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Multi-method dynamical reconstruction of the ecological impact of copper mining on Chinese historical landscapes

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ABSTRACT

This study deals with the historical impacts of mining as a result of the economic development in Eastern Asia. It focuses on landscape changes caused by the emerging copper mining industry in China's south east provinces. Since the ecological aftermath has never been documented in Chinese history, a reconstruction of dynamic landscape processes is performed. A key region for this reconstruction are the mining areas in Yunnan province. This province was the most important supplying region of copper in China during the early and mid Qing dynasty (1725–1855).

Predictive modeling of the primary vegetation in combination with dynamic agent-based reconstructions have been performed to analyze and to understand deforestation processes. Therefore a time-discrete balance between biomass removal and renewal has been carried out to characterize different periods of landscape degradation, biodiversity and agriculture. Besides the reconstruction, explanatory and experimental results have been compiled to assess the ecological impacts of mining during this period.

An 'Evaludation' of the model was performed in order to verify the applied concepts and test the integration of data as well as the conclusive generation of results. Our calculations show that while deforestation for mining was severe in the 18th and 19th century, rising populations and agricultural reclamation had a bigger impact on the clearance of forests. In addition, quantitative data for the ecological succession show that deforestation was reduced by up to 75% due to the provision of regrowing biomass. Deforested areas around the mines were either completely destroyed or of high biodiversity due to the abundance of heterogenous vegetation communities within small spaces. Lastly, two extreme scenarios were calculated which covered all positive and negative triggers of deforestation. These calculations served as reference data to evaluate model's quality: our model outputs lie within the range of comparable studies but underestimate the total deforestation reported and yet some uncertainties regarding forest fires and other uses of biomass remain. This study has led to a more holistic understanding of the interactions between copper mining and landscape ecology in Chinese history.

1. Introduction

Copper mining was a decisive contributor to the rise of the East Asian economic area since the century. Throughout the history the effects of mining on the natural forests have been severe, but none of those effects have been handed down nor recorded. Today, degraded landscapes with massive soil erosion are common where extensive primary forests must have existed (Li, 2008). The following research questions are addressed in this study: how did the landscape in copper mining areas change during the Qing dynasty? How big was the relative impact of mining and agriculture on the decline of the primary forest cover? How much did this period contribute to the situation we have today? Which were the main driving forces of landscape degradation and how did succession affect the supply of secondary biomass? Can additional information about inherent relationships in the system be inferred from the model?

Since data on vegetation, agriculture and the effects of mining are extremely scarce, the initial distribution of primary forests was modeled by using a classification tree approach (see Section 2.3). In a second step (see Section 2.4) a time-discrete agent-based model (ABM) has been developed, to take the complex system of

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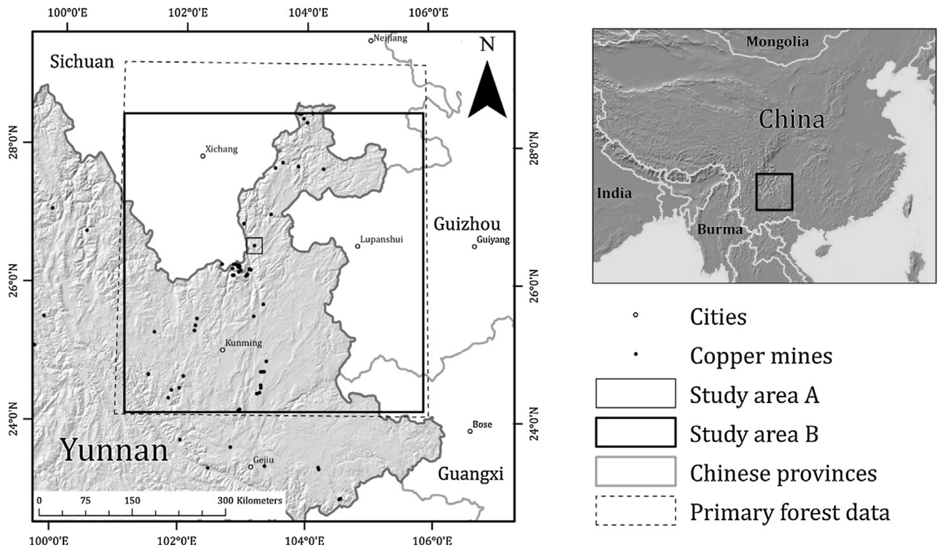

Fig. 1. Study area.

deforestation, succession and agriculture into account. The ABM is used to visualize and to analyze historical developments by simulating various scenarios in order to answer the research questions mentioned above.

2. Material and methods

2.1. Research area and period of investigation

Changes of the primary vegetation, the evergreen broad-leaved forest (EBLF, (Tang, 2010)) during the Qing dynasty (1644–1912) are at the center of this study. The copper mining industry was established shortly after 1725 and was affected by a complete collapse in 1855 (Vogel, 1989). These 130 years as a time frame for the scientific framework have been in focus by other studies as well (Kim, 2009; Yang, 2004). Since the southwestern province of Yunnan was rich in natural resources it became the main supplier of copper for the imperial mints. It is the historical center of copper mining and includes 51 of the 70 known mines of the province. While the exact locations for copper smelting facilities cannot be reconstructed, a close proximity to verified copper mines is assumed. In order to assess both local and regional processes two areas of investigation at different scales were chosen (see Fig. 1). The focus in study area A is on local landscape changes, while the total forest destruction in the Yunnan province is under review in study area B.

2.2. Datasets

For the generation of the map on initial forest distribution, 5 raster layers were included (Table B.1). Global Land Cover 2000 is a global land cover map compiled by the Joint Research Centre of the European Commission. It is based on the VEGA-2000 dataset, and is thus a compilation of recordings acquired by the SPOT 4 satellite. The second land-cover map was derived from data collected by the Advanced Very High Resolution RADAR (AVHRR), conducted by the National Oceanic and Atmospheric Association (NOAA). Two climate layers were integrated. The first layer offers information on the lowest temperatures of the winter months, the second layer reflects annual precipitation. Both layers were comprised of data from 1950 to 2000. Since several studies indicate only slight variations regarding the macroclimate of the study area, no modifications have been applied to this data (Fan, 2009; Folland et al., 2002; Ge et al., 2008; Liu et al., 2005). The Harmonized World Soil Database (HWSD) separates global soils into 32 reference groups, complemented by various pre- and suffixes. Lastly, a SRTM-digital elevation model (DEM) has been included.

The agent-based model (see Section 2.4) makes use of this initial forest distribution as an input for process-based biomass calculations. Furthermore, geographical and statistical data about copper mines and transportation routes which were collected within the research project ((Vogel, 2009)) were imported (MMF geodatabase, (Rosner et al., 2008)). The ABM utilizes information from the shapefiles attribute tables, for example the maximum copper production of each mine. Additionally, SRTM data were integrated for the derivation of topographical information.

2.3. Classification trees

A model based on classification trees was trained to derive habitat information for three major classes: EBLF, Grassland, and Bare Ground. For reference, land cover maps have been used as described in Section 2.2. Climate, soil, and elevation data were considered as observation variables.

Since mapping the land cover of the 18th century is the goal, evaluation using true reference data cannot be performed. More so, even cross validation cannot account for areas that were interpolated by this approach (e.g. coniferous forests), as training data is taken just from the core areas of the three training classes.

Despite these limitations, classification trees offer a very transparent model and direct access to the derived ruleset, which can be interpreted for validity. In addition, a couple of models were trained using varying parameterizations, and a reasonable classification scheme was chosen to create a visual interpretation of the land cover.

2.4. Agent-based simulation

As descriptions of such agent-based models (ABMs) often suffer from uncertainties and lacking reproducibility, we used the standardized ‘ODD’ (Overview, Design concepts, and Details) protocol introduced by Grimm et al. (2006, 2010).

2.4.1. Purpose

It is assumed that there is a relationship between copper mining and deforestation. However, the exact development of Chinese