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Overstory structure and soil nutrients effect on plant diversity in unmanaged moist tropical forest

Mukesh Kumar Gautam [a, *], Rajesh Kumar Manhas [b], Ashutosh Kumar Tripathi [a]

[a] Forest Ecology and Environment Division, Forest Research Institute, Dehradun 248006, Uttarakhand, India
[b] Department of Botany, Govt. Degree College, Kathua, 184104, Jammu & Kashmir, India

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ABSTRACT

Forests with intensive management past are kept unmanaged to restore diversity and ecosystem functioning. Before perpetuating abandonment after protracted restitution, understanding its effect on forest vegetation is desirable. We studied plant diversity and its relation with environmental variables and stand structure in northern Indian unmanaged tropical moist deciduous forest. We hypothesized that post-abandonment species richness would have increased, and the structure of contemporary forest would be heterogeneous. Vegetation structure, composition, and diversity were recorded, in forty 0.1 ha plots selected randomly in four forest ranges. Three soil samples per 0.1 ha were assessed for physicochemistry, fine sand, and clay mineralogy. Contemporary forest had less species richness than pre-abandonment reference period. Fourteen species were recorded as either seedling or sapling, suggesting reappearance or immigration. For most species, regeneration was either absent or impaired. Ordination and multiple regression results showed that exchangeable base cations and phosphorous affected maximum tree diversity and structure variables. Significant correlations between soil moisture and temperature, and shrub layer was observed, besides tree layer correspondence with shrub richness, suggesting that dense overstory resulting from abandonment through its effect on soil conditions, is responsible for dense shrub layer. Herb layer diversity was negatively associated with tree layer and shrub overgrowth (i.e. *Mallotus* spp.). Protracted abandonment may not reinforce species richness and heterogeneity; perhaps result in high tree and shrub density in moist deciduous forests, which can impede immigrating or reappearing plant species establishment. This can be overcome by density/basal area reduction strategies, albeit for both tree and shrub layer.

1. Introduction

Past and present management strategies of varying intensities have caused decrease in the natural forests and species diversity in tropical Asia and elsewhere (Naughton-Treves et al., 2005; Paillet et al., 2010). About 15–47% of the natural forests in tropical Asia, exist in highly degraded state because of over-exploitation and poor management (Bhat et al., 2001). Plant species diversity is critical to the ecosystem processes and functioning (Loreau et al., 2001), and of all the efforts that prioritize conservation, cessation of forest management by proscription is considered the principal mechanism to arrest biodiversity drain, and reinforce species diversity (Naughton-Treves et al., 2005; Laurance et al., 2012). The remaining natural unmanaged forests of south Asia, including India are mostly post-extracted secondary forests, which have undergone frequent silvicultural disturbances of high intensities over large areas during first few decades of bygone century (Bhat et al., 2001). As an intermediary management strategy, abandonment of disturbed forest landscapes was preferred as restoration and conservation strategy, so that they can get requisite time to resurrect pre-disturbance predisposing site conditions and recover naturally.

Accordingly, unmanaged forests are critical for the biodiversity maintenance and reinforcement, and sustainable forestry. Among managed and unmanaged forest, the latter is considered species rich and heterogeneous, having mosaic of different ages and developmental stages (Paillet et al., 2010; Sitzia et al., 2012). However, a number of studies failed to agree with the facilitative effect of unmanaged abandonment forests on species richness,

* Corresponding author. Present address: 2081 Wallace Avenue, Bronx 10462, NY, New York, USA. Tel.: +1 848 610 0250.
E-mail addresses: mukeshcric@gmail.com (M.K. Gautam), manhasrk@gmail.com (R.K. Manhas), tripathiak@icfre.org (A.K. Tripathi).

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diversity, and regeneration (Nagaike et al., 2003; Banda et al., 2006). Studies from tropical dry and moist unmanaged forests, which had a history of exploitation, reported either none or feeble effect of abandonment (Shackleton, 2000; Banda et al., 2006). To this end, studies with targeted harvesting (Battles et al., 2001; Elliott and Knoepp, 2005; Banda et al., 2006) refuted the claims of other studies (Roberts and Zhu, 2002) which advocated that cessation of management activities provide ameliorative conditions for species dispersal compared to managed forests. Studies also showed positive effect of various management strategies on species richness, diversity, and regeneration (Torras and Saura, 2008; Heinrichs and Schmidt, 2009; Ares et al., 2009). For example, several early successional plant species absent in unmanaged forest appear in the harvest gaps; and in conjugation with several late successional species already present and developed during abandonment phase, enhances the plant diversity (Nagaike et al., 2003; Torras and Saura, 2008).

Most of the contemporary protected forests in India have been disturbed significantly through intensive logging and clearfelling in the initial few decades of last century (Bhat et al., 2001). To halt biodiversity drain increasingly more forests are designated protected through proscription. It is believed that abandonment of intensively managed forests would reinstate natural succession in them, insofar that diversity restoration and reinforcement can be maximized. It is assumed that small-scale disturbances mixed with occasional large-scale disturbances allow early successional species to co-exist with late-successional species in unmanaged forest (Roberts and Gilliam, 1995; Shea et al., 2004; Elliott and Knoepp, 2005; Paillet et al., 2010). Although biodiversity recovery is the primary focus of the creation of unmanaged forests, yet retrospective studies are not prioritized to check the effectiveness of this measure in tropical forests even after protracted cessation of forest management. Under new conservation paradigm, it is suggested that biodiversity conservation and the forest management of unmanaged forests can be prioritized concurrently without jeopardizing ecosystem functioning (Naughton-Treves et al., 2005). After a successful proscription phase, rescinding protection and optimizing management strategies within intermediate intensities that mimic natural intensities, can help achieve multiple benefits, including species conservation (Ares et al., 2009). This assumption is rooted in the fact that forest management strategies akin to intermediate disturbance induce ecological processes that are beneficial to diversity (Roberts and Gilliam, 1995) including ecosystem services (Naughton-Treves et al., 2005).

Depending on the characteristics of the interventions, recovery to the natural state via abandonment of forest management is a slow process. However, length and continuance of the restitution time of abandonment can be critical to the recovery of species diversity and composition. The maintenance of species diversity in forest ecosystems emphasized evaluating the long-term impacts of forest management on species diversity (Montes et al., 2005; Paillet et al., 2010). However, information relating past management practices to current species composition and diversity in unmanaged forests is generally lacking, most importantly for tropical forests. The retrospective study of an unmanaged forest against historically managed forests offers a valuable opportunity to learn about the long-term changes in the diversity since abandonment following silvicultural disturbance. By doing so, we could gain important information needed to better predict the effects of management strategies on species diversity and composition.

Before acceding to perpetuate protection after a fairly protracted restitution time, understanding its effects on diversity, abundance, and regeneration need re-examination. In addition to this, understanding key environmental factors that help them achieve healthy state is imperative because such information may help in updating forest management strategies. In this study, conducted in the moist deciduous forests experiencing cessation from last thirty years, we studied overstory and understory vegetation, soil physicochemical properties, and sand and clay mineralogy with the objectives (a) to quantify current pattern of species richness, diversity, and structure, (b) to retrospectively evaluate difference in the species richness between pre- and post-abandonment period and qualitatively document any change in species composition based on pre-abandonment reference point, (c) to evaluate the relationship of vegetation with overstory structure and environmental factors and, (d) to use this information in vegetation management to achieve a restoration goal of reference period conditions. Finally, for management underpinning we studied sand and clay mineralogy to diagnose prospective soil nutrients status. This is important for forests growing on weathered parent material because large-scale permanent nutrients export through density reduction strategies can create growth limiting nutrient deficiencies and intensify nutrient competition, especially among regenerating species.

2. Material and methods

2.1. Study site

The study was conducted in the north Indian moist deciduous forests, Dehradun (29° 55′ and 30° 30′ N and 77° 35′ and 78° 24′ E). The average maximum and minimum temperatures were 27.7 °C and 13.8 °C, respectively. These forests receive most of their annual rainfall from June to September (Supplementary Fig. S1).

Vegetation of the region is dominated by dipterocarp Sal (*Shorea robusta*) – a climax species. *Mallotus philipp*ensis, *Syzygium cumini*, and *Terminalia alata* are important associate tree species of Sal forests (Bhatnagar, 1960; Gautam et al., 2007). Among them, *M. philipp*ensis is predominantly present as lower canopy tree. *M. philippensis–S. robusta* association is the most dominant for the regions' forest. *Clerodendrum viscosum* was the most abundant species of the shrub layer followed by *Ardisia solanacea*, and *Murraya koenigii* (Supplementary Table S2).

Doon valley forests are unmanaged and have not been influenced by direct forest management from last >30 years (Supplementary information appendix 2). Forest management here refers to the cessation of harvesting in any form and other subsidiary cultural operations. Doon valley has had a forest management plan since 1860 (online resource appendix 2). Information about the past managements and silvicultural treatments were ascertained from historic forests management records. However, all the successive management plans included only a qualitative description of a few taxa and quantitative stand data limited only to a few timber producing species until 1960 when first phytosociological study had been carried out, though limited in scope.

2.2. Phytosociological studies

We surveyed vegetation using nested quadrat method in four forests ranges, by laying 400 quadrats each for tree (100 m^2), shrub (9 m^2), and herb layers (1 m^2) in forty 0.1 ha plots. In each forest range, 100 quadrats were laid for each layer. The plants were assigned to different layers: tree layer included species with ≥5 cm diameter; shrub layer included woody species having >1 m height and 1.5–5-cm diameter; and herb layer included all the species ≤1 m height. Tree saplings were included in the shrub layer and the seedlings of trees and shrubs in the herb layer. Despite protection, peripheries of tropical forests close to roads and habitation are generally disturbed (Sagar et al., 2003). To remove any discrepancy resulting from potential disturbance, we selected sites after reconnaissance survey with no visible signs of human intervention.