Agriculture, Ecosystems and Environment 195 (2014) 231–243

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

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

Deforestation processes in south-western Madagascar over the past 40 years: what can we learn from settlement characteristics?

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ARTICLE INFO

Article history:
Received 5 March 2014
Received in revised form 5 June 2014
Accepted 7 June 2014
Available online 1 July 2014

Keywords:
Land cover changes
Mahafaly plateau
Forest fragmentation
Slash and burn agriculture
Hatsaky

ABSTRACT

South-western Madagascar has experienced large reductions in forest cover over the last decades. However, there are major uncertainties in the total extent of the country's deforestation and particularly in understanding the anthropogenic impact on land cover changes (LCC). Based on satellite image classifications, spatial bio-physical data and socio-economic data from village-level interviews, we therefore explored the role of settlement characteristics in LCC and forest fragmentation processes in the Mahafaly region during the past 40 years.

For this study, a time-series of Landsat satellite images from 1973 to 2013 was classified using a supervised approach, and deforestation and LCC trends were identified for different time periods. The studied settlements were classified according to their geographic location, socio-economic activities and economic status. The factors that directly affect deforestation processes, underlying socio-economic, and bio-physical contributors to deforestation trends were investigated at the settlement level through regression analysis.

Over the past 40 years forest losses amounted to 45% and led to increasing savannization and forest fragmentation, whereby the rates of deforestation were not constant through time. Deforestation was strongest at remote locations, and near to small settlements that are poorly connected to infrastructure and main markets and are relatively young. The causes of this diffuse deforestation pattern in the Mahafaly region changed through space and time, but one major driver is the 'clandestine pioneer-agriculture' often practiced by immigrant farmers.

1. Introduction

Land cover changes (LCC), in particular deforestation, can generate many environmental problems at global to local scales and reflect the interaction of biophysical, social, ecological and human behavioural components which often change over space and time (Serra et al., 2008; van Doorn and Bakker, 2007). It is important that landscape managers and policy makers understand the underlying relationships of LCC and deforestation processes in order to design nature conservation and sustainable management strategies (Kates et al., 2001). This is particularly true for Madagascar, where the rate of total deforestation over the last decades has been very high (Blanc-Pamard, 2009; Klein, 2002; Sussman et al., 1994; Whitehurst et al., 2009; Zinner et al., 2014), and the remnant vegetation patches have become so fragmented that almost everywhere wild species are severely affected by interactions with humans (Ganzhorn et al., 2001). Over the past 30 years, many scientists have tried to explain the causes of tropical deforestation (Casse et al., 2004; Geist and Lambin, 2001; Lambin et al., 2001; Nagendra et al., 2003) whereby shifting cultivation and population growth in conjunction with biophysical, and socio-economic factors have been reported to be particularly prominent causal agents (Blanc-Pamard, 2009; Jarosz, 1993; McConnell et al., 2004; Rudel and Roper, 1996).

In the south-western region of Madagascar, the dry spiny forests represent a unique and highly diverse ecosystem with an exceptionally high number of endemic species. It is the country's most economically and climatically disadvantaged region, and it is

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http://dx.doi.org/10.1016/j.agee.2014.06.008
0167-8809/

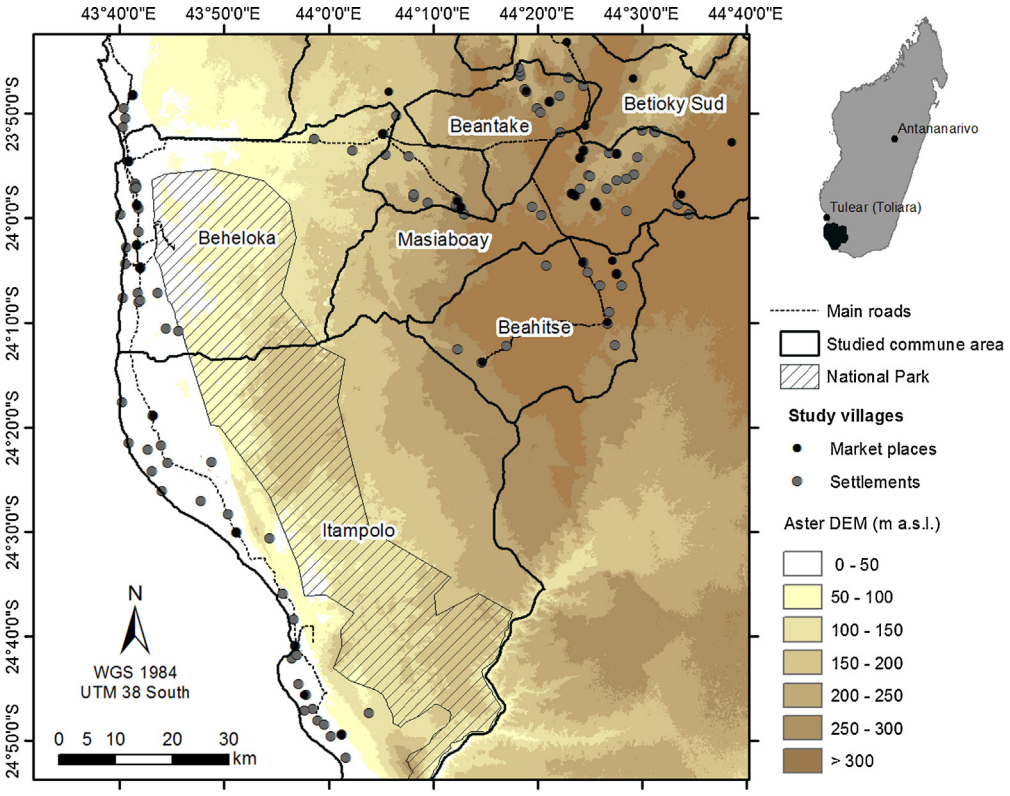

Fig. 1. Location of the study region and studied villages, Mahafahly region, SW Madagascar.

dominated by the Mahafaly people, whose livelihoods depend entirely on the exploitation of natural resources. Forest areas provide important ecosystem services including food, energy and medicine (Dawson and Ingram, 2008), and deforestation has mainly been caused by slash-and-burn agriculture, logging, and the production of fuelwood and charcoal for cooking (Casse et al., 2004; Elmqvist et al., 2007; Sussman et al., 1994). So far, analyses of changes in land use and land cover have focused mainly on changes in natural forest cover, while the total extent of deforestation and forest fragmentation processes with the isolation of forest patches remain unclear (Harper et al., 2007). Recent studies have revealed temporally and spatially much more complex relationships between human population densities and forest losses than previously assumed (Elmqvist et al., 2007; Gorenflo et al., 2013; Vågen, 2006). Overall, the effects of anthropogenic impacts on causes and trends in LCC are not well known, though this problem may be partly resolved by linking social science research with an analysis of remote sensing data (Casse et al., 2004; Fox et al., 2004; Mertens et al., 2000). Reconstructing the history of deforestation using remote sensing combined with a detailed socio-economic study allows to better understand the patterns, processes and motivation behind forest clearing in a social-ecological systems context (Fox et al., 2004; Mertens et al., 2000). However, understanding how human activities impact patterns of land use and deforestation remains a challenge (Nagendra et al., 2004). Particularly difficult is to define the appropriate spatial observation units and levels of aggregation of information derived from households or village interviews, and to establish suitable linkages between household level and remote sensing datasets (Fox et al., 2004; Mertens et al., 2000; Liverman et al., 1998). Most studies aim at combining remote sensing data with socio-economic information at the scale of administrative units (Skole et al., 1994). However, the aggregation of LCC to such coarse resolution data leads to a loss of information as the data do not really correspond to the decision unit and the interpretation of the spatial variability of the discovered trends, thus, become difficult or even impossible (Millington et al., 2009).

The objective of our study, therefore, was to integrate remote sensing data of LCC and socio-economic data of detailed field surveys at finer levels of aggregation to better understand the processes and causes of landscape transformations in a socio-ecological system in south-western Madagascar.

In this context the main objectives of our study were to: (i) identify LCC including forest fragmentation processes over the past 40 years in the Mahafaly region, (ii) characterize the associated settlements of this region according to their geographic location, size and socio-economic conditions, (iii) evaluate the role of the identified settlement types in deforestation processes and (iv) identify possible proximate causes of deforestation and the underlying socio-economic and bio-physical factors.

2. Materials and methods

2.1. Study area

The 10,000 km^2 study area is located in south-western Madagascar (Fig. 1) enclosing the Mahafaly plateau and the sandy plains of the adjacent coastal region. It comprises 185 permanent settlements (*Fokotany*[1]) and approx. 260 dispersed hamlets often with only temporary residents located in six communes: Beheloka (Toliara II District), Beantake, Masiaboay and Betioky-Sud (Betioky-Sud District), Itampolo and Beahitse (Ampanihy District). The area is characterized by semi-arid climatic conditions with irregular rainfall averaging less than 500 mm per

[1] The administrative unit that corresponds to a village and may include surrounding hamlets.