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Developmental dynamics following selective logging of an evergreen oak forest in the Eastern Himalaya, Bhutan: Structure, composition, and spatial pattern

Kristofer Covey[a,*], Charles J.W. Carroll[b], Marlyse C. Duguid[a], Kuenzang Dorji[c], Tsewang Dorji[d], Sonam Tashi[e], Thinley Wangdi[e], Mark Ashton[a]

[a] School of Forestry and Environmental Studies, Yale University New Haven, CT 06511, USA
[b] Graduate Degree Program in Ecology, Colorado State University, Fort Collins, CO 80523, USA
[c] Ugyen Wangchuck Institute for Conservation and Environment, Lamai Gompa, Bumthang, Bhutan
[d] Renewable Natural Resources Research and Development Center, Jakar, Bhutan
[e] Renewable Natural Resources Research and Development Center, Yusipang, Bhutan

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ABSTRACT

Brown oak (*Quercus semecarpifolia*, a.k.a. Kharsu, bji shing) is a biologically and economically important evergreen broadleaved tree that dominates moist temperate and lower-montane forests throughout the mid-elevation Himalaya. We demarcated two paired spatially explicit one-hectare plots in an experimentally harvested area and an unharvested old growth reserve of *Q. semecarpifolia* dominated forest in the Bhutan Himalaya. We compared the structure, species composition and diversity, and spatial relationships between the two plots. To test whether harvesting had been successful in establishing a new cohort of oak we compared regeneration in plots established in 1999, to data gathered over ten years after. Regeneration plots showed a paucity of *Quercus* regeneration in both stands. Logging did not reduce tree species richness; however, Shannon diversity, Simpson diversity, and evenness were all lower in the logged stand. We used univariate and bivariate Ripley's-K functions to assess the spatial distribution of trees in both stands and test whether single tree felling had altered the spatial relationships among and between species. Understory species were clumped at scales >30 m in canopy gaps in the old-growth reserve, whereas distribution in the logged plot was more random. Relationships between species show similar patterns with more than 80% of species showing significant clumping at scales from 12 m to 30 m, while ~70% of relationships in the logged plot showed complete spatial randomness. In the old-growth reserve several species showed significant dispersion away from canopy dominant oaks. Scarce regeneration and significant changes in spatial pattern development in the harvested stand suggest changes to current silvicultural practice are needed.

1. Introduction

Existing at elevations between 2000 and 3000 m, *Quercus semecarpifolia* (brown, oak a.k.a. Kharsu, bji shing) is found throughout the moist mid-elevation Himalaya in pure stands and in mixed communities with broadleaved (e.g. *Betula* spp., *Pyrus* spp., *Juglians regia*, *Prunus* spp., *Acer* spp., *Fraxinus* spp., *Rhododendron* spp.), and conifer (e.g. *Tsuga dumosa*, *Taxus baccata*, *Pinus wallichiana*) tree species, and often with a diverse shrub layer (e.g. *Rosa* spp., *Rubus* spp., *Virbunum* spp., *Lonicera* spp. *Pieris* spp., *Berberis* spp. and *Daphne bholua* (Troup, 1921; Sargent, 1985; RGOB, 2004). Capable of withstanding minimum temperatures of −15 °C, *Q. semecarpifolia* prefers mean annual temperatures between 5 and 17 °C, annual rainfall around 1000–2500 mm, and a dry season not extending more than 4–6 months (Orwa et al., 2009). The species is most dominant on north-facing slopes from 2400 to 3600 m though in China it grows right up to the tree line, where it becomes a thicket-forming shrub (Gamble, 1881; Bean, 1916). At maturity *Q. semecarpifolia* commonly reaches 24–30 m tall and 60–70 cm in diameter at breast height (dbh). Seedling growth rates are modest, averaging 5–10 cm a year (Troup, 1921). In youth, the species is tolerant to moderate side shade (Huxley et al., 1992), but mature individuals are less tolerant (Gamble, 1881).

Recognizing the impacts of deforestation in neighboring countries, the Bhutanese government has set as its goal the permanent

* Corresponding author.
E-mail address: Kristofer.covey@yale.edu (K. Covey).

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maintenance of 60% forest cover. Forests are to be managed for multiple values including: timber and non-timber forest products, biodiversity, water quality, grazing, fodder production, and human happiness (RGOB, 2004). Similar to other forest types in Bhutan, *Q. semecarpifolia* dominated forests have not been systematically managed in the past, and in addition are heavily grazed by cattle in the summer months, and yaks in the winter (Biswas, 1986; Davidson, 2000). Historically, silviculture has been limited to single tree removal, where canopy dominant *Q. semecarpifolia* are manually felled and removed to open gaps to promote understory development. Attempts at establishing natural regeneration of oak species in Bhutanese broadleaved forests have thus far proved unsuccessful, and there is growing concern about the suitability of this model for maintaining oak species following harvest (RGOB, 2004; Buffum et al., 2008) under current harvest regimes. Regeneration difficulties are not limited to Bhutan. In fact, most studies report a paucity of *Q. semecarpifolia* regeneration (Upreti et al., 1985; Singh and Singh, 1986; Dhar et al., 1997; Vetaas, 2000; Shrestha, 2003). Many of these studies suggest that intensive grazing is the most important factor inhibiting regeneration in Himalayan oak forests. However, oak's recalcitrant, short-lived seeds and shade intolerance are often cited as limiting vigorous regeneration as well (Bisht et al., 2012; Verma et al., 2012). It is suspected that abundant light is the essential element in securing dense regeneration with areas near forest edges and isolated parent trees well stocked with vigorous seedlings (Jackson, 1984; Orwa et al., 2009). Metz (1997) also proposed that regeneration for this forest type is limited by small gap size and a lack of catastrophic disturbances (e.g. fire or windthrow), and suggests canopy openings greater than 400 m^2 are necessary to regenerate existing stands, though ample regeneration has been observed in relatively undisturbed stands (Wangda and Ohsawa, 2006). Irregular seed production, defoliation, acorn predation, decreased or increased fire incidence and extensive lopping have also been blamed for scarce regeneration (Singh and Singh, 1986; Lorimer et al., 1994; Thadani and Ashton, 1995).

Evidence from many oak forest dynamics studies from the past three decades suggest that allogenic disturbance and initial floristics restrict the maturation and development of most oak forest systems worldwide (Oliver, 1992; Abrams et al., 1995; Baker et al., 2005). These processes are well-demonstrated in other temperate deciduous and evergreen oak systems in Asia (Sano, 1997; Suh and Lee, 1998; Wangda and Ohsawa, 2006), Europe (Reif et al., 1999; Harmer and Morgan, 2007; Dobrowolska, 2008), and North America (Oliver and Stephens, 1977; Ruffner and Abrams, 1998; Liptzin and Ashton, 1999). Taken together, these studies describe a genus that is generally long-lived and intolerant of shade. Even where it dominates the canopy *Quercus* species are generally not present in lower strata, except in the aftermath of semi-lethal disturbance (Johnson et al., 2002). This literature suggests, a disconnect between the natural regeneration patterns of *Quercus* dominated forests and the single tree selection system practiced for rural use harvesting in Bhutanese forest management units.

Although *Q. semecarpifolia* forests are important both culturally and economically, relatively little is known about them. There have been a few studies classifying the forest type (Sargent, 1985; Upreti et al., 1985), and exploring the social values of these forests (Fischer, 1976; Biswas, 1986), but to date there has been no work exploring spatial pattern, structure and composition of old-growth *Q. semecarpifolia* forests in relation to selective timber harvesting. In this study we examine the hypothesis that single-tree harvesting may not provide conditions adequate for the regeneration of *Q. semecarpifolia*. In addition, we test if selection harvesting alters the spatial relationships between and among species. We describe the composition and structure of harvested and unharvested large-spatially explicit forest plots in a Bhutanese evergreen oak forest. We analyze differences in spatial patterns, and discuss implications for the sustainable management of *Q. semecarpifolia* dominated forests in the mid-elevation Himalaya. We believe, given the dearth of information within the Central Himalayan region that this is the first careful analysis of selective timber harvesting and its effects on this forest type's spatial pattern, structure, regeneration, and composition.

2. Materials and methods

2.1. Site description

In 1999 the Bhutanese Department of Forestry developed a 9 ha *Q. semecarpifolia* research area in Chimithanka, within the Gidikom Forest Management Unit (FMU) (27°26′N, 89°30′E), 15 km west of Thimphu (Fig. 1). Set at an elevation of 3000 m on a northwesterly aspect, slopes range from 20–70° with an average slope of 25°. Annual rainfall is approximately 720 mm per year and strongly seasonal, with the majority of rainfall concentrated during the summer monsoon months from June through August. Annual temperature varies between 8 °C and 30 °C. Soils throughout the site are fairly uniform; deep, acidic, well drained, and rich in organic matter (>5.5%) (BSS/NSSC, 2003); using the USDA (1975) soil classification the soils would be considered udults. The forest is routinely grazed in both the winter and summer months; evidence of browse is nearly ubiquitous. Stems of *Q. semecarpifolia* in Gidakom FMU are generally marked for removal by a government forester on behalf of a rural villager, felled by local workmen and removed by being rolled down hill, most commonly for use as fuelwood.

Experimental felling and the establishment of understory regeneration plots took place in 2000 as part of an earlier study (Tashi and Thinley, 2008). At that time, a total of 12 large trees (9 *Q. semecarpifolia.* 1 *Quercus thompsonii,* 1 *Betula alnoides,* 1 *T. dumosa*) (~11 $m^2\ ha^{-1}$, or ~22% of total basal area) were removed from within the 1 ha harvested plot. Small diameter fuelwood was also removed from the stand at this time. Selection thinnings (as defined by Smith et al., 1997), like this one, where the largest stems of marketable species are removed are commonly prescribed for rural use harvesting in this forest type (RGOB, 2004). A network of 1142 m^2 systematic regeneration plots were established on a 30 m grid in the harvested stand at this time. Additionally 1210 × 10 m plots were established following harvest to assess the long-term impacts of cattle and yak grazing in the stand. Located near the center of the stand, across a range of existing light environments. Half of these plots were fenced with 5-strand barbed wire, while the remaining 6 were left open to grazing. A detailed report of the existing regeneration and grazing exclusion plot network and a report of individual seedling performance over the 3 years following harvest was produced by Tashi and Thinley (2008). An adjacent 10 ha area of similar density (~45 $m^2\ ha^{-1}$ of total basal area in the reserve vs. 49 $m^2\ ha^{-1}$ in the harvested) and composition (32.8 $m^2\ ha^{-1}$ *Q. semecarpifolia* in the reserve stand vs. 29.8 $m^2\ ha^{-1}$ in the harvested stand) was selected prior to harvest and set aside as an old-growth reserve to serve as a control stand prior to harvesting

In June 2009, we demarcated and measured 1-hectare spatially explicit plots within paired, experimentally-harvested, and reserve stands. Due to extreme slopes (20–65%), spatially explicit plots were shaped differently to cover similar elevation gradients. The spatially explicit plot within the harvested stand was 50 m × 200 m, and the spatially explicit plot within the reserve stand was 100 m × 100 m. Both spatially explicit plots were randomly located inside an existing systematic network of