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Exploring the solution space for different forestry management structures in New Zealand under climate change

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ABSTRACT

The concept of "solution spaces" is used to explore the potential future of forestry under climate change for different types of forestry management structures. We base the analysis in New Zealand, where forestry plays an increasingly critical role in the nation's climate policy, but the concept could be applied to any region. Understanding solution spaces and the ways in which they can be influenced at different levels of ownership is a critical step towards effective climate change adaptation. Building on the base of existing climate projections, scenarios, and economic and social science literature, we form an assessment of the capacity of each forest owner typology to influence their solution spaces into the future. Different management structures have strengths in different areas – while industrial forest managers may be able to utilise emerging technologies better than their smaller scale counterparts for example, they may be less agile and flexible. The sector as a whole may benefit from working collectively to draw on the respective strengths of each typology. Critically, planning now to expand the space into the future will be essential.

1. Introduction

With the long time horizons involved in forestry, consideration of the future has always played a critical role in forest policy and management (Hengeveld et al., 2017; Schüll and Hoogstra-Klein, 2017; Monge et al., 2018). The forest sector faces many different factors influencing its future, not least of which is climate change. Both the physical impacts of climate change on forest growth and production, as well as the role of forests as Carbon Dioxide Removal mechanisms (West et al., 2020; Schenuit et al., 2021), will fundamentally drive the future of forestry. The uncertainty surrounding the future makes forest management in the present challenging. Haasnoot et al. (2020) introduce the concept of a "solution space", as a way to consider options for the future when uncertainty is high. We use this idea in this paper to define and explore the size and shape of the operating space for forest manager decision-making, examining the different solution spaces within heterogeneous ownership and management structures.

We use New Zealand as an example to assess the solution space for forestry. The country is an ideal exemplar with forestry central to its climate change response. Although New Zealand does not have a national forestry strategy, it does have a range of relevant legislation that directly affect forestry. New Zealand recently enacted a relatively ambitious climate change legislation with a target of net zero emissions by 2050 (Climate Change Response (Zero Carbon) Amendment Act 2019), using forests as a short-term carbon sink. The New Zealand Emissions Trading Scheme (NZ ETS) prices carbon and is the only ETS in the world to include forest carbon credits (West et al., 2020) with respective deforestation liabilities. Forestry in New Zealand is plantation-based with monocultures of Radiata pine ***(Pinus Radiata)*** (94 per cent) and Douglas fir (four per cent) of the 1.7 million ha (Yao et al., 2019). Indigenous forestry is very limited with the crown estate protected as conservation forests (Pizzirani et al., 2019). Hence, this paper focuses on the plantation sector.

The solution space, as introduced by Haasnoot et al. (2020), is "the space within which opportunities and constraints determine why, how, when and who adapts to climate risks" (p.1). The concept is similar to

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the "opportunity space" illustrated by the IPCC (IPCC 2014), with similarities also to the "safe operating space" concept (Rockström et al., 2009). It is shaped by biophysical, cultural, socio-economic and political-institutional dimensions at a given point in time.

Scenarios are another way to stimulate decision-makers to think about possible future opportunities and challenges and the courses of action available to them (Jarke et al., 1998). A range of scenarios are used in the context of climate change: The physical impacts can be identified from Representative Concentration Pathways (RCPs) (van Vuuren et al., 2011) of future global greenhouse gas emissions. The Shared Socioeconomic Pathways (SSPs) (O'Neill et al., 2014, 2017) developed by the international climate community present alternative development pathways at the global scale, and changes to the policy environment are modelled by Shared Policy Assumptions (SPAs) (Kriegler et al., 2014).

Considering the New Zealand context, the RCPs and earlier SRES futures (Nakicenovic et al., 2000) have been used in NZ to develop generic understanding of climate impacts (Ministry for the Environment 2018). Frame et al. (2018) develop short descriptions of nationally relevant socio-economic scenarios nested within the downscaled SSPs and SPAs for New Zealand, and Ausseil et al. (2019) develop a site-specific assessment of future scenarios, combining economic and biophysical models, coupled with regional environmental and land-use policies. While all contribute to the local context, none of these studies provide insights specific to the forestry sector. Daigneault et al. (2019) develop detailed SSP narratives for the global forest sector, and Daigneault (2019) simulates the impact of global SSPs on New Zealand's forestry sector.

Together, this existing body of work provides a solid foundation for understanding the range of potential futures under a range of climates and socio-economic conditions. The scenarios do not provide probabilistic understanding of the future but rather an understanding of a range of potential futures based on different levels of radiative forcing, and the socio-economic conditions that arise from society's (internationally and locally) ability and willingness to mitigate and adapt to climate change. Hence, for economic and social adaptation planning, scenarios do not reduce decision-making uncertainty but provide an opportunity space to explore potential options by those affected, with their expert and locally-specific knowledge.

In this article we build on the existing scenarios and relevant research to develop an understanding of the space for action. What do scenarios mean for forest managers who need to make decisions now in the absence of any estimation of likelihood? What are they able to influence directly and what actions can they take that will be robust across a range of futures? (Hallegatte et al., 2009). A better understanding of the solution space for climate change adaptation, and ways to influence this space, is critical to accelerate adaptation action (Haasnoot et al., 2020).

Comprehensively assessing the solution space will require a range of approaches to both quantitatively identify, map, model and test options, costs and benefits and pathways of action. In this article we focus on two propositions from Haasnoot et al. (2020): that the solution space can be applied to any actor group and will differ among them, and that there are opportunities for actors to influence the solution space, both opening it up or closing it down. We begin to identify and describe the main features of the solution space for a range of forest owners in New Zealand, with a particular emphasis on identifying the opportunities for different actors in influencing the solution space. We do this with the intention of both providing a starting point for future reflection and planning of this sector, as well as more broadly demonstrating how solution spaces can be an empowering approach to conceptualising action in uncertain futures.

The paper is laid out as follows: Section 2 provides a brief introduction to the New Zealand forestry context and its management structures. Section 3 describes the analytical approach, while Section 4 presents and discusses the New Zealand forestry solution space. Section 5 concludes.

2. The New Zealand forestry context

Forestry in New Zealand is largely a commodity industry, with c. 50 per cent of annual production exported, and 50% of those destined for China, and with total export earnings of $NZ 6.9 m (NZFOA, 2019).

Forestry is exposed to the direct risks of climate change (Dunningham et al., 2012) and potential trade risks caused by climate risk and policies within global markets. The physical risks in NZ arise from the lack of natural resilience due to the monoculture nature of plantations e.g. fire, pests, weeds and disease (Watt et al., 2019) and from extreme events, particularly where forests are located on steep erodible land (Monge et al., 2018, Monge and McDonald 2020). Ninety-five percent of New Zealand plantation forests are privately owned, in diverse ownership structures, including the crown forestry licenses (the trees are licensed, with land ownership being retained by Government or Iwi (indigenous ownership)); owned by national or international corporate firms and managed by those owners or by forest management companies; privately owned forest (i.e., trees and the land); Iwi; as well as many smaller forests on diversified farms, investment blocks and lifestyle owners (Yao et al., 2013).

Different owners, or types of owners, will take different actions and decisions in similar situations, with their decisions being sensitive to changes in different external and internal factors (Hengeveld et al., 2017; Soucy et al., 2020). We classify forest owners in New Zealand into five broad groups, based on their ownership structures and understood /implied goals. These types were identified and adapted from existing typologies in the literature (Dewes et al., 2011; Rodenberg and Manley, 2011; Blanco et al., 2015) and the National Forest Description Survey (NEFD, 2019), and are described below:

1. Large-scale industrial – own forest more than 1000 ha; objective: profit-making; management intensity: high; run and manage forests using professional managers with clear forest management plans;
2. Enterprise/ mixed – own land between 50 ha and 999 ha of forests; objective: multiple (and multiple land uses e.g., beef and sheep, dairy, etc.); management intensity: medium; some with forest management plans;
3. Lifestyle/ non-profit [1] own forest below 50 ha; objective: private consumption, nature conservation, environmental quality and aesthetic; management intensity: low; no management plans;
4. Māori trust - own forest more than 1000 ha; objective: explicit to meet the trust's aspiration for retention and utilisation; management intensity: high; run and managed forests using professional managers with management structure and plans; and
5. Māori smallholder forest owner – own forests below 50 ha with no management structure; objective: aspiration for retention and utilisation. Management intensity: low, passive

3. Analytical framework

The analysis in this paper takes a mixed-methods approach, primarily based on review of the relevant literature, complemented by expert elicitation. In order to develop a systematic overview of the solution spaces for New Zealand forest management, we developed an analytical framework consisting of three key dimensions driving the solution space for the five different management types. This framework guided the implementation of the literature review and expert consultation, with details provided in the following section.

[1] Note: Small forest owners are characterised to have < 50 ha but management of owners may differ and is poorly understood. (NEFD, 2019; Rodenberg and Manley, 2011)

3.1. Dimensions of the solution space

The three dimensions that determine the solution space for forestry in the context of climate change are biophysical, institutional, and socio-economic (Haasnoot et al., 2020). While these will all be shaped over time by global trends, we can identify the current state of these dimensions in New Zealand based on literature and examine how these may influence and affect the solution space for each of the forest owner types. We briefly describe the components of these different drivers below:

3.1.1. Biophysical drivers

The biophysical drivers for New Zealand forestry in the context of climate change are summarised in Watt et al. (2019). They form the boundaries of the solution space, although some of them will present harder limits than others. Risks to productivity increase within increasing global temperature (IPCC, 2019) from changes in frequency and severity of extreme events, wind damage, fire, and the ability of new and existing weeds, pests and diseases to establish and prosper. While there may be some productivity gains from increased CO_2 in the atmosphere, this is uncertain, and the risks are likely to constrain any gains.

Adaptation options for these biophysical impacts are identified in Dunningham et al. (2012). Once trees are planted the options are limited to changing the rotation lengths, thinning and managing pests and diseases, thus anticipatory actions including diversification of species and location are preferable (Yousefpour et al., 2016; Vannoppen et al., 2020).

3.1.2. Institutional dimensions

Institutions broadly cover a range of levels that collectively govern the behaviour of actors (Andrews-Speed, 2016), ranging from norms, beliefs and ideas; the institutional environment, including political, economic and legal systems and governance structures; the institutions which govern transactions including policies, laws and policy instruments; and finally behaviours, the actual transactions that determine prices and output quantities.

In the context of this study, the primary institutions involved in determining the solution space for forestry are the norms, beliefs and ideas of the sector or the decision-makers, the political, economic and legal systems they operate in, the property rights they hold, and the markets that they operate in.

In the current New Zealand context the primary pieces of legislation affecting forestry in the context of climate change are the Climate Change Response (Zero Carbon) Amendment Act (2019) (hereafter referred to as the Climate Change Act), the Climate Change Response (Emissions Trading) Amendment Act 2008 and the Resource Management Act (RMA). The main mechanism to achieve the goals of the Climate Change Act 1991 is the Emissions Trading Scheme (ETS), of which forestry is an active trader. Agriculture is due to enter the ETS in 2025,[2] with a price on biological emissions, which may change the relative viability of some agricultural systems and forestry. The RMA, through its consenting process, and though a series of national policy statements and national environmental standards (e.g National Environmental Standards for Plantation Forestry), creates both opportunities and barriers to afforestation and harvesting, and affecting compliance costs. The government's One Billion Trees programme seeks to accelerate forest planting for both climate and non-climate benefits such as erosion control and biodiversity through cash grants and technical support, though carbon forests are permanent and cannot be harvested without deforestation liabilities.

The National Policy Statement on Freshwater, while not affecting forestry directly, may put pressure on other land-uses leading them to consider converting land to forestry.

The NZ Forest Owners Association and NZ Farm Forestry Association are non-government associations and the prime industry representatives in the plantation forest growing sector. Their members are spread throughout the country. They play a large role in promoting the industry to the public. Investment by the industry through the Forest Growers Commodity levy in research and technology projects helps the industry to be innovative and sustainable. The 2017 New Zealand Growers Science and Innovation Plan identifies and describes the key research objectives for the transformation of plantation forestry from a log production business to market-led and automated capital-intensive manufacturing industry, which the levy would fund.

Three other institutions are illustrative of mechanisms that can influence climate change responses of the sector. The government has established industry biosecurity agreements that share decision-making and responsibility for managing biosecurity threats and incursions (www.gia.org.nz); The forest sector has a compulsory commodity levy on all harvested wood products, which is applied to activities such as biosecurity surveillance, fire prevention and research. Plantation forests (66 per cent) have international environment certification from either Forest Stewardship Council or Programme for the Endorsement of Forest Certification (NZFOA, 2019).

3.1.3. Socio-economic dimensions

Socio-economic drivers affecting forestry decisions are diverse and range from the global context affecting trade and market conditions, through to the firm level resilience, as well as the resilience of businesses, available technology, and the interactions with the dynamic societal context. We discuss these drivers below.

3.1.3.1. Global futures, trade and markets. The SSPs are globally established (O'Neill et al., 2014, 2017) yet require further consideration to understand what they might mean for New Zealand. As noted previously, New Zealand forestry is very different from most other countries as it is nearly totally based on exotic plantations of *P. radiata*, (whereas most other countries have significant industries that utilise native mixed species forests). In the absence of a forestry policy, it is feasible that current owners of forests can convert land to other land uses. Socio-economic impacts that arise from global and national approaches to climate change and adaptation can influence forest ownership and management decisions. New Zealand has over the last two to three decades seen a reduction in new plantings (NZFOA, 2019) and some regionally significant land-use change, particularly from forestry into dairy production (Monge et al., 2016) – although forest plantings are increasing again as a result of the current institutional environment (West et al., 2020).

Socio-economic spaces are shaped in part by the potential future trading worlds for NZ timber products. Limited international agreement and effective action on climate change mitigation would increase the likelihood of risk and the biophysical impacts as emissions concentrations increase; generate significant extra costs as the world prioritises just-in-time adaptation; and where production efficiencies within institutions occur that wind back improvements in environmental protection and social conditions. For forestry, a lack of international leadership could reduce mitigation efforts, reversing carbon pricing, or lowering trading unit prices. International trade is critical and one of the defining drivers for a profitable NZ forest sector. The solution space is bounded by futures that enhance and enable trade, and ones where trade barriers restrict trade. In a progressive future world, increases in forest area will be based on their ability to provide environmental benefits (e.g water quality) and at least in the medium term, the role of forests in carbon sequestration. In a production-oriented world, forest area will decrease based on conversions to more immediately profitable agriculture, and changes will be exacerbated if environmental protections are removed and incentives such as the ETS are removed (Daigneault,

[2] In the absence of an alternative industry-developed plan to reduce emissions

2019).

Daigneault (2019) examines the quantitative effects for New Zealand forestry: *Forest area* is expected to increase under all but one of the SSPs. The largest increases are expected to occur in the high growth pathways (SSP 1 and SSP5). These increases are based on the assumptions that New Zealand is expected to emphasise freshwater quality and enhancing carbon sinks, which increases the attractiveness of forestry relative to some other land uses. In SSP3, forest area is expected to decrease as forest land is converted to pasture for more profitable internationally traded meat and dairy products (to feed the large global population in that pathway), as there are no explicit environmental regulations. Timber production is expected to continue in a cyclical fashion, with moderate differences between the SSPs with the exception again for SSP3 where production is expected to decline as land area declines, and *exports* follow a similar trend.

Although there are differences in magnitude between SSPs 1, 2, 4 and 5, the general direction for forestry is similar across these scenarios. The difference lies in SSP3, which is a fragmented world with very high population growth, low economic growth, low forest product demand, locally focused markets and limited land use regulations.

3.1.3.2. Organisational resilience. Organisational resilience is a useful lens through which to consider the resilience of each firm in the context of these wider challenges. Organisational resilience has been researched from many perspectives, but it broadly consists of assessing a business's level of ex ante preparedness or capacity to adjust, and its effectiveness in responding and adjusting when a disruption occurs (Korber and McNaughton, 2018).

There are different measures of operational performance that can be used to assess the organisational resilience of businesses. In this study, there were five categories adapted from Neugebauer et al. (2016) used to determine the solution space for forestry firms:

- Profitability. The ability to profit from product-related attributes to ensure economic viability. It includes aspects such as value creation, costs structures, liquidity, degree of indebtedness, and cashflow turnover ratio.
- Human and technological productivity. The ability to fully utilise human skills and technical capital in the business. It includes aspects such as technological improvements, efficiency, cost savings, and level of living standards for employees.
- Consumer satisfaction and social acceptance. The ability to maintain customer satisfaction. It includes aspects such as customers' willingness to pay as a function of utility, value-in-use, value-based selling, services and support, and reputation.
- Business diversity and complexity. The characteristics of the business structure. It includes aspects such as diversification rate, complexity of products, level of specialisation, dependency on natural resources, market demand, and weather conditions.
- Long-term capital and knowledge investments and planning. The ability to ensure constant capital stocks (e.g. general investments, reproducible capital, technical developments) and human capital investments over a longer time period to ensure self-reliance.

Within these categories, there are a number of management options or actions that can help a business to increase their adaptability and business continuity. Emmanuel-Yusuf et al. (2017) and Reeves and Levin (2017) suggest these include increasing redundancy, diversity in the workforce, modularity, adaptation capacity, planning and local integration. Redundancy refers to duplicating elements (such as having multiple factories that produce the same product) or by having different elements that achieve the same end. Diversity in the workforce creates an environment that fosters multiple ways of thinking and doing things. Modularity allows individual elements to fail without the whole system collapsing, albeit while forgoing the efficiency of a tightly integrated organisational design. They also suggest that adaptive organisations are designed for flexibility and learning rather than stability and minimal variance. Planning calls for developing contingency plans and analysing system vulnerabilities. Finally, local integration requires a business to articulate a purpose aiming at serving important societal needs to ensure that the company does not find itself in opposition to society and inviting resistance, restriction, and sanction.

The ability of a business to shape their adaptive space by implementing any of these management options is subject to a set of characteristics of its decision-making structure (i.e. governance) and resources (Bissonnette et al., 2017; Blanco et al., 2015; Gardner et al., 2001; Linnenluecke et al., 2013). For example, access to financial resources by small private forests owners can vary widely and are more affected than big operations (Isakson, 2015), also affecting their ability of increasing local integration by participating in consultation and policy-making initiatives. On the other hand, redundancy and modularity might be more difficult to achieve on a highly specialised, efficiency-driven business, while sole operators might not have the ability to be exposed to different perspectives in order to innovate but could also be more able to evolve through trial and error.

3.1.3.3. Technology. The solution space may be expanded by accessible technologies that (i) help to adapt to the impacts of climate change, e.g water efficiencies, disease resistance, weed control, (ii) improve production efficiencies in monitoring and assessment, (iii) reduce costs of forest management including acute events such as fire management and erosion and debris flow management systems or erosion resistant systems.

A range of emerging technologies have the potential to transform forest management, timber harvesting and production chain efficiencies over coming decades. Forestry management decisions will be aided by an increasing deployment of automated remotely and near-sensed data acquisition technologies, providing information on tree health, forest structure, climate, growth rates, nutrients, pest damage and fire (Zou et al., 2019). These technologies will deliver a huge volume of complex data, and in addition may be interpreted using data processing technologies that are increasing in power, such as artificial intelligence, neural networks and data mining. Forest managers in coming decades will be provided with an array of new tools to evaluate and optimise decision-making in response to changing environmental conditions. These developments may also be integrated with information from the forest production chain, for example, optimising timber harvesting times using analyses of market demand using block-chain technology, big data and AI, which are fed into processes that determine the standing stock of timber via remotely sensed forest inventory appraisals (Figorilli et al., 2018; Proto et al., 2020). These linked technological advancements will also encompass improvements in harvesting and planting efficiencies using robotics, contributing to new forms of 'precision forestry' which have increasing potential for greater resilience and resource use efficiency (Parker et al., 2016). Computational methods also have the potential to optimise transport networks by improving timber product chain routings so that carbon emissions are minimised, and operational efficiencies increased (Lam et al., 2010, Monge et al., 2019). Incentives will increase in coming decades for substituting fossil fuel derived feedstocks with woody biomass in high value biochemical product chains, particularly as the technological capability of this sector develops (Giurca and Späth, 2017, Suckling et al., 2018), potentially delivering additional economic capacity within the sector for adaptation. While genetic modification offers the potential to adapt to some climate stressors, current legislation in New Zealand does not allow for its use so this potential remains unavailable.

Overall, the array of emerging technological innovations affecting the forestry sector in coming decades has considerable potential to increase the decision-making space for adaptation to climate change by delivering greater information and tools to enable precision decision making, but these tools will only be available to forestry actors who are large enough to afford access to this technology and are able to influence its design.

3.1.3.4. Societal attitudes. Diverse groups in New Zealand are increasingly expressing concern regarding the perceived afforestation of productive agricultural land. The concerns are widely reported in the media yet afforestation is currently much lower than it was in the 1990 s and forested area is around 73,000 ha smaller than in 2000 (Ministry of Primary Industries, 2020). Community groups are concerned about the potential loss of employment, population and associated effects on the community and services if widespread afforestation and displacement of sheep and extensive beef farms occurred. Other societal concerns relate to the perceived lack of biodiversity in plantation forests, and the effects on water availability, as well as the environmental effects during and after harvesting. The aesthetic implications on the landscape of widespread changes in land use are a further concern for some groups. Other land-users are concerned that the relative profitability of forestry will lead to widespread land-use change (Harrison and Bruce, 2019).

Table 1
Drivers of the forestry solution space, with a brief description of the nature of their influence and the scale at which they originate.

Driver	Nature of influence	Scale of driver (global, national, firm)
Biophysical	Results in biophysical changes that present challenges to forestry production	Across scales
Institutional		
International cooperation on emissions reduction	Avoids the worst impacts of climate change and reduces the need for adaptation over the long-term	Global
Climate mitigation policy	Current policy relies on forestry as a Carbon sink and is thus favourable to forestry.	National
Environmental policy	Regulations that limit nutrients or water use may favour forestry. Regulations that restrict expansion into forestry or certain forestry practices could constrain the sector	National
Norms and values	May limit or enable action in the sector	Firm and national
Socio-economic		
Global futures, trade and markets	Global futures will determine the level and condition of international trade. Increasing population may increase demand for wood products and related products such as biofuels and biochemical. Increased concern for sustainability may require changes to practices and increased certification	Global
Organisational resilience	The structure and philosophy of a firm may influence their capacity to expand their solution space and increase their overall resilience	Firm
Technological development and transfer	Successful industries require development of and access to new technologies.	Across scales
Societal attitudes values	Societal attitudes to poor forestry practices may reduce social acceptability in some areas, limit conversions of farmland, increase local government surveillance.	National and firm
Culture	Cultural values will shape the way forest companies operate and their practices. Cultural values determine some of the social preferences.	National and firm

The main dimensions of the New Zealand forestry solution space are summarised in Table 1, with a description of the nature of their influence and the scale at which they operate.

4. The New Zealand forestry solution space

4.1. The solution space for New Zealand forestry as a whole

We develop an initial assessment of the solution space for New Zealand's forestry sector as a whole, based on the assessment carried out through literature and industry documentation, and complemented by expert opinion (Fig. 1), using the three dimensions described in Section 3. The solution space is bounded by the biophysical risks from climate change and the global socio-economic trends. Within the space, solutions arise from the ability to identify, plan for and adapt to changing risks.

Beginning from the left-hand side in Fig. 1, the darker shaded area is the likely solution space in the absence of proactive adaptation, planning and management. Currently in New Zealand, the space is relatively large, due to the generally favourable bioclimatic conditions and institutional environment. Some pressure on the space is occurring from declining societal acceptability. Over time however, the space narrows down without intervention due to the climatic pressures (acknowledging the potential productivity benefits from CO_2 fertilisation, which may keep the space wider than in the absence of that effect). Other factors that may further constrain the space in future include increasing societal pressure, a more tightly controlled domestic regulatory environment, and a global future with higher demand for food and lower demand for forest products. These factors and their timing are uncertain, but their occurrence will be influenced by the actions of the forest sector now. This leads on to the actions that could help to expand the space out into the lighter shaded area.

In the short term, management strategies to adapt to a changing climate may allow the sector enough space to continue operating current systems (Dunningham et al., 2012). At the same time however, planning for the longer term and identifying adaptations necessary to address future climate change should also begin now. Some of these adaptations may require long lead-times, for example investing in research into new varietals that may be more suited for future climates, or technologies that will support the sector. Investing in new locations around the country for future planting to create a portfolio of climates may be another option that requires longer term planning. Approaches such as adaptation pathways (Haasnoot et al., 2013; Cradock-Henry et al., 2020) may help identify and sequence actions over time.

These types of adaptations will have some success at expanding the solution space for forestry (e.g. long term planning in Fig. 1 allowing a range of actions expanding the space to occur over time as required), but some of the biophysical risks posed by climate change may ultimately prove limiting. Other factors however are much more malleable, if appropriate action is undertaken early on. Social acceptability, for example, could become either a constraining or enabling factor, depending on the way the industry engages with the public and other land users (green line/s in Fig. 1). Focusing on the critical importance of forestry as a carbon sink and one of the country's primary means of achieving its domestic and international climate change obligations may help to keep the institutional environment favourable for forestry. The forestry sector will need to ensure that they are proactive in adapting to the climate impacts to ensure the carbon stores are not lost through fire or other damage.

To some extent there is less that the sector can do to influence the potential global futures as conceptualised in the SSPs. However, diversifying trading partners, as well as products supplied, and developing strong relationships are all likely to be positive actions that will keep the solution space open regardless of the climate future. Developing domestic demand and processing for timber would also improve resilience if the international context changes (given the current dominance of

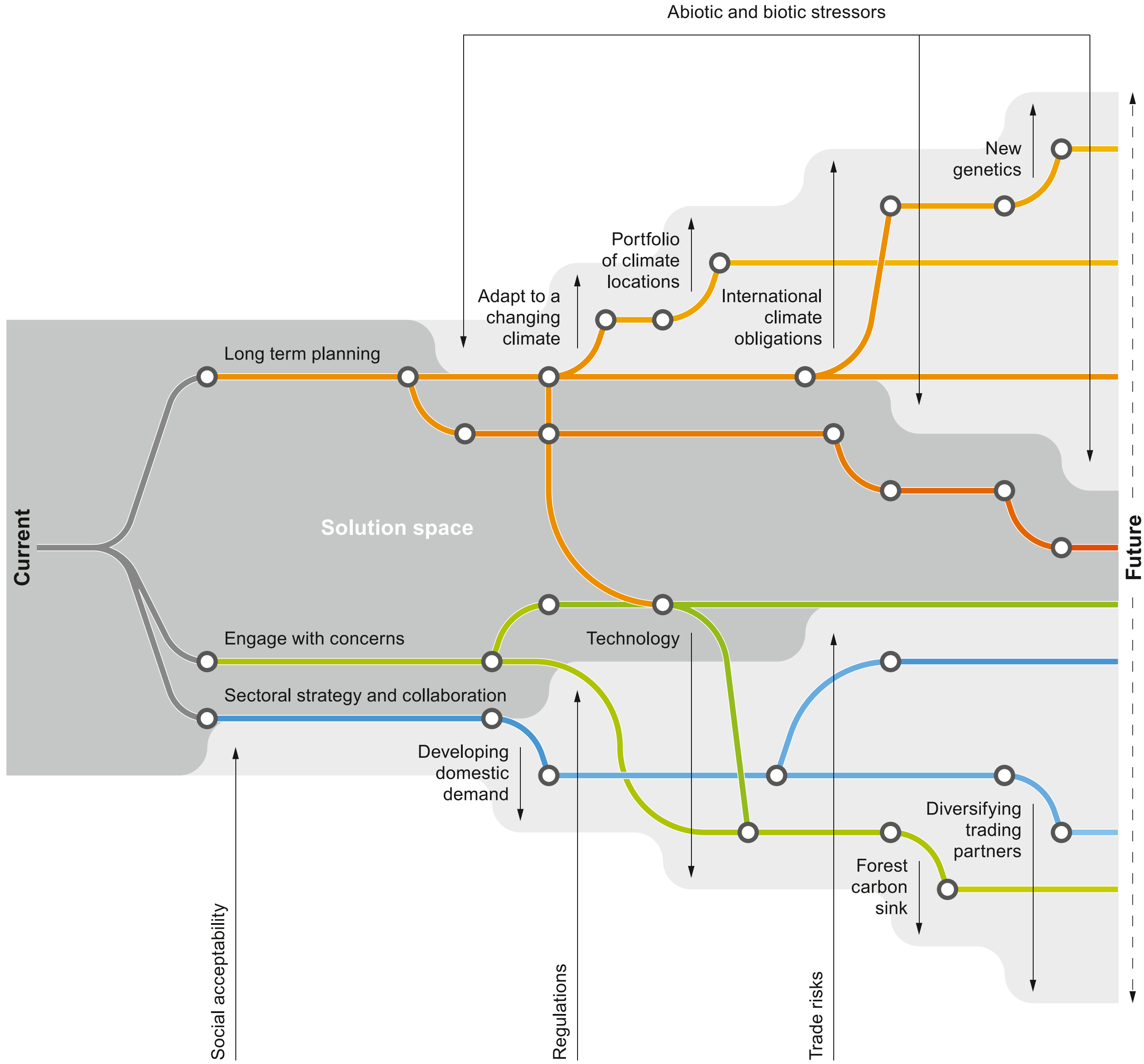

Fig. 1. A conceptual solution space for New Zealand forestry with an explicit temporal dimension. Opportunities are represented by outward arrows and help to increase the solution space. Constraints are represented by inward arrows that reduce the solution space. The dark grey area represents a solution space without any adaptation whereas the light grey area represents one with adaptation planned for and implemented over time (the current time period is shown on the left and the future on the right side of the figure). Beginning now, examples of potential options to increase resilience include long-term planning, engaging with the public and sectoral strategies and collaboration. Social acceptability is already constraining the sector, and over time the biotic and abiotic stressors exert increasing constraints. Regulation, possibly in response to the societal concerns, increases, and further into the future trade risks increase. The dark grey area becomes increasingly limited over time. The adaptation strategies, for example effective long term planning, allow decisions and actions to be implemented over time to expand the solution space. An absence of term planning means that the solution space decreases, remaining within the dark grey area. Long term planning could include investing in research for forest technology and improved harvesting strategies, that would be implemented when more stringent regulations are introduced, to expand the solution space (lower green line), rather than remaining static (horizontal green line). The planning also allows a range of adaptation actions to be implemented over time, continually expanding the space. By engaging with societal concerns (green line), the sector is able to expand the solution space compared with an absence of engagement. Ultimately this could lead to forests being valued as effective carbon sinks over time, with societal support. A coherent sectoral strategy and collaboration, beginning now, could expand the solution space to ultimately diversify trading partners and minimise the risks posed by changing international trade agreements.

exports to China) (Monge et al., 2019). Further detail is provided in the figure's caption.

In the following section we examine the different types of forest owners and their capacity to influence the solution space.

4.2. Solution spaces by forest owner

We discuss the implications of the dimensions of the solution space for each forest owner category and their capacity to influence the space, based on literature and expert opinion. A summarised assessment of the key dimensions and characteristics of forest managers critical to influencing the solution space is provided in Table 2.

4.2.1. Non-industrial/lifestyle

These forest managers will have some potential to be flexible and adaptive in their planting strategies, but they will be locked into the

Table 2
Preliminary assessment of each forest owner type's potential to expand their solution spaces by driver/ characteristic.

Forest Owner Type	Flexibility	Diversification (of species or landuse)	Ability to adapt practices	Operational resilience	Technology	Social acceptability of type
Non-industrial, lifestyle	high	high	med	low	low	med-high
Entrepreneur, mixed	high	high	high	med	med	med
Industrial	low	low	med	med	high	low - med
Māori Trust	med	high	med	high	med	high
Māori small, multiple ownership	high	high	med	low	low	high

typical 20–30 year harvest rotation length for *P. radiata* within New Zealand. They can choose to harvest early if conditions are unfavourable. The small size of the operation means that protective measures (e.g. shelter belts, nurse trees) could be put in place against some of the climate impacts.

The small size and access to capital of this management group means they will potentially have a low level of access to transformational technology. These limits mean that they will have a low level of influence over technological design and implementation. The overall benefits of such technology will be limited for these users.

While this group is likely to be less driven by efficiency and be highly flexible, in terms of other aspects of operational performance (Neugebauer et al., 2016) the group is less likely to have attributes that would contribute to improved performance and increase the solution space.

In terms of institutional drivers, this group is likely to be influenced by the norms of their peers, which may be allow them to try new approaches but may also be relatively conservative. They are likely to benefit from policies promoting afforestation and may expand their forested land. Small forest owners, despite their large numbers (estimated at about 10,000 owners based on NEFD, 2019) have no formal communication channels or representatives while some are not members of any forestry associations.

Key strengths: potentially agility and flexibility, able to try different management practices and species and diversify sources of income.

4.2.2. Entrepreneur/mixed

The small size of these operations means that some flexibility in planting strategies is potentially available, but management decisions are locked into the typical harvest rotation length of 20–30 years for *P. radiata* in New Zealand. Economic incentives may allow decisions to choose to harvest early if conditions are unfavourable.

Depending on the technology, larger and more agile users may be able to rapidly adopt and influence the deployment of some technologies (e.g. sensor networks (Bayne et al., 2017), big data and UAV, Blockchain, and Remote sensing). The small size of these users generally means that they will have limited capacity to adopt and influence the deployment of other technologies (e.g. automation and robotics, big data, remote sensing, AI & neural networks, gene editing, low carbon logistics, supply chain coordination, biofuels and biorefineries).

This group may have some degree of specialisation and efficiencies, together with a high degree of flexibility, which may allow them to expand their solution space. However, like the lifestyle group, they have fewer options to diversity their workforce and are unlikely to have sufficient volumes for modular production.

This group is likely to be more innovative and adopt new practices for adaptation. Those with mixed operations may expand their forestry portfolio depending on the incentives for forestry and the pressures on other land uses.

Key strengths: Agility and flexibility, ability to switch land-uses, early adoption of new practices and strategies. These owners would not only be able to build redundancy into the system and diversify sources of income, but unlike the lifestyle group, are more likely to have the resources to collaborate in joint initiatives, such as exploring new value-added alternatives or participate in policy-making processes.

4.2.3. Industrial

This group has some flexibility in planting strategies, but are locked into harvest rotation length. Moreover, their capacity to adapt is also constrained by market dynamics and existing infrastructure associated with delivering the product chain.

This group has a high potential to expand their solution space through technology, having a high degree of influence over design, implementation and deployment of almost all potential technologies (within the current regulatory environment).

Industrialised growers are generally more efficiency driven than some other types of managers, and possibly have less capacity to build 'slack' into the systems. They do have opportunities to develop diversified workforces, and the potential to achieve the desired organisational culture.

Established forestry companies are often foreign-owned, and tend to operate a conservative business model, with the primary driver being the return-on-investment. They may have quite rigid planning horizons, which may make them less adaptable to anticipated changes. Like other forest owner types, they are likely to benefit from afforestation incentives.

Traditionally these types of owners operate mono species plantations, primarily the non-native tree species *P. radiata*. This type of system may be less resilient to climate risks than more diversified forests. They also are the subject of most of the public concern regarding the perceived negative impacts of forestry. Therefore, while this group has a relatively high space to operate in from a technological and economic sense, their space may narrow more than other groups' due to the institutional restrictions and social pressures.

Key strengths: ability to invest in and influence technology for adaptation; ability to withstand some biophysical losses; potential to develop new markets and products, ability to build modularity and diversity in their system, ability to foster diversity in their workforce, financial resources to participate in policy-making.

4.2.4. Māori trust

Due to a wider set of aspirations, e.g. cultural and inter-generational, this group are likely to have a more diverse portfolio of species in their forest stock, particularly native species with longer rotation periods (Monge et al., 2018; Pizzirani et al., 2019). This potentially locks this group into greater harvest rotation lengths than other forest managers, but slower growing native tree species may have greater resilience to climate change stressors than non-native pine species typically grown in industrialised forestry settings.

The capacity of this group to influence technological development and deployment is variable, dependent on the size of the organisation and associated governance structures, as well as the professional forestry consultant or manager.

This group is likely to have some degree of specialisation and efficiencies, while retaining a high degree of flexibility. There are likely to be different perspectives on the governance board, which could increase resilience. This group is also likely to have a diverse workforce. It may have the scale to make production modular and may be able to expand their forestry operations.

This group is likely to have a moderate influence over some forms of technology (e.g. sensor networks, big data, blockchain, remote sensing and UAVs) but a limited capacity to uptake it, depending on the size of the business.

Key strengths: due to the potential species diversity, this group may face less social resistance. They tend to have longer planning horizons than other forestry typologies, considering future generations, which may enable them to keep their solution space more open into the future. They combine the flexibility of the Entrepreneur/mixed typology but could also have the scale and resources of the industrial typology.

4.2.5. *Māori, small, multiple owners*

This group may be incentivised to plant a more species diverse forest stock, including native species which would have a greater potential for climate change resilience. Further protective measures (e.g. shelter belts, nurse trees) could be implemented within small scale operations to mitigate some climate impacts such as wind. These forest managers will be locked into the typical 20–30 year harvest rotation length for *P. radiata* within New Zealand if they chose to plant this species. They will have the flexibility to choose to harvest early if conditions are unfavourable, but this flexibility is reduced if decisions to grow native tree species are made. The size of their forest farms (<50 ha) is not conducive for participating in the ETS.

The small size and low access to capital means that this group will have a low level of access to the range of emerging technologies. They will have limited potential to influence the design and implementation of new technologies, meaning that the benefits of such technology will be limited for this forest management group.

This group is likely to be less efficiency-driven, and highly flexible. They may have a diverse workforce, but a potential lack of coordination. They are unlikely to be able to influence or implement many forms of technology, so this is unlikely to allow them to expand their solution space.

Key strengths: similarly, to the Māori Trust typology, this group may face less social resistance due to the diversity of species and objectives of their forestry operation. Like the lifestyle typology, they could develop agility and flexibility in their system (through diversifying their tree species).

The dimensions and typology characteristics that are key to influencing the solution space by forest owner type are presented in Table 2, with an assessment of the level (low, med, high) of capacity to utilise each.

5. Conclusion: towards a roadmap for the future

This assessment has the ultimate underlying aim of identifying how the New Zealand forestry sector is positioned proceeding into an uncertain future. How can the diverse groups of forest owners understand and plan to maximise their space to manoeuvre faced with myriad dynamic challenges, opportunities and constraints?

Our initial assessment provides some reflections for the different types of forest owners and the industry as a whole, as a basis to begin to understand the capacity of current business models to face future challenges. We have outlined some actions that the sector could take now and over time to increase their resilience to climate stressors.

Our assessment highlights that each forest owner type has different areas where they can expand the solution space. It is worth considering what collective initiatives could be established by combining the different strengths across the diverse sectoral groups. There may be opportunities from collaboration to reconcile divergent perspectives, interests, and options to expand the overall solution space for forestry.

The solution space for forestry exists and interacts with other solution spaces, particularly other land-uses including food production. The expansion of the forestry space may result in a contraction of the agricultural space. Further work would involve developing a joint or complementary space for land use in New Zealand.

We suggest that research into a greater understanding of the barriers to expanding the solution space will be essential to opening the space for forestry to manoeuvre into the future. Our initial assessment identifies a range of barriers across ownership typologies and scales. At the policy/strategic level, the lack of an overarching coherent forest policy in New Zealand presents a barrier for longer-term research as well as a lack of certainty for land-users and decision-makers. Uncertainty and inconsistency regarding existing policies and mechanisms create further barriers – for example, the inclusion of forestry in the ETS but the current exclusion of other land uses. Engaging collectively with policy initiatives will be important to ensure the space for action is not constrained, particularly now when the policy environment is evolving rapidly.

As in all aspects of decision-making when human behaviour is involved, several behavioural barriers exist across the scales of ownership, from social norms and practices through to corporate practices and risk perceptions. Sectoral bodies have a role to play in supporting owners and managers to overcome some of the barriers that may be hindering effective action. The New Zealand Forest Owners and Farm Forestry Associations are instrumental in shaping and navigating the solution space. Building on their current partnership with the government and their levy-funded research strategies, they can support the small forest owners' needs (particularly Māori) and extend the research and technological advancement in partnership. This includes identifying adaptation options appropriate for each forest owner type.

While the absence of certain technologies (such as genetic modification) presents a barrier to adapting to some climate risks, its presence may increase other constraints such as social acceptability and access to some markets (Saunders and Cagatay, 2003), so the net effect is not obvious.

The research community can contribute to a more detailed exploration and planning of the future solution space through working together with the sector across scales and ownership types to jointly identify a detailed plan for the future. This may involve hindcasting exercises to work backwards from an ideal state to identify what actions need to occur in order to that state. It is likely also to involve identifying triggers and thresholds for action (Stephens et al., 2018), in order to handle the uncertainty of climate change in a flexible and agile way. Further work understanding the relative costs and benefits of different adaptation actions, as well as an assessment of the damage costs if adaptation does not occur is also essential foundational work to build on. This would enable the development of graphs with detailed solution spaces for different scales and ownership types similar to the one shown in Fig. 1.

CRediT authorship contribution statement

Anita Wreford: Conceptualization, Project administration, Formal analysis, Writing – original draft, Writing – review & editing. **Andrew Dunningham:** Formal analysis, Writing – original draft. **Alan Jones:** Formal analysis, Writing – original draft, Writing – review & editing. **Oscar Montes:** Formal analysis, Writing – original draft. **Grace Villamor:** Formal analysis, Writing – original draft, Writing – review & editing. **Juan J. Monge:** Funding acquisition, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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