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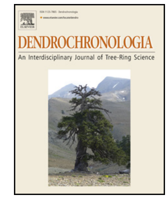

Applied dendroecology informs the sustainable management of Blue Pine forests in Bhutan

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ABSTRACT

Tree ring science is a new discipline in Bhutan but has contributed substantially to our understanding of climate history and informed sustainable forest management practices in the country. This paper describes dendroecological contributions to the second aspect for Blue Pine using three case studies. i) The effects of livestock grazing impact on Blue Pine radial growth were quantified. Radial growth increment was tendentially higher after three years of livestock exclosure, as compared to continued grazing. However, differences remained statistically not significant, likely due to the brevity of the treatment period. ii) Radial growth rates of Blue Pine were characterized across a 400 m elevation gradient. Cumulative radial growth over 40 years differed by a factor of more than three between the low and the high end of the gradient. However, below 2300 m, radial growth showed a continuous decline from 1990, likely as a results of drought due to climate change. iii) Effects of three levels of prescribed thinning of pole stage (DBH 30–50 cm) Blue Pine in central Bhutan showed distinct response to thinning. Heavy thinning lead to a thinning shock in the year after harvest and did not lead to significantly higher radial growth as compared to moderate thinning, which is thus recommended for the species. A positive thinning effect remained for seven years post operation. The case studies were incorporated into national guidelines on sustainable forest management in Bhutan and prove the demand for tree ring based research to inform policy and practice.

1. Introduction

In Bhutan in the eastern Himalayas, forests dominate land cover, occupying a total of 2,730,889 ha, which equals to 71% of the country's territory (Forest Resources Management Division, 2016). The maintenance of at least 60% forest cover is a constitutional requirement (Constitution of the Kingdom of Bhutan, 2008) and to maintain this, the Ministry of Agriculture and Forests (MoAF) is challenged to balance the environmental pressures on forests that arise from the country's rapid economic development and climate change, with maintaining the integrity and natural health of forests. Towards this goal, the MoAF has adopted several policies and emphasized on research to inform sustainable management practices that were prescribed in the Forest Management Code of Bhutan.

Tree ring research played an important role in this process after its introduction to Bhutan in 2002 by the Tree Ring Laboratory of the Lamont Doherty Earth Observatory (TRL-LDEO), Columbia University. Initially, studies were restricted to the conifer zone, with an emphasis on environmental change, using long (500–700 years) tree-ring records. Since 2002, tree ring studies in Bhutan investigated matters of concern to multiple-use forest management and the role of climate on tree growth at local (Wangda et al., 2009), regional (Buckley et al., 2005; Krusic et al., 2015) and continental scales (Cook et al., 2010). Consequently, more applied applications focusing on sustainable forest management received emphasis.

Though Bhutanese tree-ring collections have contributed to our understanding of large-scale climate variability over the greater South Asia region, this paper focuses on various applied uses of tree-ring information to address practical questions related to sustainable, multiple use forest management in Bhutan, including silvicultural operations, animal husbandry, and basic forest growth-and-yield research. Providing scientific evidence for sustainable management of Blue Pine

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(*Pinus wallichiana* A.B.Jacks.) forests was an early identified priority. Blue Pine is a light demanding, drought tolerant pioneer species (Gratzer et al., 2004) with relatively large seeds that regenerates well under moderate grazing pressure and exhibits remarkable growth rates. The timber is easy to work with, can be carved, does not warp and is relatively durable (Tenzin and Hilton, 2001). In central Bhutan, Blue Pine does not have major pests, but in the west it is heavily infected by mistletoes (Dorji, 2007). Blue Pine is the most preferred species of Bhutanese carpenters and is the material of choice for traditional houses, some of which require up to 90 trees for construction. Additionally, needles are used for animal bedding and rituals. Blue Pine forests cover most of the high altitude inner dry valleys of the eastern Himalayas above 2200 masl. with distinct climatic conditions (Schweinfurth, 1956). Here Blue Pine primarily occurs in secondary mono-specific even-aged stands that have regenerated on land formerly used for extensive agriculture. Additionally, Blue Pine is an important intermixed species in the dry variants of mixed conifer forests between 2400 and 2900 masl.

The largely Blue Pine covered high altitude inner dry valleys of Bhutan, including Thimphu, Paro and Bumthang are the main political, economic, cultural, religious and population centers of the country. It is thus unsurprising that the species is the most intensively utilized in Bhutan, even though Blue Pine forests represent only 4% of the total forest area of Bhutan (Forest Resources Management Division, 2016). Blue Pine forests are subject to anthropogenic pressures including land use change, demand for timber and firewood, increased fire incidence and over grazing.

Forest grazing is an important component of land use in Bhutan, as 90% of rural Bhutanese households own cattle (Norbu, 2002), forest grazing provides 22% of the national fodder requirement (Roder, 2002) and agricultural production heavily relies on nutrient transfer from forests via manure (Roder et al., 2003). Even though extensive animal husbandry practices, including forest grazing are increasingly replaced through intensive practices, such as stall feeding (Wangchuk et al., 2014), forest grazing remains an important forest use throughout the country and has been at the center of professional debates on sustainable forest management for a long time. While several studies on the impacts of forest grazing on the regeneration of conifer (Darabant et al., 2007; Gratzer et al., 1999; Wangchuk et al., 2012) and of broadleaf forests (Davidson and Project, 2000; Norbu, 2002; Seydack and BG-SRDP, 2001) have been carried out, the impacts of grazing on tree growth remained unexplored.

Blue Pine is a species with a very wide ecological amplitude and can span an altitudinal gradient of 1200 m (Grierson and Long, 1983). Across its range, Blue Pine is found in regions where rainfall varies from 450 mm to 1500 mm whereas in Bhutan it is restricted to locations where precipitation varies from 1000 mm to 1500 mm in the country (Tenzin and Hilton, 2001). Due to lack of weather station inside the forests in the country, very little is known about the climatic conditions inside the forested areas of the country. While basic growth and yield data were available from average growth conditions in inner dry valleys (Rinchen et al., 1998), the range of variability along its altitudinal range required characterization.

Blue Pine forests frequently form even-aged stands that have regenerated after transformation in land use practices in the 1960s and 1970s. Once these stands have entered the stem exclusion phase, mortality set in on large scales, increasing the predisposition for bark beetle calamities and fires. Thinning of these stands thus became a management priority along with the knowledge on the growth and yield characteristics of Blue Pine under different thinning regimes (Rosset, 1999). While various growth and yield characteristics have been addressed (Rai et al., 2010) and informed current thinning practice of Blue Pine in Bhutan (Darabant et al., 2012), annual increments under different thinning regimes based on tree ring analysis remained an open research question.

Key priorities for applied dendroecological research thus included improved knowledge on growth and yield of Blue Pine, specifically addressing the impacts of grazing on radial increment (Case Study 1), the altitudinal variability of radial increment (Case Study 2), and the impacts of different thinning operations on radial increment (Case Study 3).

2. Materials and methods

Case study 1 assessed the impacts of uncontrolled cattle grazing on the growth of Blue Pine. For five years, from 1998 to 2003, 60 acres of forested grazing land was divided into two plots, one of which was fenced. 38 cattle grazed in the unfenced plot, while grazing was excluded from the fenced plot. In autumn 2003, 32 randomly located trees were cored (two cores per tree) in each plot to explore the impact of grazing on Blue pine radial increment.

Case study 2 on growth patterns of Blue pine along an altitudinal gradient was conducted in a mono-specific Blue Pine forest in Dotey block in Paro valley (Tshering, 2013). Sampling was carried out along an altitudinal transect located between 2100 and 2500 masl with constant exposition. Five recording plots were established at 100 m altitudinal intervals. In each plot, five trees free of signs of disease or damage were randomly selected for each of the diameter classes 10–20 cm, 21–30 cm and 31–40 cm diameter at breast height (DBH). From each sampled tree, two increment cores were collected, resulting in a total of one hundred and fifty increment cores.

Case study 3 was conducted in an unmanaged even-aged Blue Pine forest that regenerated in the mid to late 1960s. In 1986, three plots of 60 m by 60 m were established for a thinning trial. Two plots were randomly assigned to two different intensities of selection thinning, while the third plot remained untreated. The two thinning treatments were defined by the removal of a prescribed percentage of the initial basal area: *i*) moderate thinning (25% removal) and *ii*) heavy thinning (35% removal) (for details of thinning regimes refer to Rai et al. (2010)). In 2003, every fifth tree from each plot was cored and analyzed.

In all case studies (Fig. 1), tree-ring sampling was performed using increment cores, due to convenience of coring, conservation laws, and the immensely remote conditions of many of Bhutan's forested regions. Increment cores were prepared in the traditional manner, mounted on wooden core mounts, sanded to a highly polished surface (Krusic et al., 1987), and crossdated (Stokes and Smiley, 1968). Crossdated samples were measured through a 1–40x variable zoom stereoscope above a Velmex measuring stage (0.001 mm precision). Data capture was performed by the tree-ring measuring program PJK (Krusic, 2013). The integrity of the cross dating and ring-width measurement was evaluated using the software COFECHA (Holmes, 1983), and chronology development is performed using the software ARSTAN (Cook et al., 2015).

3. Results

3.1. Case study 1

For trees in the fenced plot, the mean inter-series correlation (Rbar) was 0.522 and the expressed population signal (EPS) was 0.972 (Wigley et al., 1984). For the samples taken in the unfenced plot, the Rbar was 0.709, and the EPS was 0.988. Differences in mean growth rates of trees between fenced und unfenced plots were not statistically significant at any point of time during the investigated period of 1998–2003. However, from 2000 onwards, a statistically not significant trend of higher mean growth rate in the fenced plot as compared to the unfenced plot was observed (Fig. 2).

3.2. Case study 2

The cumulative mean radial growth rates diminished consecutively with increasing altitude. Cumulative radial increment was highest at