# Social Extension of Quantitative Portfolio Framework – Literature Review

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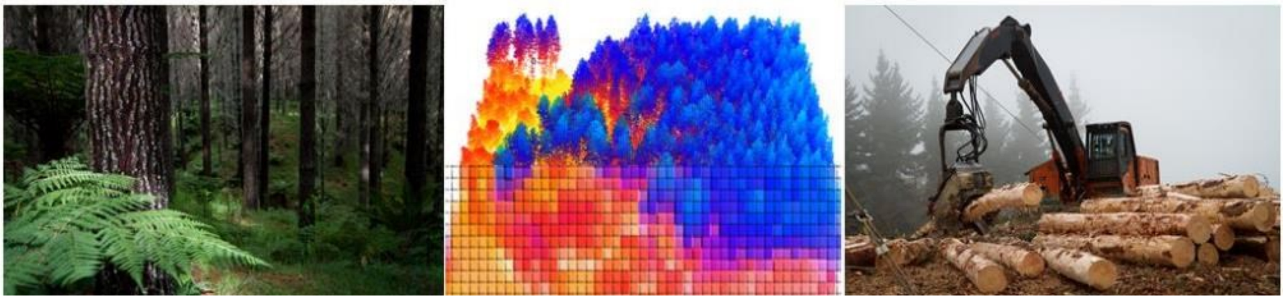

**Date:** 15/06/2021

**Report No:** RFP-T013

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# EXECUTIVE SUMMARY

Forest management decisions are made in the face of market, biological, social and climatic risks. The application of modelling techniques that explicitly account for risk and uncertainty can result in more robust decision making in which a collection of management options is selected as optimal, rather than a single strategy. Modern portfolio theory is a decision-making tool that can be applied to forestry. It utilises computer modelling of the variance of levels of future risk versus expected trade-offs in economic performance. Decision-making using this technique is able to identify options that minimise risks for acceptable levels of return, or maximise returns for acceptable levels of risk. Forests are also managed for a wide range of economic, environmental and social benefits which could potentially be quantified and modelled in a similar way. Increasingly forestry management decision support systems are being used to develop strategies that result in more resilient forests to better provide these benefits.

This report provides a summary of a literature search undertaken as the first stage of an investigation into the incorporation of the social dimension of forest management into quantitative decision making in general, and in particular using modern portfolio theory and similar approaches.

There is a large literature on optimisation of ecosystem services from forests, but social and cultural elements are seldom covered adequately and are often excluded altogether. Employment is frequently the only social criteria adopted because it has many of the attributes required for quantitative modelling, being quantifiable and scalable. Clearly the social and cultural benefits provided by natural and forested environments extend beyond employment. The recreational, aesthetic, health and spiritual values associated with forested landscapes and their natural settings are difficult to capture and quantify and cannot be represented with a single “social license to operate metric”. Differences in expected values and variance of these factors that arise under alternative management options are also difficult to determine. However, there is scope to identify key social concerns relevant to New Zealand forest management and formally capture these within the planning process.

# INTRODUCTION

Forest management decisions are made in the face of market, biological, social and climatic risks. Explicitly incorporating these risks in the decision-making process creates the opportunity to future-proof forests, giving potential investors more confidence to undertake afforestation projects, such as those needed to achieve the goals of the One Billion Trees programme and Zero Carbon Target. We hypothesise that implementing a diversification of forest management practices will provide greater resilience to future uncertainties.

RA1.1 of The Resilient Forests research programme will integrate novel social and biological systems models into modern portfolio theory to assess the impacts of different diversification strategies on overall resilience, using *Pinus radiata* as a test case.

Our aim is to develop a quantitative method for decision-making that will integrate the biological and economic uncertainties, focusing on bio-physical and price risk. We will build on this to include social and cultural risk within the quantitative modelling framework.

This technical note provides a review of the literature relating to the inclusion of social objectives, constraints and risks within quantitative modelling systems for decision making, particularly in reference to modern portfolio theory.

## Objectives

The aim of this work was to investigate how a quantitative modelling method assessing trade-offs between biophysical and economic risks can be extended to include social risks. This would allow identification of optimal management alternatives that integrate social drivers of influence, rather than a portfolio framework being solely based on economic criteria.

Objectives to be addressed:

- Are there social aspects to forest management that need to be considered in the forestry decision making process?
- Have these social aspects been successfully incorporated previously within a quantitative portfolio theory framework in (a) forestry or (b) other industries?
- Have these social aspects been incorporated within other quantitative decision management methods in (a) forestry or (b) other industries?
- How can social aspects be included within the quantitative portfolio framework developed in RA1.1?

# METHODS

An initial literature review of the role of decision support models in forest management was undertaken, together with a separate review of social risks relating to the forest industry in New Zealand. The latter draws on work assessing factors affecting forestry's social license to operate, carried out both within and outside the Resilient Forests programme.

A further literature review focused on the ways that the social dimension and risk have been captured in quantitative modelling, particularly within modern portfolio theory and stochastic optimisation approaches - decision-making tools that account for probability and variance in variables affecting system performance – that can be applied to forestry.

Keywords were compiled to include a broad range of modelling approaches and primary and extractive industry domains, together with conservation and environmental management (Figure 1). The search was restricted to literature published in the last ten years, with further publications obtained through citations linked to this existing literature base.

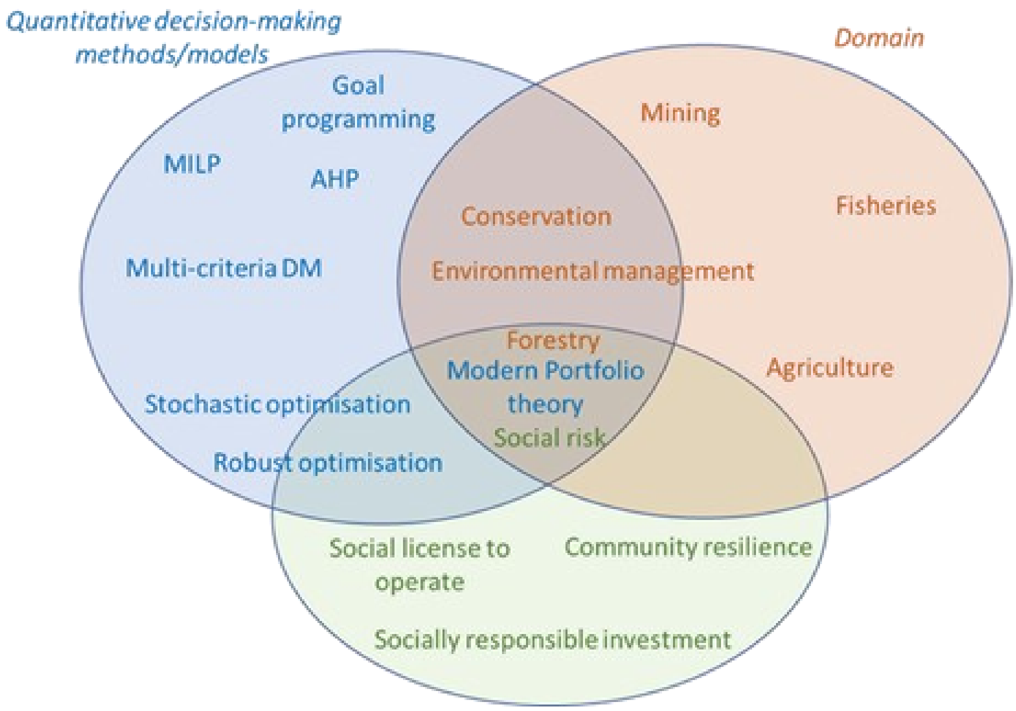


**Figure 1. Coverage of literature review - keywords**

# RESULTS

## Forest Management

Definitions for “forestry” and “forest management” have changed over time as the profession and practice of forestry has evolved. Chazdon et al. (2016) provide an historical overview starting with the development of theory-based sustainable timber management in Germany in the 18th Century.

A key development in the early 20th century was the concept of multiple use forestry. This was a utilitarian concept driven by concern over the over-exploitation of forests on public land. Gifford Pinchot, influential as the first Chief of what is now the USDA Forest Service and often referred to as the father of American professional forest management, believed that public forests should be managed to achieve the greatest good, for the most people, for the longest period of time. At this time conservation was understood to mean conserving resources for future use, rather than preservation. The multiple use concept was adopted by the New Zealand Forest Service, leading to recreational facilities being provided in both indigenous and plantation forests (Roche 1990). However, segregation of uses through zoning was more usual, with no expectation that all areas of forest would provide the full range of potential benefits.

In 1993 the General Guidelines for the Sustainable Management of Forests in Europe, signed as part of the Helsinki Resolution[1], defined “sustainable forest management” as “the stewardship and use of forests and forestlands in such a way and at such a rate that maintains their biodiversity, productivity, regeneration capacity, vitality and their potential to fulfil, now and in the future, relevant ecological, economic and social functions at local, national, and global levels and that does not cause damage to other ecosystems" (Schuck et al 2002).

In Europe and North America, forest management definitions have over time encompassed a broader remit, with attention not just on sustainable timber production, but also the delivery of non-timber forest products, biodiversity conservation, ecosystem services delivery, human well-being, landscape approaches, adaptive management and socio-ecological resilience (Chazdon et al 2016). The ecosystem services approach to forest management also recognises four sets of benefits (Table 1):

**Table 1. Four types of Ecosystem Services**

| ES Type | Examples |
|---|---|
| Provisioning | Timber and non-timber forest products |
| Cultural | Spiritual, religious, aesthetic, and recreational needs |
| Regulating | Air and water quality, climate, erosion control |
| Supporting | Production of oxygen, soils, habitats |

In New Zealand the NZ Forest Service was disestablished in 1987 with a subsequent privatisation of State forests. There has been recognition since that industrial plantations should continue to provide multiple environmental and social benefits. Impetus for this includes forest Stewardship Certification, the Emissions Trading Scheme and local and central government policies and regulations, such as the National Environmental Standard for Plantation Forestry as market-based and regulatory interventions.

[1] https://www.foresteurope.org/docs/MC/MC_helsinki_resolutionH1.pdf

## Forest Management Decision Support Systems

Quantitative decision support tools have been applied in forest management for decades, recognising that trade-offs between risk within economic and non-market returns have been an ongoing concern.

Optimisation models in particular have been extensively applied in the forest industry for over forty years. Applications of these methods vary widely in terms of the scales of time involved and focus areas covered. For example, the age class distribution of the forest may be modelled over time in response to simulated activities such as planting, harvesting and replanting, allowing annual flows of inputs and outputs to be modelled. Within such models, forest management decisions are appraised, including decisions on what to plant and where, where and when to harvest, and what silviculture to implement. (Ronnqvist 2003; Kaya et al. 2016). There has been a trend of increasing scale and complexity of these forestry models, with increased integration of data sources including GIS. Non-market services are more frequently considered alongside multiple-objectives such as securing long-term sustainable yields from productive forest (Vacik and Lexer 2014).

In commercial forestry it is common to formulate optimisation problems involving functions that maximise economic profit. Other forest management objectives are often considered to be constraints on this, simply because the range of forest ecosystem services are not readily translated into economic terms. This is especially the case for social and environmental factors.

The impact of risk and uncertainty on decision-making has been incorporated using stochastic models, which are specifically designed to account for this. Where this appraisal takes place management strategies with a high expected value of economic return may not be preferred, if they also contain significant negative risks.

Forest estate management optimisation tools used in New Zealand include FOLPI (Manley et al. 1991) and Woodstock (Remsoft). These forest estate modelling tools enable a wide range of ecosystem services to be modelled and expressed as part of the intended objectives or inherent constraints. Anything associated with a forest management activity, information describing a forest area or forest age class can be incorporated, including multiple land uses. For example, FOLPI was used to compare forestry with agroforestry and farming, in terms of revenues, labour requirements and erosion control (Knowles 1989).

Hildebrandt and Knoke (2011) investigate the difficult long-term character of forestry investments in a methodological review of decision making under uncertainty. Approaches include a range of methods that account for stochastic factors, market volatility and risk, using an understanding of their variance. These include stochastic dominance, mean variance analysis, option pricing and robust optimisation. Reviews of Multi-Criteria Decision Analysis tools and methods are provided by Diaz-Balteiro and Romero (2008), Ananda and Herath (2009), Velasquez and Hester (2013), Segura et al (2014), Uhde et al (2015), and Ortiz Urbina et al (2019).

## Social issues in forestry

The social licence to operate of an industry is the degree to which public attitudes and perceptions of the impact of its activities are considered acceptable. This concept applies across primary sectors, and has been particularly related to acceptability of extractive industries such as mining, but this social influence can also affect land and sea based primary production. The social and environmental impacts of developments can affect marine or forestry operations if they become unacceptable to communities. These issues have been found to reduce the return on investment in mining operations by up to 70%.

Some New Zealand forest management practices create social impacts, that can affect the industry's licence to operate, such as:

- Human health and safety in operations, including logging truck and harvest accidents;
- Visual amenity and clear-fell logging, including residue known as slash spoiling landscape views and posing environmental hazards;
- Post-harvest erosion in steeplands including slash and sedimentation, leading to water quality and debris impacts downstream.

Other aspects of forestry that may concern local communities are related to externalities such as market volatility or closure, reducing employment, human or biotic biosecurity risks; and effects of climate change such as extreme weather, pest and disease and fire risk. Land use change and afforestation policies may also impact on forestry's social licence to operate, depending on where and how forests are planted.

**Incorporating social issues in quantitative modelling frameworks for forest management decision support**

One of the ways to think about how to translate the social acceptability of forest management practices is to consider these factors as assets. This method has been applied previously in the USA to characterise the elements of social acceptability around five factors: perceptions of risk and uncertainty; personal and technical knowledge; trust in managers (including regulators and enforcers); visual and other aesthetics; and social and environmental impacts. This creates an opportunity to explore levels of concern or scales around quantifiable factors that could be mapped over time and different issues or scenarios of forest management activities such as steep land harvest and use of chemicals in production.

Rather than assume a linear relationship of growth in social acceptability as an asset (although this could potentially be done with increased social, cultural and environmental values generated through forest development), it could be seen in a state of balance. When tipped out of balance, severe costs to an individual company or the industry can occur from devalued levels of social acceptability, which is a risk to be avoided. Managers of forests can take steps to build this asset via: building trust, strengthening relationships, understanding concerns, responding to perceived problems, and open communication, in order to build social capital. A different return on investment may be realised through generating direct and indirect benefits to communities and what they value.

Creating a framework that values ecosystem services alongside the economic values that forests provide is another way of monetising value. Quantification of these elements can help to characterise the relative value of non-market values against economic returns. Importantly, the benefits of meeting community expectations around forest services, including provisioning, cultural, supporting and regulating services can ensure that production forests retain their social licence to operate.

Wyatt et al (2011) analyse various social concerns on forest vegetation management in Canada and consider how these could influence choices in various situations. These concerns are situated within the broader context of forest decision-making. They outline the fundamental concepts involved in understanding the nature of social values, attitudes and social acceptability in forestry. They also summarize the effects of: information about management actions, trust in resource managers, and public participation in forest decision-making.

Harshaw et al (2007) found that social indicators used in Canadian forest management were weakly developed compared with economic and environmental indicators.

## Modern Portfolio Theory in Forestry

Modern portfolio theory is an approach to maximising expected returns where risk exists and the investor or manager is risk-averse (Markowitz 1952). It is based on the relationship between risk and return and the covariance structure of each, such that an optimal portfolio of investment options can be found that offers the best return for any given level of risk.

Kolm et al. (2014) review applications and trends in portfolio optimisation in practice in the financial sector. They note the difficulty in estimating returns and covariances for even a single period, making multiple period models impractical as well as computationally intensive.

Modern portfolio theory has been applied widely outside the financial sector from its introduction. It has been used in appraisals of performance for fisheries, forestry, agriculture, spatial planning, invasive pest and disease surveillance, climate change adaptation, and biodiversity conservation (Alvarez et al. 2017).

In situations where multiple management options are available and each has future payoffs and associated risks, each option is treated as an asset. A portfolio of assets represents the management options chosen for implementation, such as alternative silvicultural regimes or species. Alvarez et al (2017) highlight the ways in which natural resource managers differ from financial portfolio managers, chiefly because they consider longer time horizons and inclusion of non-monetary goals. Thus “asset returns” may be recreation opportunities or any other ecosystem value, and where they cannot be easily expressed in monetary units it may be better to use more natural metrics, such as visitor days. However this can give very different results where social benefits have a non-linear relationship with the physical metric used to represent return, and where they may limit the return on investment due to a loss of social licence.

Managers are often more concerned with negative risks than the whole variation of possible outcomes throughout a statistical distribution – the potential for unexpectedly good results does not need to be mitigated. To address this, ‘lower partial moments measures’ are commonly used to appraise negative risk measures in modern portfolio theory applications (Alvarez et al 2017).

Of the 16 examples of empirical natural resource portfolios tabulated by Alvarez et al (2017), only two considered social elements:

- Hills et al (2009) used categorical measures of return (and risk) developed through a participatory approach to optimise ecosystem services provided by seascapes.;
- Halpern et al (2011) looked at the trade-off between resource use and social equity across space in fisheries management.

Matthies et al (2019) provide a review of the application of modern portfolio theory in environmental research and an extension of the framework provided by Alvarez et al. (2017) to better consider the special features of natural resource management, such as the wide scale and multiple decision-makers.

Neuner et al. (2013) apply the theory of portfolio selection to a private forest enterprise in Germany, in a useful introduction to practical applications. The portfolio theory assists in finding a financially optimal combination of at least two different assets. In this case tree species are regarded as financial assets or components in a portfolio. Their analysed portfolio consisted of eight tree species.

According to Markowitz (1952), an adaptive mixture of risky assets can achieve a reduction in the possible range of portfolio yield deviation, thereby reducing overall risks to return on investment. The resulting portfolio consequently achieves a lower risk for a given yield or a higher yield for a given risk when compared with the performance of its individual constituents. This result is eloquently summarized by Markowitz’s definition of the ‘diversification effect’.

Neuner et al (2013) provide an example and calculate the optimal composition under financial and risk aspects (fluctuations in timber prices and the risk of calamities) for this particular forest enterprise with modern portfolio theory. The six steps to derive optimal tree species composition were:

1. Definition of the portfolio components: Depending on aims and circumstances this may include different tree species (i.e. different growth rates and risks), different regimes (pruned, unpruned), different establishment (number; artificial/natural regeneration).

2. Simulating growth data: The natural data of the stand development of different tree species is simulated by a stand growth simulator integrating specific site and growth conditions but also certain treatments of silviculture.
3. Grading of logs: Simulated timber volumes of the harvested stems must be graded depending on specific criteria.
4. Financial assessment: From the priced timber volumes, less logging costs and the expenses during the stand life (establishment, pruning…) expected cash flows for the considered stand types can be calculated and transformed into annuities via application of an appropriate interest rate.
5. Integration of risk: volatility of timber price and risk of calamity modelled with Monte-Carlo simulation; SD is taken as an analogue for risk; The Value-at-Risk (VaR) and Lower-Partial-Moments nth order (LPMn) are important examples. Interdependencies and correlation were considered in various forms: via bootstrapping the historic correlation structure between the timber prices of all considered tree species was retained. The often-observed immediate effect of calamities on the timber prices was accounted for by reducing the net revenue flow after a calamity by 50%. New approaches should thus also test tree species portfolios under various future scenarios. An alternative would be to apply robust optimization techniques.
6. Portfolio optimization: Depending on the number of iterations in the Monte-Carlo simulation, a frequency distribution of the calculate annuities results for each of the considered types of stands. From this distribution, the above-mentioned risk measures can be calculated for the stands and serve as a basis for the portfolio optimization. A portfolio is assembled, by which the target function is fulfilled.

In this case 55% of their portfolio was formed by more profitable tree species (i.e. Douglas fir, Norway spruce) and 45% by species that lowered overall risks (Scots pine, Larch and hardwoods), with robust optimisation being considered as the most promising option for future research. A constraint of the approach shown in this study is that both timber prices and the probabilities of failure are based on historic data. Aside from market fluctuation and transient fashion, both of which are difficult to predict and have a strong effect on the price of timber, the probabilities of failure caused by calamities are likely to vary due to changing environmental conditions as a result of climate change.

In earlier work, Reeves and Haight (2000) focused on maximizing economic revenue and taking into account different financial risks (optimal forest plans with loblolly pine under different levels of allowable risk. Plans are expressed as the proportions of the forest assigned to different management regimes). They calculate different rotation ages and outcomes (sawlog and pulpwood and likelihood of price regimes).

Figge (2003) explains the principles of portfolio theory on biodiversity. He describes biodiversity as an asset whose value is deducted from a future flow of benefits. Secondly, portfolio management is concerned with the question of the optimum composition of a portfolio of different assets (analyst vs. portfolio manager view). Portfolio theory allows comparison of the expected return of a portfolio of genes, species or ecosystems with the expected risk. He gives examples of combining different species to construct a portfolio with an optimised risk–return ratio by optimising the mix of genes, species or ecosystems in the portfolio.

Knoke (2008) finds that mixed forest ecosystems outperform pure forests (in this case: Norway spruce vs. mixture of Norway spruce and European beech). The study compares three different models (mean-variance, second order stochastic dominance, and the information-gap approach) and their financial benefits via net present value. The information-gap approach was felt to be most promising.

Hildebrandt et. al (2010) assessed mixture of two species (Douglas fir and Rauli (*Nothofagus alpina*)) in Chile under financial aspects under uncertainty with different risks scenarios. The approach was to investigate differences in volume growth of mixtures of large blocks and single tree mixtures of both species.

Campos et al (2017) investigate multifunctional silviculture in natural forests (not plantation). They provide a summary of the status of published research on silviculture geared to multifunctional forest management and economics, especially in two examples, Spain and California (oak forests with hunting and grazing). They summarize multiple-criteria decision-making approaches and compare the Economic Accounts for Forestry with the more holistic, extended, scientific Agroforestry Accounting System. Also, a summary of self-consumption of e.g. non-timber forest products and public forest products (environment, recreation, carbon, water). The spatial variability of ecosystem services of forest is one key aspect here and several examples are cited.

Messerer, Pretzsch and Knoke (2017) introduce a new, non-stochastic, robust portfolio model optimisation approach in forestry and compare it to a classical portfolio optimization (i.e. mean-variance portfolio optimisation). Their study demonstrates the high-performance of a robust optimization approach for forest management planning. It can be performed based on very limited data. The context of their study is a possible transition from even-aged forestry to continuous cover forestry. The portfolio scenarios consist of two species (Norway spruce and European beech) and different rotation ages. The land allocations of different ages cohorts and species within these non-stochastic portfolios were distributed more evenly for changing uncertainty levels compared to those from stochastic optimization. They concluded that non-stochastic portfolios become more diverse, if decision-makers expect increasing uncertainties, represented by larger sizes of uncertainty spaces considered. The greater the considered uncertainty spaces, the more diverse are the resulting portfolios.

This also means that considering rather large uncertainties is aligned with uneven-aged forestry strategies. If forest owners instead expect uncertainties of limited size, they would rather tend to an age class management system, although still with diversified harvesting spread over several time periods.

Their results show that non-stochastic portfolio optimization may support forest management decisions successfully, even when various rotation age cohorts are part of the optimization problem. Further research is needed to integrate ecological effects among tree species and other biodiversity aspects into management decisions.

Knoke, Messerer and Paul (2017) give a review of different studies that interrelate differences between economic diversification and multifunctionality. They also review drivers and consequences of diversification like time or subsistence. The results show several strengths of economic diversification in forest management. Diversification can reduce economic risks and increase economic return and subsistence what different studies show.

They provide an example calculation using robust optimisation approaches, showing that with improved, robust optimization approaches, diversified forest portfolios will emerge that provide improved levels of multiple ecosystem services (a so-called ‘multifunction effect’). This approach allocates land proportions to forest stand types in a way that minimizes the greatest (worst) deviation from the maximum ecosystem service level achievable by the options considered. The approach does not allow for compensating factors among ecosystem services and requires high (minimum) levels for each single indicator.

They compare the optimization results (tree composition) for the single service of economic return with that obtained when considering multiple services. However, it becomes clear that the optimal levels of multiple ecosystem services will not result from economic optimization under uncertainty alone, as ‘wake theory’ would suggest. In fact, the mean annuities will reduce by 45% to achieve optimal multifunctionality. The reduced risk of the multifunctional forest portfolio hardly provides appropriate compensation for this economic loss. Improved optimization could possibly find strategies to reduce these costs.

Dragicevica (2019) investigates the economic performance of *Pinus pinaster* monocultures in France, comparing it with an array of other land use opportunities in that region (agriculture, agroforestry, solar energy). The optimal land-use allocations derived by this study are based on two models from the literature on portfolio theory, i.e. the Markowitz mean-variance model and the conditional-value-at-risk (CVaR) model. Several non-market risks are considered, such as calamities in different asset classes. Historical data and Monte Carlo simulated data are both compared in the study.

Risk is shown to be generally minimized with greater portfolio diversification. In the case of Monte Carlo simulated data and mean-variance method, under low risk scenarios solar energy is by far the dominant asset. In contrast, fruits & vegetables dominates at the CVaR model approach.

Dragicevica concluded with a future work recommendation that other assets should be analysed including mixed forests to enhance both tree productivity and forest stability against natural hazards.

Paut et al (2019) applied modern portfolio theory to diversified horticultural systems.

Modern portfolio theory shows how risk can be reduced when several assets are combined together in a portfolio, and when asset returns are not perfectly correlated. In this case, diversifying the portfolio represents a shift from monoculture to a combination of crops: modern portfolio theory is used to explore different crop mixtures and study their impact on risk and return of the generated portfolios.

In this case 44 crops were selected and portfolio combinations involving two chosen crop species were calculated - 946 crop combinations in total. Interactions between the crop species themselves are not taken into account, so these portfolios should be considered as appraisals of cropping patterns at the farm scale, rather than at the field scale. However, preliminary work in this direction showed that intercropping could lead to both a reduction of risks and yield increases since most crop associations lead to an overall increase in production.

The risk inherent with a portfolio is expressed as the standard deviation of the expected portfolio return (σ). Portfolio variability depends on the proportion and the variations of each individual crop, but also on the covariance of the expected returns from two crops. The yields of two crops may be positively or negatively correlated depending on how their yields have historically varied over time.

Results from Paul et al. (2019) suggested that the overall risk is likely to be decreased through crop diversification and that this risk reduction is quantifiable through the diversification benefit metric. One of the main results is that risk can be reduced up to 77% by choosing the proper association of crops.

A major limitation of their study lies in the use of the criterion ‘crop productivity’, instead of an economic value. Economic returns and market price would be a closer estimate of farmer's objectives. However, a profitability analysis requires additional information on crop prices and crop production costs (and their predicted development in the future).

Sharma and Cho (2020) compare three different scenarios from modern portfolio theory to multi-objective optimization programming using a range of different temporal scenarios. Here, their objective was to extend current conservation applications of MPT to develop a framework for the cost-efficient spatial budget distribution for a forest carbon payment program that optimizes risk–reward trade-offs in the presence of economic condition induced risk. They addressed spatial correlations of forest carbon return on investment resulting from spatial and temporal variation in land-use opportunity costs under future economic growth uncertainty in the optimal spatial targeting of forest carbon payments. They used forecasts of opportunity costs, based on past occurrences of economic growth fluctuations, instead of historic estimates.

Busby et al (2020) looked at optimising global timber investment portfolios based on the application of modern portfolio theory. Numerous studies have shown the benefit of timberlands as an asset class when incorporated within portfolios containing other types of investments, but this research focussed on global timberland investment portfolios with species, management and returns typical of investment opportunities.

Knoke et al (2020) developed a dynamic approach for accounting for ecosystem services (ES; here biomass production, carbon storage, climate and water regulation, soil quality) and socioeconomic (or biodiversity) objectives in land-use decisions in Ecuador. They compared three different scenarios including only socioeconomic aspects (SE), socioeconomic aspects and ecosystem services (ES-SE), and socioeconomic and biodiversity aspects (B-SE). They used a reference point method to consider multiple objectives combined with robust optimization to integrate uncertainty about future conditions.

Their approach considered uncertainty spaces for each objective. These uncertainty spaces account for potential variability among decisionmakers, who may have different expectations about the future. When determining the optimal land-use allocation they rule out compensation among objectives: higher performance in one objective cannot compensate for poor performance in another. Instead, their approach is to minimize the maximum distance between the reference point and the actually achieved level across all objectives and all the input values contained in the uncertainty spaces.

As a result, accounting for ecosystem services and socioeconomic objectives can reduce as well accelerate deforestation, depending on the shares of forest cover in the area. Initial landcovers of natural forests of 38-80% lead to high deforestation rates, whereas at low forest shares, the elevated levels of some ecosystem services provided by natural forests are so important that further reduction of natural forest is greatly reduced or even ruled out; accounting for multiple ecosystem services would stop deforestation when natural forest cover falls below 10%. The deforestation resulting from expected scenarios follows both the past trend in land use and land cover (LULC) change (1975–2015) and predictions by an independent, spatially explicit stochastic model.

Augustynczik et al (2020) include biodiversity into socially optimal forest management under climate change conditions. Their study proposes a novel approach for defining socially optimal biodiversity levels, wood supply and taxation schemes under climate change. They introduced an optimization model, which aims to maximize consumers' and producers' surplus, taking into account the flow of wood and biodiversity until the end of the century. They used a utility function between wood consumption and biodiversity supply (on a household basis), taking bird abundance as a biodiversity measure. Forest growth was modelled using the 4C forest growth model to investigate the impacts of climate change and management regimes on forest development.

Their case study includes 63 management alternatives of the Black Forest landscape in SW-Germany. They computed a first-best and a second-best taxation scheme to internalize the social value of biodiversity into the forest sector.

The optimal management portfolio here showed a focus on biodiversity, with an increase in rotation length and decrease in thinning intensity. The substitution of spruce by beech and oak forests contributed to the biodiversity increase along the planning horizon. Wood consumption increased while wood production decreased.

In summary, applications of modern portfolio theory in forestry have focussed on environmental and economic objectives. Social benefits are often implicit e.g. it may be assumed that the public will prefer higher levels of biodiversity and more diverse forests, or these may be justified on economic grounds.

# CONCLUSION

The literature and previous experiences within the New Zealand forestry sector confirm that:

- Consideration of risk and uncertainty influences the ‘optimum’ solution determined through deterministic, quantitative modelling to such an extent that they should be reflected in the decision-making process.
- There are social aspects to forest management that need to be considered in the forestry decision making process.

The social acceptance of forestry operations arises through approaches to ongoing processes rather than being simply an effect. The effect of a loss of forestry’s social license to operate is value lost or the additional costs that arise due to the loss of public consent. Social acceptance can be treated as an asset but there are limited ways of quantifying this, and we have found little evidence to address the questions:

- Can we parametrise forestry’s social license to operate concerns, and then use them in a meaningful way to support decision makers in considering their decision making relative to social or cultural risk concerns?
- Have these social aspects been successfully incorporated within a quantitative portfolio theory framework in (a) forestry or (b) other industries?
- If not, have these social aspects been incorporated within other quantitative decision-making frameworks in (a) forestry or (b) other industries?

The prospect of quantitatively modelling all of the many factors that underpin forestry’s social license to operate within a modern portfolio theory approach appears remote, so the best way forward may be to elicit key public concerns and determine how these can best be incorporated into the decision-making process, i.e:

- In considering communities as pertaining to SLO, what are the key social and cultural concerns? What are the risks and opportunities for managers in responding?
- How can we best include social aspects within the quantitative portfolio framework developed in RA1.1?

As forests provide services through employment, infrastructure and ecological functions, they can benefit communities. However, where communities feel disengaged and disempowered, there may be costly repercussions for forest investors. This suggests that there may be benefits in considering communities and ecosystems including their cultural authorities and caretakers explicitly as part of the forest system assets. Forestry would then become a joint undertaking with shared responsibility for risks.

The recreational, aesthetic, health and spiritual values associated with forested landscapes and their natural settings are difficult to capture and quantify, and cannot be represented with a single ‘social license to operate’ metric. Differences in expected values and variance of these factors under alternative management options are also difficult to determine. However, there is scope to identify key social concerns relevant to New Zealand forest management and formally capture these within the planning process.

## Further work

The next Task within this sub-RA is to develop a roadmap for extending the modelling framework developed within the Research Programme to include the social dimension, building on stakeholder engagement work undertaken as part of this project.

# ACKNOWLEDGEMENTS

Milla Baker helped with the literature search and Alan Jones helped with review and editing. Funding for this research came from Scion and the Forest Growers Levy Trust, with the support of the NZ Forest Owners Association (FOA) and the NZ Farm Forestry Association (FFA).

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