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Research article

Effectiveness of management interventions on forest carbon stock in planted forests in Nepal

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ABSTRACT

Nepal has successfully established more than 370,000 ha of plantations, mostly with *Pinus patula,* in the last three and a half decades. However, intensive management of these planted forests is very limited. Despite the fact that the Kyoto Convention in 1997 recognized the role of plantations for forest-carbon sequestration, there is still limited knowledge on the effects of management practices and stand density on carbon-sequestration of popular plantation species (i.e. *Pinus patula)* in Nepal.

We carried out case studies in four community forests planted between 1976 and 1990 to assess the impacts of management on forest carbon stocks. The study found that the average carbon stock in the pine plantations was 217 Mg C ha^{-1}, and was lower in forests with intensively managed plantations (214.3 Mg C ha^{-1}) than in traditionally managed plantations (219 Mg C ha^{-1}). However, it was the reverse in case of soil carbon, which was higher (78.65 Mg C ha^{-1}) in the forests with intensive management. Though stand density was positively correlated with carbon stock, the proportionate increment in carbon stock was lower with increasing stand density, as carbon stock increased by less than 25% with a doubling of stand density (300–600). The total carbon stock was higher in plantations aged between 25 and 30 years compared to those aged between 30 and 35 years.

1. Introduction

Plantation forests have increasingly been recognized for their effectiveness in reducing the negative consequences of global warming since the Kyoto Convention (UNFCC, 1998; Haghdoost et al., 2012). Large-scale plantations started in the degraded hills of Nepal in the 1980s (Gilmour et al., 1990). Since then, approximately 370,000 ha of plantation forests have been established (DoF, 2012). *Pinus patula* was the most widely planted species as it grows considerably faster than other indigenous pine species of Nepal, such as *Pinus roxburghii* and *Pinus wallichiana* (Jackson, 1994).

The main objective of plantation forests in Nepal was to maximise biomass production (Gilmour et al., 1990). Productivity and yields of the planted forests were expected to be sustainable at most sites, provided regular silviculture operations were carried out (Evans, 2000). Evidence shows that intensively managed plantations yield higher production of both timber and other biomass (Fox et al., 2007). Intensive forest management involves the manipulation of soil and stand conditions to ameliorate factors that limit tree growth and productivity. Such factors include stand density, genetics, competition control, fertilisation, and soil quality (Fox, 2000). However, intensive management of plantation forests is generally neglected (Neinninger et al., 2013) as forest managers follow traditional management practices which are typically performed by “selective logging”: extracting a small number of commercial species from a large number of non-commercial species (Griscom and Cortez, 2013). The traditional management practices of plantation forests cause not only poor productivity but also limited generation of scientific data to assess the effects of thinning on the plantation stands (Neinninger et al., 2013).

Silviculture practices have important implications on the carbon

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budget of forests. Prolonging the harvesting rotation generally results in less carbon sequestration per unit area, as the growth rate decreases significantly when a stand reaches final felling or rotation age (Silva and Dudley, 2009). However, it can be difficult to assess the impacts of forest management practices on carbon sequestration because forest management measures may increase the aboveground production but may also cause soil carbon loss at the same time (Gelman et al., 2013). There are still information gaps in understanding the links between plantation forest management and carbon sequestration, including the quantity and long-term fate of carbon in litter, below-ground biomass, and soil carbon (Silva and Dudley, 2009). Dangi et al. (2009) strongly suggest further studies on the impact of management on forest carbon so as to develop decision support tools for appropriate management and harvesting techniques of planted forests and to capture benefits in the context of carbon trading. Forest management aims to balance ecological and economic services. However, the full extent to which management activities affect the carbon budget of forests is little understood. This study aims to contribute further to the understanding of the implications of management practices in different forest carbon pools, particularly in pine plantations in developing countries.

2. Methods

2.1. Study sites

The study was carried out in the community forests of the Chaubas ridge in Kavrepalanchok District (Fig. 1), where more than 400 ha of pine plantations were established (mainly *Pinus patula* and *Pinus wallichiana)* since the 1980's (Gilmour et al., 1990). A total of four community forests with *Pinus patula* plantations of varying ages (25–35 years) and densities were selected. The initial plantation stocking were 1600 plants ha^{-1} (Chand and Ghimire, 2006). In addition to planting stocks, some local species such as *Alnus nepalensis* and *Qurcus species* regenerated naturally in some part of the Dharapani forests. The plantation stocking now has been reduced to 323–579 stems ha^{-1} as a result of management interventions involving intensive and traditional practices (Table 1). At least three thinnings (thinning from below) were carried out in intensively managed forests adopting thinning guidelines for *Pinus patula* and *Pinus roxburghii* (DFRS, 2006) and selective removal of stems was undertaken under traditional practices.

All four community forests (Table 1) have a similar altitudinal range (1800–2000 M. msl.), aspect (Southwest and Southeast), soil composition (clay mixed with pebbles), slope (20-30°), and situated within 3 km range. Based on the records from the nearby hydrological station, the annual average precipitation is 1923 mm, which falls mainly between June and September (NEA, 2011).

2.2. Data collection

Clear geo-referenced maps were not available for all four community forests, which would have been crucial to make an exact estimation of the areas of the study sites so as to allocate sample plots. Therefore, we carried out boundary surveys using GPS and developed maps of the community forests using Arc View Software. The required numbers of sample plots were estimated through a pilot survey following the formula adopted by ICIMOD for carbon measurement methodology (ICIMOD, 2007) as below.

$$n = CV^2 t^2 / E^2$$

where,

n = Number of sample plots required
CV = Coefficient of variation
t = Value of t obtained from the student's t-distribution Table at n-1 degree of freedom of the pilot study at a 10% probability
E = Sampling error at 10%

In total, 11 sample plots were required but as the study was conducted in conjunction with a growing stock and increment survey, 60 sample plots were systematically allocated in four forests to collect information on different carbon pools including: above ground tree biomass (AGTB), above ground shrub biomass (AGSB), below ground tree biomass (BGTB), leaf, herbs and grass (LHGs) and soil organic carbon (SOC). The measurement methods were adopted from “Guidelines for Measuring Carbon Stock in Community-Managed Forests” (Subedi et al., 2011).

To estimate the AGTB, all trees larger than 5 cm diameter at breast height (DBH) within a circular plot of 8.92 m radius were counted, diameter was measured in centimetres at a 1.3 m height using diameter tape, and total tree height was estimated in meters using a Vertex instrument.

Within this plot, several small nested plots were established to measure other carbon pools (Fig. 2). For AGSB, a 5.64-m radius subplot was established for counting and measuring the DBH of saplings (1–5 cm diameter) and a 1-m radius plot was established to count regenerations (<1 cm DBH). Within the 1-m radius plot, a 0.56-m radius plot was established to take samples of leaf litter, herbs, and grass (LHGs). All the litter (such as dead leaves and twigs) within the plots was collected and weighed. Approximately 100 g of evenly mixed sub-samples were brought to the laboratory to determine moisture content and convert to dry biomass. Similarly, live herbs and grasses within the plots were cut at ground level, kept in plastic bags, weighted, and brought to the laboratory to determine oven dry-weight.

Soil organic carbon was measured taking soil samples up to 30 cm deep within 0.56-m radius plots at the center (IPCC, 2006). Near the center of the plot, soil samples were taken from three default depths within a pit: (0–10) cm, (10–20) cm, and (20–30) cm with the help of a soil corer. These samples were separately weighed, labelled properly, and brought to the laboratory for further analysis.

2.3. Data analysis

The raw data collected from the field was first screened and outliers were removed. Soil samples were tested by the Department of Forest Research and Survey (DFRS) Nepal to estimate bulk density and soil organic carbon. The guidelines for measuring carbon stocks in community-managed forests (Subedi et al., 2011) were adopted for overall carbon analysis. MacDicken (1997) and Husch et al. (2002) were also referred to for conversion factors, specific wood density, and moisture content values. Constant values such as intercept and slope to estimate fresh biomass of saplings were adopted from MFSC's (2011) carbon measurement guidelines. Dry tree biomass was calculated using the following allometric equations provided by Chave et al. (2005).

$$AGTB = 0.0509 \times (\rho \text{ x } DBH^2 \text{ x } H) \quad (1)$$

where, AGTB = above ground tree biomass of the sampled tree (kg), DBH = diameter at breast height (cm), H = tree height (m), ρ = wood density (gm/cm3). This equation is suitable for the moist region, which is the case for our study areas (Kavrepalanchok district is categorised as a moist region). For saplings, the following allometric equation was used (Tamrakar, 2000);