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Original Research Article

Impact of biogas interventions on forest biomass and regeneration in southern India

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A B S T R A C T

Programs to provide alternative energy sources such as biogas improve indoor air quality and potentially reduce pressure on forests from fuelwood collection. This study tests whether biogas intervention is associated with higher forest biomass and forest regeneration in degraded forests in Chikkaballapur district in Southern India. Using propensity score matching, we find that forest plots in proximity to villages with biogas interventions (treatment) had greater forest biomass than comparable plots around villages without biogas (control). We also found significantly higher sapling abundance and diversity in treatment than control plots despite no significant difference in seedling abundances and diversity in treatment forests, suggesting that plants have a higher probability of reaching sapling stage. These results indicate the potential for alternative energy sources that reduce dependence on fuelwood to promote regeneration of degraded forests. However, forest regrowth is not uniform across treatments and is limited by soil nutrients and biased towards species that are light demanding, fire-resistant and can thrive in poor soil conditions.

1. Introduction

Biomass is the fourth largest source of energy in the world, and in many countries, 90% of the total energy comes from traditional fuels such as wood, straw and dung (Hall, 1997). While fuelwood as an energy source has the advantage of being renewable and accessible to even the most marginalized, it also has disadvantages such as contributing to forest degradation, carbon and methane production from burning, and health hazards from household air pollution (Bluffstone et al., 2013; World Health Organization, 2014). Many programs aim to reduce consumption of fuelwood through providing alternative energy sources and efficient cooking stoves (International Energy Agency, 2016). These programs have met with mixed

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success, with some programs leading to reduced carbon emissions from burning (Feng et al., 2009; Garfí et al., 2012; Katuwal and Bohara, 2009).

Reduction in fuelwood use also theoretically allows forests to recover. Possible benefits for forests of programs that provide alternatives to fuelwood include increases in biomass, carbon sequestration, and recovery of species composition that enable the sustainable provision of ecosystem services in the future. Studies have examined the impact of alternatives to fuelwood and efficient cooking devices on tree selection by local people (Timko and Kozak, 2016), and the role of plantations and agroforestry on degraded lands to meet fuelwood demands and sequester carbon (Gruenewald et al., 2007; Khamzina et al., 2012). Yet, we could not find any study that explicitly examined forest recovery following an intervention to reduce fuelwood use. Studies on forest recovery examine recovery from mining, agriculture (Ruiz-Jaen and Aide, 2005) and other land uses and extraction activities (Jones and Schmitz, 2009), but do not examine recovery from fuelwood extraction. While recovery can be assisted (active restoration) or unassisted (passive restoration) (Chazdon, 2008), it is also important to examine 'incidental' restoration, where recovery is an unintended consequence of an intervention as these may follow trajectories different from the already complex trajectories of recovery (Aronson and Galatowitsch, 2008; Jacquet and Prodon, 2009; Matthews et al., 2009; Suding, 2011). Studies that examine impact of biogas and other initiatives to reduce fuelwood wood demand on forest growth and regeneration, preferably using longitudinal field studies that include surveys taken prior to and after an intervention (Baylis et al., 2016), will help establish patterns and understand trajectories. However, such studies take time, and policy-relevant answers are urgently needed.

This study used an existing biogas intervention, where the intervention was first implemented in 2005 (ten years prior to the study), to assess the impact of the intervention on forest recovery. In this study, we tested whether implementation of a biogas intervention in communities that previously harvested wood from nearby forests was associated with (1) higher biomass; (2) higher regeneration, and (3) different species composition than comparable forests where such an intervention did not take place. We also investigated other factors associated with forest recovery, including biophysical, socio-economic and landscape variables. Such a study is of particular importance in India, where restoration of degraded forests constitute an important component of its Nationally Determined Contribution (NDC) to the United Nations Framework Convention on Climate Change (UNFCCC) (Government of India, 2015), but the study results suggest a universal response that might be of global significance.

2. Materials and methods

2.1. Study site

The study was located in Chikkaballapur district in the state of Karnataka, India (Fig. 1 and 13.4324° N, 77.7280° E). This region is arid and receives an average of 731 mm of rainfall annually, 69% of which is from June to October. Population density is high in the district (298 individuals per km^2), and 88% of people are landless and dependent on work as agricultural laborers (Karnataka Forest Department, 2014). Around 40% of landholdings are <0.5 ha, while another 46% of landholdings are between 0.5 and 2 ha (Government of India, 2011).

Forests in the study area consist of dry deciduous and scrub forests on soils that are derived primarily from a bedrock of hornblende schist, although outcrops of granitic gneiss, laterite and dolomite are irregularly distributed in the landscape. The Forest Department Working Plan reports that heavy use for fuelwood and charcoal production in the past, as well as low rainfall and poor and shallow soil, has led to low biomass forests and branchy, stunted trees with diffused crowns. Common overstory species in the area include *Albizia amara*, *Cassia fistula*, and *Anogeissus latifolia*, and the understory consisted of *Lantana camara*. Poor regeneration of indigenous species such as *Hardwickia binata*, *Chloroxylon swietenia*, *Semecarpus anacardium* and *Cassia fistula* in these forests led the Forest Department to develop plantations of *Eucalyptus* species, *Prosopis juliflora*, *Senna siamea*, *Dalbergia sissoo* and *Casuarina equisetifolia* in the district (Karnataka Forest Department, 2014).

The forests in the district constitute 17% of the total land area, and are officially managed by the Forest Department. Forests are mostly located on hilly areas and have steep slopes that are inaccessible for management. The two largest blocks, or management units, in the study area are Narasimhadevarabetta (~160 km^2) (henceforth, NDB) and Ittikaldurga (~100 km^2) (henceforth, IKD), and it is unclear how long the forests in these blocks had been isolated from each other. The Forest Department also restricts many activities in the forests: grazing and collection of grass to stall-feed cattle is allowed in some forest areas; and the Forest Department Working Plan reports that grazers set fire to the forest to augment production of grass. These forests are also home to wildlife such as leopards, blackbuck, chital, cobras, porcupine, black-naped hares and rodents (Karnataka Forest Department, 2014).

Biogas digesters were introduced in the area in 2005 with the aim of replacing fuelwood in 885 villages. The project itself constituted an agreement between French company VELCAN Energy and a village-level social organization called the Coolie Sangha in 2005 – a 39 year old organization of smallholder farmers from the villages in the district – and between Dutch company Fair Climate Fund and the Coolie Sangha in 2008. The local NGO facilitating the project installed 16,682 biogas units in villages where members of the Coolie Sangha were enthusiastic about using biogas interventions to solve their fuelwood problems. Individual families took a loan from the village-level Coolie Sangha to purchase the biogas units.

These biogas units were underground composters that used cattle dung to generate gas that was piped to a kitchen stove and used for cooking. A comparison of households with and without biogas units in the area identified that households with biogas units had improved diets and time allocation (Anderman et al., 2015). Due to absence of historical reference sites or