners, including land held by Crown Forestry. Crown Forestry indicate they will continue to divest of a range of forestry assets, including land currently leased for exotic plantation forestry from Maori landowners. Such changes present an opportunity for Maori landowners to utilise forest land resources in new ways. These entities may consider alternative forestry practices, including implementing diversified species mixes and plantation forestry using indigenous species. Such shifts present a further opportunity for the forestry industry to develop new value chains and silvicultural practice.

Water quality regulations

The National Policy Statement for Freshwater Management is unlikely to have any foreseeable negative impact on forestry, but it will increase compliance pressures for nitrates and other water pollutants for on agricultural and grazing sectors, especially regarding monitoring and mitigation of their downstream impacts. These pressures are set to increase progressively until 2030, when Freshwater Management policy targets are expected to be met. Farms with marginal profits may choose to sell up under these conditions and this would potentially make greater areas of land available for forestry. Smaller-scale afforestation within-farm may also form part of a solution. Land used for forestry has lower levels of nitrogen leaching than grazed land. Moreover, riparian tree species such as alder or willow can specifically mitigate the run-off impacts of nitrates and other pollutants from grazed land if planted alongside waterways. These practices, if used in combination with other forms of on-farm forestry, could deliver alternative models for small-scale commercial forestry that benefit outcomes for freshwater quality.

Forestry harvest residues are a negative impact of commercial forestry operations, which have potential for debris flow with considerable negative downstream impacts on catchments. Currently, there are no anticipated legislative or policy outcomes that would affect forestry industry activities in addressing this. Future policies, however, may be developed in response to social license problems with debris flow, thereby compelling forestry operations to effectively manage these harvest residues and prevent such downstream impacts.

Regional economic stimulus

Government policy to support rural economies via the three-year Provincial Growth Fund, recognises that the success of NZ’s economy rests on that of regional economic development, including primary industry activities such as forestry. The government may continue to direct economic resources at this goal, thereby developing conditions that further support forestry activity in the regions.

Non-climate related global drivers and disruptions

At the time of writing, the world is in the midst the COVID-19 pandemic. While the full impacts of this are uncertain and will depend on how the pandemic plays out, it is already clear that the economic disruption caused will be significant, potentially even greater than the Global Financial Crisis. The domestic flow-on effects of this global shock on the NZ forestry industry were observed much sooner than the direct effects of the virus itself entering the country. With 80% of export logs going to China, the crash of this market had damaging impacts on the industry, particularly for the workforce involved in logging, forest roading and logging truck drivers. While this kind of global disruption is almost impossible to predict, it illustrates the risks of concentrating in one market, as well as the risks associated with globalisation. Some of the strategies for increasing resilience to climate risks may also help with resilience to other shocks.

Modelling futures under uncertainty

The next stage of this project is to develop a report on the inclusion of probabilistic climate change scenarios (bio-physical and socio-economic) into a quantitative adaptation framework used in the context of the forest sector in NZ. In choosing how to simplify or frame the factors affecting the NZ forestry sector under climate change there will be trade-offs among accuracy, precision, tractability, and utility, among other traits. The most precise results, for example, may be too detailed to be useful in practical decision-making processes. However, caution must also be exercised to avoid reducing too much detail or hiding uncertainties or complexities.

Although we have a reasonable understanding of the bio-physical impacts of climate change on NZ forest systems as outlined previously, still large uncertainties remain around the precise location, magnitude and timing of changes. All projections of future climate change are subject to "cascading uncertainty" (Wilby and Dessai 2010), and attempts to make assumptions about probabilities can lead to decisions that are not robust to a range of futures (Kalra et al. 2014).

However, for some types of quantitative analysis, it is necessary to make assumptions about the probability distributions in order to analyse the performance of our adaptation options. In terms of the climate models used to drive the RCPs for NZ's climate projections, no assessments have been made on the relative plausibility of the six GCMs used thus, and so in the absence of more specific information we can treat each as being equiprobable. The relative plausibility or the RCPs, however, are not as unknown. The two end-member RCPs (2.6 and 8.5) are both considered less likely than the two middle range RCPs (4.5 and 6.0). On the one hand, it has been argued that rapid decarbonisation and negative emissions would be necessary to achieve the RCP 2.6 future; on the other hand, momentum is growing globally to avoid the more extreme climate change effects in many ways, which suggests RCP 8.5 is also less likely. These assumptions would allow us to prescribe coarse approximations in terms of the RCPs probabilities.

These approaches and methods for developing scenarios into a quantitative adaptation framework will be expanded in the subsequent report. Other approaches that are worth exploring for modelling the future are Bayesian updating which can be combined with evidence theory of Dempster-Shafer for coping with non-stationary risks or combined with optimization algorithm (Yousefpour et al. 2014).

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