Forest Ecology and Management 404 (2017) 126–140

Contents lists available at ScienceDirect

Forest Ecology and Management

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

Bringing ecosystem services into forest planning – Can we optimize the composition of Chilean forests based on expert knowledge?

Britta Uhde[a], Steffi Heinrichs[b], Carolin Ronja Stiehl[b], Christian Ammer[b], Burkhard Müller-Using[c], Thomas Knoke[a,*]

[a] Institute of Forest Management, TUM School of Life Sciences Weihenstephan, Technische Universität München, Hans-Carl-von-Carlowitz-Platz 2, 85354 Freising, Germany

[b] Department of Silviculture and Forest Ecology of the Temperate Zones, Georg-August-Universität Göttingen, Büsgenweg 1, 37077 Göttingen, Germany

[c] Departamento de Silvicultura, Universidad de Concepción, Victoria 631, Barrio Universitario, Concepción, Chile

ARTICLE INFO

Keywords:
Forest composition
Ecosystem service indicators
Multiple objective planning
Analytic hierarchy process
Robust portfolio optimization
Uncertainty
Forest management
Expert opinions

ABSTRACT

In the following paper, we use robust optimization to calculate portfolios of Chilean forest stands which minimize the greatest underperformance among all considered ecosystem services (ES) and biodiversity. Forest experts were asked to score the six most important ES indicators and biodiversity for forest stands with either exotic or native tree species. Average scores and their variation were used to form an optimal forest portfolio (proportions of the five stand types). Quantitative indicators of ES were used to calculate the reference portfolio. Portfolios based on expert opinions (49% *Eucalyptus* plus *Pinus*, 51% native *Nothofagus* and mixed *Pseudotsuga*) did not differ significantly from portfolios based on quantitative indicators (51% *Eucalyptus* plus *Pinus*, 49% *Nothofagus*, mixed *Pseudotsuga* and *Acacia*). Both portfolios offer good protection against low achievement levels and prevent the degradation of important ES and biodiversity, while pure stands showed low achievement levels for specific ES. We conclude that integrating expert knowledge into forest planning may well support considering ES and biodiversity. Forest owners in the Mediterranean region of Chile should be encouraged to integrate native Nothofagus species into their forest portfolios to better provide for multiple ES and the conservation of biodiversity.

1. Introduction

The choice of a forest's tree species or stand types is one of the most influential decisions in forest management (Schall and Ammer, 2013), which has long lasting ecological and economic consequences. Forestry is an important form of land use, where economic return is imperative for decision making regarding land allocation, which may compromise ecological functions (Clough et al., 2016). Economic indicators are also important tools for choosing tree species or stand types (Cubbage et al., 2007). Forest owners usually respond to economic risks and opportunities when allocating forest land to tree species, at least if plantation forestry is considered. However, ecosystems provide numerous services for human welfare, apart from direct economic benefits. Ecosystem services (ES) comprise "… *the aspects of ecosystems utilized (actively or passively) to produce human well-being* …" (Fisher et al. 2009, p. 654) and result from ecosystem structures, ecological processes or functions that people use[1] directly or indirectly. However, though repeatedly suggested (Bončina, 2011), values other than financial return are often not considered when planning the future tree species or stand type composition of a forest.

One opportunity for considering the value of multiple ES when deciding about the future forest composition is to integrate already published estimates for economic values of ES (economic value coefficients), a method which is based on benefit transfer (Czajkowski et al., 2017). However, forest optimization studies considering economic values of comprehensive sets of ES are very rare. An example is Ovando et al. (2017), who developed an approach of spatially valuing environmental assets which considers benefits and costs of carbon sequestration, water provisioning, production of construction timber, pinenuts and fire-wood, as well as cork and grazing resources for Andalusian silvopastoral farms. However, a formal optimization of land use/forestry activities was not the aim of the mentioned study, although

* Corresponding author at: Institute of Forest Management, TUM School of Life Sciences Weihenstephan, Department of Ecology and Ecosystem Management, Technical University of Munich, Hans-Carl-von-Carlowitz-Platz 2, 85354 Freising, Germany.

E-mail addresses: uhde@forst.wzw.tum.de (B. Uhde), steffi.heinrichs@forst.uni-goettingen.de (S. Heinrichs), carolin-ronja.stiehl@forst.uni-goettingen.de (C.R. Stiehl), christian.ammer@forst.uni-goettingen.de (C. Ammer), burkhardmusing@yahoo.de (B. Müller-Using), knoke@tum.de (T. Knoke).

[1] Other sources of benefit include non-use values, such as option or bequest values (Krutilla, 1967) as well as cultural heritage or existence values (Goulder and Kennedy, 2011).

http://dx.doi.org/10.1016/j.foreco.2017.08.021
Received 18 March 2017; Received in revised form 12 August 2017; Accepted 12 August 2017

various management scenarios have been considered.

If appropriate economic value coefficients (i.e. the estimated economic values of ES) are not available for all relevant ES, models capable of formal optimization of ES may be based on a large set of methods from the field of multi-criteria decision analysis (Uhde et al., 2015). Decision variables associated with these optimization approaches may be discrete (e.g. pre-defined management options) or continuous (e.g. allocation of land proportions to management options). Either the average achievement is maximized, often leading to the dominance of one well performing option, or more balanced solutions are possible, depending on whether or not there is an allowance for averaging among indicator achievement levels. Balanced solutions should comprise diversified forest portfolios[2] including many stand types with similar proportions. For example, Estrella et al. (2014) as well as Diaz-Balteiro et al. (2017) combined the maximization of average achievement levels with the minimization of non-achievement (i.e. aiming at more balanced solutions) into one objective function (hybrid approach) to solve goal programming problems.

As examples for analyzing discrete decision problems, several collaborative studies have developed methods to quantify the impact of different land uses in Germany with respect to varying intensity of the provision of multiple ES (Allan et al., 2015; Tsonkova et al., 2015), and to rank restoration options for abandoned tropical lands based on their average performance in providing multiple ES (Knoke et al. 2014). However, these studies address the plot scale only and do not consider whole "landscape portfolios" for analyzing the consequences of diversification, even though forest composition and management both have an important impact on multiple ES (Gamfeldt et al., 2013; Triviño et al. 2017).

As another complication, there is an ongoing debate about the importance of indicators for ES and biodiversity (Carpenter et al., 2009) and which indicators to include. However, we must simply admit that we often do not know the exact importance of the indicators, because the preferences of current and future generations are unclear or even unknown (Hou et al., 2013). One should thus use as much information as possible by including different indicators and information sources.

Expert opinions could enrich the available information and might form a qualified basis for integrating ES and biodiversity into formal forest optimization. Such expert opinions should support building a more diverse pattern of land-use to buffer the detrimental effects of intensified land-use (Lapola et al., 2013) and should incorporate the management of remaining natural forests. These forests are often damaged or degraded after over-exploitation (Lara et al., 1997; Olivares, 2000; Reyes and Nelson, 2014). To gain knowledge on an optimized forest composition that promotes a multitude of ES, extensive information about ES and biodiversity of different forest stand types is necessary. Obtaining this information, e.g. with extensive field surveys and measurements, can be difficult and expensive. Alternatively, expert opinions could be used. For example, a pragmatic method for quantifying the supply of ES is the "matrix approach", where experts score the supply of various ES (matrix rows) for various land-use types (matrix lines) (Jacobs et al., 2015). Particularly in the case of forestry, expert opinions form a very valuable source of information regarding the usefulness of designating forest functions (Simončič and Bončina, 2015). Such information may be easier to obtain compared to in situ measurements concerning e.g. water quality or biodiversity of various taxonomic groups. The expert knowledge could therefore be integrated into forest planning.

However, building the future tree species or forest stand composition (i.e. a portfolio of forest stands or tree species) on expert opinions may be problematic. Predictions of experts about the future may be biased, because they may follow an ideology rather than evidence. For example, Mizrahi (2016) argues that expert opinions are not necessarily more likely to be true than opinions of lay people. Experience from medical sciences supports that expert opinions may mirror current biases rather than actual evidence (Drake et al. 2001). Consequently, it is of interest to test the suitability of forest expert opinions about ES of forest stand types for building forest portfolios. Another open question is if the variability among expert opinions is suitable to consider the uncertainties of ES in portfolio modelling.

Here, we use a recently published innovative optimization method for various Chilean forest types, which is new in the context of forest optimization and which has so far not been informed by expert opinions about ES, biodiversity and their variability (Knoke et al., 2016). Chile is a good example to test a new approach for optimizing forest composition. The negative perception of plantations is growing in the Chilean public (Salas et al., 2016), which has supported the desire of forest companies to obtain forest certification (Cubbage et al., 2010) and which has stimulated incentives to incorporate high environmental standards (Heilmayr and Lambin, 2016; Salas et al., 2016). Consequently, assessing and optimizing forest composition should not only focus on financial factors, but on a wide range of ES. Natural forests of south-central Chile (mainly between 33 °S and 42 °S) are biodiversity hotspots with a large number of endemic species existing under high anthropogenic pressure (Myers et al., 2000; Mittermeier et al., 2004). Since 1974, with the passing of the Decree Law 701 that granted huge subsidies for afforestation, the natural forest area has decreased substantially in some regions (Echeverria et al., 2006). The species-rich natural forests were widely replaced by short-rotation, even-aged monocultures of *Pinus radiata* and *Eucalyptus* species (mainly *Eucalyptus globulus* and *E. nitens*) that now dominate the forest area in the regions Maule and Bío-Bío (35 °S–37 °S; Heilmayr et al., 2016; Miranda et al., 2017). Although deforestation rates have decreased, natural forest conversion is still an ongoing process (Miranda et al., 2015; Zamorano-Elgueta et al., 2015).

The vast expansion of plantations contributed significantly to the economic growth in Chile. They have provided most of the timber and biomass for national and international markets, with exports mainly to China, the USA and South Korea. With a share of approximately 7% of Chile's total exports, forestry is the third most important economic sector (INFOR, 2015; Salas et al., 2016). In sharp contrast to their economic importance, the industrial plantations affect ecosystem functions and services negatively: exotic plantations have been shown to reduce biodiversity (Stephens and Wagner, 2007; Paritsis and Aizen, 2008), nutrient retention (Oyarzun et al., 2007), and water availability (Little et al., 2009, León-Muñoz et al., 2017), while soil erosion (Woda, 2003) and water runoff increase in comparison to (secondary) natural forests. Another negative impact of plantation forestry is the expansion of highly competitive alien species, which may cause unforeseeable changes in ecosystem properties such as fire susceptibility (García et al., 2015). Moreover, the increase of plantation area has been associated with increasing poverty in local communities, increasing conflicts with the indigenous people and increasing economic inequalities between large forest companies and local farmers or forest owners (Carruthers and Rodriguez, 2009; Reyes and Nelson, 2014; Andersson et al., 2016).

The method developed in this study aims at supporting the planning of future forest composition. Composition in our example means the percentage shares of land covered by various forest types when establishing new forests on cleared areas (e.g. through fire or harvesting activities). The basic methodological approach has been adopted from Knoke et al. (2016), who applied multi-objective optimization to find the optimal composition of rehabilitated tropical lands. The method is portfolio based and considers possible positive or negative deviations (i.e. uncertainty) from the available information. While Knoke et al. (2016) used field-recorded or modeled ES indicators as well as indicators extracted from household surveys, the present study utilizes scores based on expert opinions for the optimization. We are not aware

[2] The composition of a forest referring to the area shares of various forest types is considered a forest portfolio, which may be optimized in regard to the number of included forest stand types and their specific shares (i.e. portfolio weights).