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Evaluating management tradeoffs between economic fiber production and other ecosystem services in a Chinese-fir dominated forest plantation in Fujian Province

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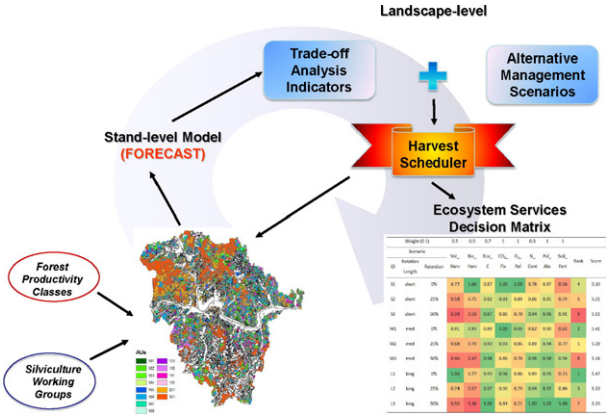
HIGHLIGHTS

- We examine the flow of ecosystem services from Chinese fir plantations in Fujian.
- We utilized the ecosystem-based, stand-level model FORECAST to drive the simulations.
- Eight different indicators of ecosystem services were analyzed using model output.
- We employed the model to evaluate different rotation lengths and harvest intensities.
- A decision matrix was constructed to evaluate landscape-scale results for indicators.

GRAPHICAL ABSTRACT



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ABSTRACT

Chinese fir (*Cunninghamia lanceolata*) is not only a valuable timber species, but also plays an important role in the provision of ecosystem services. Forest management decisions to increase the production of fiber for economic gain may have negative impacts on the long-term flow of ecosystem services from forest resources. Such tradeoffs should be taken into account to fulfill the requirements of sustainable forest management. Here we employed an established, ecosystem-based, stand-level model (FORECAST) in combination with a simplified harvest-scheduling model to evaluate the potential tradeoffs among indicators of provisional, regulating and supporting ecosystem services in a Chinese-fir-dominated landscape located in Fujian Province as a case study. Indicators included: merchantable volume harvested, biomass harvested, ecosystem carbon storage, CO_2 fixation, O_2 released, biomass nitrogen content, pollutant absorption, and soil fertility. A series of alternative management scenarios, representing different combinations of rotation length and harvest intensity, were simulated to facilitate the analysis. Results from the analysis were summarized in the form of a decision matrix designed to provide a method for forest managers to evaluate management alternatives and tradeoffs in the context of key indicators

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Alternative management scenarios
LST

of ecosystem services. The scenario analysis suggests that there are considerable tradeoffs in terms of ecosystem services associated with stand and landscape-level management decisions. Longer rotations and increased retention tended to favor regulating and supporting services while the opposite was true for provisional services.

1. Introduction

Ecosystem services refer to the benefits humans obtain, either directly or indirectly, from ecosystems. Specifically, they are the environmental conditions formed and maintained by ecosystems that are essential for human survival and well-being (Costanza et al., 2007; Daily, 1997). Ecosystem services are commonly divided into four broad categories, including: provisioning services, supporting services, cultural services and regulating services (Millennium Ecosystem Assessment, 2005). Historically, humans have tended to prioritize the development of provisional services that provide short-term economic benefits often at the expense of other ecosystem services (Tallis et al., 2008). Indeed, the dynamic tradeoffs among different ecosystem services are the most challenging aspects of managing natural resources (Rodriguez et al., 2006). Such tradeoffs are more evident between economic development and ecological services due to the conflict between limited natural resources and seemingly unlimited human needs. The management of forest ecosystems has been exceedingly challenging in this regard.

Forest management activities can significantly influence ecosystem services derived from managed landscapes. In some cases, management decisions made with the goal of improving the flow of economic resources will have negative impacts on important supporting and regulating services provided by forests (e.g. Nelson et al., 2009; Seely et al., 2004; Steffan-Dewenter et al., 2007). Thus, it is essential for managers to evaluate the long-term implications of alternative management options in the form of tradeoff analyses. In this paper we explore the tradeoffs among a range of ecosystem services provided by Chinese fir forests in Fujian Province, China subjected to alternative management regimes.

Chinese fir (*Cunninghamia lanceolata* (Lamb.) Hook.), an evergreen conifer species, is one of the most important commercial species in China. It is a valuable timber species with qualities that render it useful for construction and furniture manufacturing (Huang, 2013; Zhang et al., 2013). It is also commonly used for biomass energy (Li et al., 2013). In addition to its importance as a source of fiber, Chinese fir plantations play an important role in providing forest ecosystem services including water and soil conservation, soil productivity, pollutant absorption, etc. (Tian et al., 2002; Wang et al., 2009).

We developed a Landscape Summary Tool (LST) by employing the stand-level, ecosystem-based FORECAST model (Kimmins et al., 1999) in conjunction with a simplified harvest scheduling model to facilitate the trade-off analysis. The LST model was used to project the impact of alternative management scenarios on both wood production and the development of biophysical forest attributes in a managed landscape dominated by Chinese fir plantations. A diverse suite of indicators of ecosystem services was derived from a similar Chinese study (Wang et al., 2008). These indicators were linked to modeled stand attributes and utilized as the basis for the analysis presented here.

2. Methods

2.1. Study area description

The study area (29,361 ha) is located in Shunchang County in the north of Fujian Province (117.48°–118.23° E and 26.63°–27.20° N) (Fig. 1). Terrain in the north and southwest portions of the study area is generally higher than south central areas, which contain the major rivers. Shunchang has a subtropical maritime monsoon climate but is also influenced by an adjacent region with a continental climate. The annual average temperature in the study area is 16.9 °C with a frost-free period of 305 days and an average annual rainfall of 1628 mm. Shunchang is located in the central production area for Chinese-fir (Yu et al., 1980). The soils in this region, classified as red earth under the Chinese soil classification system, are acidic and contain considerable organic matter. The texture of the soils is predominantly loam and clay with depths commonly over 1 m.

Forest inventory survey data from Shunchang County in 2007 were used to establish initial conditions for the analysis. Productive forest land (19,034 ha) within the study area is dominated by Chinese-fir plantations (53.5%; the principal economic species with the region), and Masson pine (*Pinus massoniana* Lamb.) (15.0%). The remaining productive forest area (31.5%) consists of mixed broadleaves that are not managed for economic production. The Chinese-fir stands within the study area range in age from 1 to 52 y and have developed on soils with varying productivity.

2.2. FORECAST model description and calibration

2.2.1. Model description

FORECAST (Kimmins et al., 1999) is an ecosystem-based, stand-level, forest growth simulator. The model was designed to accommodate a wide variety of harvesting and silvicultural systems in order to compare and contrast their impacts on forest productivity, stand dynamics, and various biophysical indicators of non-timber values. The model uses a hybrid approach whereby local growth and yield data (often from locally calibrated empirical growth and yield models) are combined with other descriptive data to derive estimates of the rates of key ecosystem processes related to the productivity and resource requirements of selected species. FORECAST uses derived measures of decomposition, nutrient cycling, light competition, and other ecosystem properties to simulate forest growth and ecosystem dynamics under changing management and environmental conditions. Like many forest growth models, FORECAST is not directly driven by climate data. Rather, the regional historical growth data used to calibrate the model are assumed to be representative of the local climate. The biological properties of individual species, as defined by the input data, determine their relative competitiveness for limited resources. The ability of FORECAST to project the development of stand attributes related to both timber and non-timber values in an integrated system provides a strong foundation for an analysis of ecosystem services.

The FORECAST model has been widely applied as a long-term management evaluation tool in a variety of forest ecosystems (Blanco et al., 2006; Blanco et al., 2007; Seely et al., 2002; Sun et al., 2012; Wei et al., 2003), including Chinese fir plantations (Bi et al., 2007; Wei and Blanco, 2014; Xin et al., 2011). A detailed description of the FORECAST model is provided in Kimmins et al. (1999) and Seely et al. (1999).

2.2.2. Model calibration

The calibration of FORECAST includes two stages (Blanco et al., 2007): 1) data assembly, input, and validation; 2) establishing the ecosystem condition for the beginning of a simulation run (by simulating the known or assumed history of the site). Calibration input data for FORECAST were principally derived from mensuration datasets from a range of Chinese fir forests located in southeastern China and varying in age and nutritional quality (Wei and Blanco, 2014). Additional data were obtained from relevant literature, including research reports from Fujian, Hunan, Jiangxi, Guangxi and other climatically similar