Journal of Asia-Pacific Biodiversity 9 (2016) 144–151

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Journal of Asia-Pacific Biodiversity

journal homepage: http://www.elsevier.com/locate/japb

Journal of Asia-Pacific Biodiversity

Original article

# Patterns of diversity and regeneration in unmanaged moist deciduous forests in response to disturbance in Shiwalik Himalayas, India

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ARTICLE INFO

*Article history:*
Received 16 June 2015
Accepted 7 January 2016
Available online 16 January 2016

*Keywords:*
forest disturbance
intermediate disturbance
population structure
regeneration
unmanaged forest

ABSTRACT

We studied vegetation attributes in Indian tropical moist deciduous unmanaged forests to determine the influence of forest disturbances on them. We enumerated 89 species: 72 under moderate disturbance and 54 under least disturbance. The data from 3399 stems [>5 cm diameter at breast height (dbh)] decreased linearly along the disturbance gradient. The basal area was largest in least disturbed forests (61 $m_2$/ha) and smallest in intensely disturbed forest (41 $m_2$/ha). Under least and moderate disturbance, tree density-diameter distribution had negative exponential curves, whereas highly disturbed forests had unimodal-shaped curves where a few trees 5–10 cm and >50 cm in diameter were recorded. Most tree and shrub layer species under heavy and intense disturbance had impaired regeneration. Moderate disturbance intensity thus apparently benefits species diversity, stand density, and regeneration. Decline in seedlings and saplings, especially tree species, threaten forest regeneration and the maintenance of species diversity of unmanaged tropical forests.



## Introduction

Several factors at different spatial scales influence species diversity, composition, and structure of tropical forests (Peña-Claros et al 2012). On the regional and local scale, diversity and structure are strongly influenced by natural and anthropogenic disturbances (Wright 2005; Peres et al 2006; Sheil and Burslem 2003).

The relationships between disturbance with plant diversity, composition, structure, and regeneration have been discussed in many studies. Natural and anthropogenic disturbances are critical to plant diversity, structure, and regeneration of forest ecosystems (Pandey and Shukla 2003; Sagar et al 2003; Mishra et al 2004; Zhu et al 2007) because both forms of disturbance alter environmental conditions, ecosystem processes, nutrient availability, and plant–plant interactions (Sheil and Burslem 2003; Walker 2012). Empirical studies show that, as the frequency and intensity of disturbance increase, plant diversity and other associated vegetation attributes decrease (Peltzer et al 2000; Sapkota et al 2009; Takafumi and Hiura 2009; Pretto et al 2010; Mayor et al 2012). This phenomenon occurs because only a few disturbance-resistant and/or disturbance-tolerant species can persist under intense and frequent disturbance (Roberts and Gilliam 1995). Connell (1978) postulated that as disturbance increases, species diversity should also increase to the point of intermediate disturbance intensity, size, and frequency because disturbance-resistant and superior competitor species can coexist with many species persisting as intermediate species in various stage of recovery. In particular, several field-based studies from tropical and temperate forests report that species richness, diversity, and regeneration peak at intermediate disturbance and decrease beyond that point (Hobbs and Huenneke 1992; Peltzer et al 2000; Molino and Sabatier 2001; Bongers et al 2009; Mayor et al 2012). By contrast, other studies report noncompliance to the intermediate disturbance effect on species diversity (Shea et al 2004; Kershaw and Mallik 2013). A significant increase in anthropogenic disturbance and coupled ongoing biodiversity loss necessitate learning about the relation of disturbance with species diversity, structure, and regeneration.

In general, in most fragmented tropical forests, a very large network of reserve forests has been created that is unmanaged or under protection. The motive of this exercise is postdisturbance forest (i.e. vegetation) recovery by weakening disintegrating forces inimical to the forest structure and diversity. Despite protection and

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Peer review under responsibility of National Science Museum of Korea (NSMK) and Korea National Arboretum (KNA).

http://dx.doi.org/10.1016/j.japb.2016.01.004
pISSN2287-884X eISSN2287-9544/Copyright © 2016, National Science Museum of Korea (NSMK) and Korea National Arboretum (KNA). Production and hosting by Elsevier.

all best efforts to conserve biodiversity, tropical forests experience anthropogenic disturbance. The intensity and frequency of anthropogenic disturbance change periodically. Large-scale felling may not occur, but several small-scale intensive and frequent disturbances (e.g. pruning and lopping for fuel wood and fodder, grazing, browsing, and fire) occur, which may have similar effects as large-scale felling on diversity and structure. Several studies report the prevalence of ancillary disturbances (e.g. pruning, lopping, fire, grazing, and browsing) in protected and reserve forests and their simultaneous impact on plant species diversity, stand structure, and forest regeneration (Muthuramkumar et al 2006; Torras and Saura 2008; Sapkota et al 2009).

With increasing anthropogenic disturbances and consequent transformation of tropical forests, even in protected/reserve forests (Muthuramkumar et al 2006), it has become imperative to assess whether such areas realize their goal of biodiversity conservation. The prioritization and realization concerning the conservation potential of protected forests would evidently benefit from diversity-disturbance studies from tropical forests. This factor needs further elaboration because the effects of different disturbance levels on diversity, structure, and regeneration of unmanaged forest are deficient, if not missing. Hence, the diversity-disturbance debate needs further work in unmanaged forests to understand how the conservation of such optimal zones can be prioritized under scenarios of anthropogenic disturbances. Because of the lack of disturbance studies focusing on unmanaged forests, this study was undertaken to provide a disturbance index for moist deciduous unmanaged forests, to characterize the compositional and structural changes along various disturbance intensities (DIs), and to explore the relationship of these intensities with the change in species diversity, structure, and regeneration. We anticipated that in protected forests, which are now unmanaged, disturbances should be concentrated on lower diameter at breast height (dbh) trees or lower story trees. We further anticipated that the effect of disturbance would be distinctive for different tree layers and different vegetation layers. We further anticipated that the least and mild disturbances had a moderating effect on diversity, structure, and regeneration of unmanaged forests.

## Material and methods

### Study site

This study was performed in four forest ranges of moist deciduous forests in Shiwalik Forest Division (Dehradun District) of India (29°55′ and 30°30′ North and 77°35′ and 78°24′ East), which is dominated by late successional *Shorea robusta* (Sal) (Figure S1). Elevation of the study region ranges 600–800 m above the mean sea level. The region has a humid tropical monsoon climate with three seasons: hot and humid summer (March–June), hot and humid rainy season (July–September), and winter (October–February). Annual temperature ranges from 1.8°C (in January) to 40.0°C (in June). The region receives average annual rainfall of 2,025.43 mm, the bulk of which is received during the rainy season from June to September. The study forests were growing on the alluvial piedmont plain, which consists of deep, medium to moderately fine-textured, well-drained loamy soils belonging to Inceptisols and Alfisols. Epipedon showed feeble O-horizon and A-horizon with a less dense litter layer, especially at sites that were heavily disturbed. The soil $pH_{H2O}$ was moderately acidic (5.34–6.46). The percentage of organic carbon was 1.02–2.70%: Organic matter was in the range of 2.50–3.74%: The total nitrogen and available nitrogen were 0.08–0.19% and 0.01–0.03%, respectively. Cation exchange capacity ranged from 18.37 cmol (p+)/kg to 9.97 cmol (p+)/kg. The exchangeable calcium ranged was from 5.58 cmol (p+)/kg to 3.96 cmol (p+)/kg. The exchangeable magnesium ranged from 4.38 cmol (p+)/kg to 2.79 cmol (p+)/kg, and potassium ranged from 0.67 cmol (p+)/kg to 0.42 cmol (p+)/kg.

Forests in the Shiwalik belt have a long history of disturbance. Their natural distribution was radically altered in the past 150 years of disintegrating anthropogenic interventions (Appendix S1). In 1980, these forests were classified as reserved forests through enactment of conservation laws to halt the recede in their cover and reinforce conservation. Despite protection, anthropogenic pressures on these forests are increasing in the form of expanding habitation, illegal harvesting, lopping, grazing, forest fires, tourism, and industrial expansion. Human population increased by 1123% and density by 900% during the past 130 years in the region. From 1880 to 2001, arable land increased from 41,000 ha to 709,740 ha and livestock population increased from 168,000 animals to 887,918 animals.

### Sampling design, data collection, and disturbance assessment

In each of the four forests, 10 sample plots of 0.1 ha were established. Within each plot, 10 quadrats of 10 m × 10 m were laid to inventorize the tree layer. Within the center of each 10 m × 10 m quadrat, a 3 m × 3 m quadrat and a 1 m × 1 m quadrat were nested to inventorize shrub and herb layers species composition and diversity. Plants were assigned to different layers, based on their height and diameter: trees > 5 cm dbh, shrubs (and woody species) > 1.0 m in height and/or 1.5–5 cm in diameter, and herbs (all species) < 1.0 m in height and/or < 1.5 cm in diameter. Saplings (i.e. trees) were included in the shrub layer, whereas seedlings (i.e. trees and shrubs) were included in the herb layer. In every quadrat, the number of individuals (for abundance) and the diameter of each species were recorded. For trees, the diameter at breast height (dbh) was obtained, and for shrubs and herbs, the collar diameter was measured.

Various prevailing influencing and causative disturbance factors were identified and their intensities were recorded. The major disturbances (i.e. causative factors) in these forests were grazing-browsing, fodder/fuel wood cutting/lopping, fire, and insect attack. The influencing factors (i.e. factors that influence the frequency and intensity of disturbances) that were included in devising the DIs were distance from a road, distance from human settlements, and distance from agriculture and tourism. All disturbances were anthropogenic, except for insect attack and grazing (which include wild animals). Disturbance intensities for various forests were estimated in accordance with the method of Sagar et al (2003) and Zhu et al (2007). A site that was at the maximum distance from a road, agricultural land, habitations, or recreation spots was assigned intensity 1 (i.e. minimum intensity). The intensities for the other sites were calculated as the ratio of the distance of site to the distance of other sites. For instance, the criterion for adjudging the site disturbance intensity is the maximum values for the disturbance factors (i.e. 9,000 m, 9,140 m, 8,921 m, and 8,789 m) for a site's distance from a road, habitations, agricultural and tourism spots respectively (i.e. impact factor 1). The nearest distance of a site from a road, habitations, recreation spots, and agricultural land was 300 m, 330 m, 300 m, and 320 m, respectively. Thus, the highest impact factor for road (9000/300), habitations (9,140/330), tourism spots (8,921/300), and agricultural land (8,789/320) were 30, 27.77, 29.73, and 27.46, respectively. Cutting/lopping and insect attack intensities were similarly calculated by the relative trees affected (%) and that of GP (grazing pressure) by sapling density. Fire intensity was assessed from the forest records; the past 10 years' fire incidences were collated and categorized as "recent" (i.e. < 2 years; intensity 2), "old" (i.e. > 2 years but < 5 years; intensity 3) and "very old" (i.e. > 5 years; intensity 1). Sites