Ecosystem Services xxx (2018) xxx–xxx

Contents lists available at ScienceDirect

Ecosystem Services

journal homepage: www.elsevier.com/locate/ecoser

Implications of future climatic uncertainty on payments for forest ecosystem services: The case of the East Coast of New Zealand

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A R T I C L E I N F O

Article history:
Received 9 October 2017
Received in revised form 23 April 2018
Accepted 26 April 2018
Available online xxxx

Keywords:
Stochastic dominance
Land-use change
Climate change
Benefit-cost analysis
Spatial optimisation
Forest ecosystem services

A B S T R A C T

Forestry's long-term nature and associated uncertainties play against its consideration in land-use decisions. This study's objective was assessing the implications of uncertainty on the feasibility of afforesting erodible land with natives. The New Zealand example has global relevance enabling: innovative statistical representation of climatic uncertainty, economic uncertainty analysis due to existing payments for services, and the profitability of long-rotation species due to Māori's socio-cultural aspirations. We complemented a deterministic optimisation approach with Monte-Carlo methods to identify optimal afforestation areas representing uncertainty probabilistically. With stochastic dominance/efficiency tests, relevant to landowners, we identified that the uncertainty and profitability of long-rotation species increase at low discount rates, plausible due to low opportunity costs and inter-generational aspirations (not possible in competitive circumstances). At low discount rates, the high profitability odds of the long-rotation alternative compensate its high uncertainty and make it the preferred one even for highly risk-averse owners. With a probabilistic cost-benefit analysis, relevant to policymakers, we identified that the benefits necessary to cover erosion-reduction investments would need to be higher than expected to hedge against climatic uncertainty. These results were obtained through the uncertainty analysis. The methods/results covered in this study are relevant to land-use studies/models seeking to measure uncertainty impacts simply.

1. Introduction

Forests provide some of the most valuable ecosystem services in the world, the other ecosystems being wetlands and rangelands (Costanza et al., 2014). An ambitious attempt made by Costanza et al. (2014) valued forest ecosystem services at $22 billion/year.[1] The importance of valuing these services stems from the need to acknowledge their economic contributions to society, hence fostering their preservation and expansion.

The measurement and valuation of these services has fostered the creation of policies that economically reward their generation (e.g. emission trading schemes). The creation of advanced measurement and valuation protocols and technologies (e.g. remote sensing and social media) has sparked the calibration of what used to be theoretical ecological and economic models to simulate the generation of ecosystem services as well as their demand (and valuation) temporally and spatially. However, these models rely on calibration processes that entail a certain degree of uncertainty, since they are based on sampled data, and use probability distribution functions (PDFs) to simulate properties about entire populations. Hence, the consideration of uncertainty in the modelling of ecosystem services is a critical extension to their early deterministic counterparts.

Monte Carlo methods popularised the probabilistic representation of uncertainty since the 1940s (Metropolis, 1987). Their early uptake contributed to their extensive use in various disciplines sparking the development of multiple specialised software

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[1] $ will represent New Zealand Dollars throughout the article. The going exchange rate at the moment of the development of the article was NZ$1.37/US$. Hence the original value assigned for forest ecosystem services was approximately US$16 billion/year.

https://doi.org/10.1016/j.ecoser.2018.04.010
2212-0416/

packages as well as routines in common programming languages. Their use in the specific context of decision-making under uncertainty have sparked the creation of various ranking tests that take as inputs the entire range of possible events in a variable's domain incorporating the human behavioural dimension (e.g. risk or loss aversion) (Hardaker, 2004). The application of these approaches in the area of ecosystem services has enabled the numerical and empirical assessment of the effects of risk aversion, for example, on the ranking and choice among various uncertain alternatives (Benítez et al., 2006; Goldstein et al., 2006; Djanibekov and Khamzina, 2016; Monge et al., 2016).

The advantage of the explicit consideration of uncertainty has been proven quite extensively in the land-use decision-making literature applied to ecosystem services. The development of spatial economic optimisation models mimicking decision-making has grown exponentially in the last couple of decades (Heckelei et al., 2012). The most commonly-used optimisation approach is mathematical programming due to its simplicity and tractability. Although uncertainty can be represented in these models to a certain extent (e.g. scenarios or quadratic programming), more complex approaches using heuristic methods have been developed to improve the shortcomings experienced with the former type of models (Musshoff and Hirschauer, 2009; Lehmann et al., 2013; Rabotyagov et al., 2014). However, the complexity of heuristics (e.g. search algorithms, non-convexities and stochastic processes) has precluded their use in large scale assessments (Doole and Pannell, 2008; Doole, 2015).

Hence, there is an opportunity to add value to widely-applied deterministic mathematical-programming methods by complementing their sets of deterministic results with widely-accepted Monte-Carlo simulation approaches and the economic theory developed to treat risk and uncertainty (e.g. stochastic dominance tests). The appeal of both approaches is their simplicity, tractability and wide use. Although there are far more comprehensive and complex methods, the benefit of using widely-accepted and relatively simple approaches would be to adequately use them to answer a specific question rather than developing complex models to answer these questions.

Although there have been several methods developed to cope with uncertainty in the ecological and economic disciplines, climate change poses an interesting opportunity to develop new ways to cope with biophysical uncertainty (e.g. ecosystem services) using economic theory. Empirical and process-based models (e.g. Rahmstorf (2007) and Keenan et al. (2011)), taking as inputs the results from complex Earth System Models (ESM) or General Circulation Models (GCM) (e.g. Scholze et al. (2006)), have helped to model biophysical relationships under future climatic uncertainty.

1.1. Case study area: East Coast of New Zealand

The current study took place in the East Coast region of the North island of New Zealand, namely the Waiapu catchment in the Gisborne district (Fig. 1). New Zealand as a whole and the specific region in question offer a relevant case study to the uncertainty literature for four major reasons: (1) Current GCMs and ESMs often poorly represent some physical processes in the region, (2) the East Coast is one of the most erosion-prone regions in the world, (3) the existence of two environmental policies rewarding regulating services from forests, and (4) the region's predominant Māori population and its implications for the preference of native forestry products with uncertain niche market circumstances. These four points are expanded upon below. Hence, the forest ecosystem services considered in this study are: product provisioning (e.g. timber and honey), carbon sequestration and avoided erosion under climate change.[2]

There is currently a National Science Challenge in New Zealand to properly model the climate processes in the Southern Ocean and Antarctica, namely the "Deep South" region.[3] The core objective of the Challenge is to assemble the first New Zealand ESM (NZESM) to properly model physical processes of atmospheric and oceanic circulation in the region. However, the relatively recent launch of the Challenge precludes the use of the potentially more refined results from the NZESM. Hence, this lack of data presents an opportunity to use sparse GCM-downscaled spatial data from previous projects (Tait et al. 2016a) and statistical techniques that do not require large datasets to fit a probability distribution function, namely the use of non-parametric empirical distribution functions.

The East Coast is one of the most erosion-prone regions of New Zealand and the world (Cumberland et al., 1980; Glade et al., 2006). This is the legacy of a massive land-use change phenomenon that started back in the 1880s when the first Europeans settled in the region and cleared most of the native forests for pastoral farming purposes. This drastic erosion vulnerability of the land has exerted negative effects on the productivity of rural land, its profitability and, hence, the economic growth of the region.

The region has the highest proportion (~45%) of the Māori ethnic group in New Zealand, with strong cultural, environmental and intergenerational aspirations (NZ Parliamentary Library, 2012). Furthermore, the tribal and permanent land ownership structures, the resulting lack of access to financial credit (i.e. no easily tradable collateral) and geological impediment of the land (i.e. steep slopes) make alternative investments other than forestry less appealing. Due to these aspirations and circumstances, forest systems consisting of native tree species that stabilise the soil with their root systems could turn out to be the most sustainable alternatives. Native species with the potential to contribute to productive planted forest systems analysed here are Mānuka (*Leptospermum scoparium*), Tōtara (*Podocarpus totara*) and Kawakawa (*Piper excelsum*). These species have been chosen for this study due to their high cultural significance and potential high profitability, which is conditioned on the uncertain niche markets where their products would be traded due to their uniqueness.

New Zealand provides an ideal location for this study due to the existence of environmental policies incentivising two important regulating services from forestry, namely climate change mitigation (i.e. carbon sequestration) and erosion control. The New Zealand Emissions Trading Scheme (NZ ETS) is a domestic policy implemented to meet the nation's international climate change obligations. Through the NZ ETS a price is assigned to a tonne of carbon dioxide equivalent (tCO_2e) sequestered, or a New Zealand Unit (NZU) (i.e. 1 tCO_2e = 1 NZU), creating an incentive to plant trees (Ministry for the Environment, 2017). The Erosion Control Funding Programme (ECFP) is a regional initiative, led by the Gisborne District Council and the Ministry for Primary Industries, granting landowners funding to control erosion on the worst eroding or erosion-prone land in the district. Eligible treatments include the establishment of indigenous forestry in retired grazing land (Ministry for Primary Industries, 2017b).

The uncertain benefits obtained from these policies, due to their design and the effects of climate change, have important implications for landowners and governments alike. Previous modifica-

[2] Forests provide other relevant ecosystem services that are not considered in this study such as biodiversity, recreation, tourism, etc.

[3] http://www.deepsouthchallenge.co.nz/

Please cite this article in press as: Monge, J.J., et al. Implications of future climatic uncertainty on payments for forest ecosystem services: The case of the East Coast of New Zealand. Ecosystem Services (2018), https://doi.org/10.1016/j.ecoser.2018.04.010