Dendroecological studies in the Nepal Himalaya - review and outlook in the context of a new research initiative (TREELINE)

N. Schwab, U. Schickhoff, B. Bürzle, J. Hellmold & M. Stellmach

Physical Geography, Center for Earth System Research and Sustainability (CEN)
University of Hamburg, Bundesstr. 55, 20146 Hamburg, Germany
E-mail: niels.schwab@uni-hamburg.de

Dendroecological studies in the Nepal Himalaya with regard to treeline elevations

Himalayan treeline ecotones show considerable differences in altitudinal position as well as in physiognomy and species composition (Schickhoff 2005). In Nepal, treeline ecotones from closed subalpine forests to the upper limit of crippled and stunted tree individuals correspond approximately to the altitudinal range between 3600 and 4300 m (north-facing slopes), with slightly increasing elevations in an eastward and in a northward direction. This paper reviews the history of dendroecological work in Nepal with special consideration of studies in treeline environments, introduces a new research initiative (TREELINE) focusing on the detection of climate change signals in the treeline ecotone of Rolwaling Himal, Nepal, and presents first results.

According to our knowledge, first tree-ring samples in Nepal were collected by Rudolf Zuber in 1979/80 (under the direction of Fritz Schweingruber) with the objective to develop ring width chronologies, respective results were published by Bhattacharyya et al. (1992; see also Gaire et al. 2013). Some of the presented chronologies are based on sampling at near-treeline locations (3620-3720 m) using increment cores from *Abies spectabilis* and *Larix potanini*. The results were considered promising with respect to dendroclimatological correlations, which have been and still are, however, constrained by the lack of sufficient meteorological data (cf. Bhattacharyya et al. 1992).

Prior to this publication, Suzuki (1990) presented a first dendroecological study focusing on the correlation of *Abies spectabilis*, *Pinus wallichiana* and *Picea smithiana* tree-ring widths with climatic variables, based on sampling in montane/subalpine forest stands (c. 3100 m) in West Nepal. He also addressed the influence of changing canopy cover on tree-ring widths and resulting chronologies. In the aftermath of these pioneer studies, dendroecology in Nepal witnessed a significant upturn in the number of publications, giving attention to the establishment of chronologies and/or following dendroclimatological, dendroarchaeological, and modelling approaches (e.g., Schmidt 1992; Gutschow 1994; Romagnoli & Lo Monaco 1995; Schmidt et al. 1999, 2001; Zech et al. 2003; Bräuning 2004; Udas 2009; Tenca & Carrer 2010; Sano et al. 2010; Bräuning et al. 2011; Scharf et al. 2013; Dawadi et al. 2013; Shrestha 2013). Detailed dendroclimatological reconstructions were provided by Cook et al. (2003) and Sano et al. (2005) for seasonal temperature, and by Sano et al. (2012) for precipitation. Recently, an increasing number of tree-ring research studies has been initiated at Nepalese universities, the results of which are documented in hardly accessible M.Sc. or Ph.D. theses (e.g., Suwal 2010) and to some extent also in published papers (Chhetri 2008; Chhetri & Thapa 2010; Gaire et al. 2011; see Gaire et al. 2013 for further unpublished theses and conference papers). These studies indicate an increasing dissemination of tree-ring research expertise in Nepal, also reflected in the percentage of nationalities of involved researchers conducting dendrochronological/-ecological studies. 50 % of the studies were carried out by only Nepalese and 29 % by only foreign scientists, while joint projects account for 21 % (Gaire et al. 2013).

The majority of the above cited studies (see Tab. 1 in the appendix for a complete overview) is based on material sampled well below treeline elevations, and scarcely any of these studies is embedded in an integrated approach to detect climate change effects at treeline elevations with regard to treeline dynamics. In the following, we highlight hitherto available studies that used dendroecological approaches to detect the response of Himalayan treelines in Nepal or of upper subalpine forest trees to climate change. In general, there is increasing evidence suggesting that growth response of Himalayan treeline trees to climate change and variability is spatio-temporally differentiated, species-specific and not unidirectional (Schickhoff et al. 2014). A positive relationship of ring widths to increasing winter temperatures was ascertained in several studies. E.g., Bräuning (2004) reported a strong positive relationship between high elevation *Abies spectabilis* ring width and November-January temperature in Dolpo. Gaire et al. (2014) found tree growth of *Abies spectabilis* in Manaslu Conservation Area to be positively correlated with higher winter temperatures prior to growing season, and stressed the positive effects of earlier snow melt and increased melt water supply for growth.

Recently, an increasing number of studies in western and central Himalaya have revealed a strong sensitivity of tree growth to pre-monsoon temperature and humidity conditions (cf. Schickhoff et al. 2014). Increased evapotranspiration and soil moisture deficits induced by higher temperatures during the relatively dry spring months obviously impedes tree growth in particular on sites which are prone to drought stress. In Nepal, significantly negative correlations with long-term pre-monsoon temperature series were detected in *Abies spectabilis* tree-ring data from near-treeline sampling locations in Humla District (Sano et al. 2005) and in Langtang National Park (Gaire et al. 2011; Shrestha 2013). The pre-monsoon period has been shown to be also critical for broad-leaved treeline trees. Dawadi et al. (2013) assessed for the growth of birch trees at treeline sampling sites in Langtang Valley a positive correlation with March-May precipitation and an inverse relationship with pre-monsoon temperatures. Reduced pre-monsoon moisture availability being a primary growth-limiting factor for *Betula utilis* at treeline and the coincidence of years with high percentage of missing rings or narrow rings with dry and warm pre-monsoon seasons was confirmed by Liang et al. (2014) for study sites in Sagarmatha National Park, Langtang National Park, and Manaslu Conservation Area (Nepal) (for Manaslu see also Gaire et al., 2014). Results from current research of the present authors based on a ring-width chronology of *Betula utilis* from treeline sites in Langtang Valley dating back to AD 1657 confirmed a negative correlation of tree-ring width with pre-monsoon temperature and a positive correlation with pre-monsoon precipitation (in review).

Other studies in treeline environments of Nepal incorporated dendroecological techniques to infer more general information on stand characteristics, recruitment of tree species, and treeline dynamics. Bhuju et al. (2010) provided baseline information on structural parameters, recruitment and growth patterns of *Abies spectabilis* and *Betula utilis* assessed at two permanent plots in the treeline ecotone in Sagarmatha National Park. Gaire et al. (2011) addressed dynamics of *A. spectabilis* based on tree-ring and stand structural data from a treeline ecotone in Langtang National Park. By analysing the altitudinal distribution of tree, sapling and seedling densities and comparing total tree age distribution with elevation wise distribution the authors found an upward shift of *A. spectabilis* during recent decades. Recruitment patterns of *A. spectabilis*, derived from dendrochronological data, were assessed by Lv & Zhang (2012) from a study site in Mt. Everest Nature Reserve (across the border between Nepal and Tibet), showing a positive correlation with mean summer temperature. Shrestha (2013) ascertained significant but inconsistent growth responses to growing season and non-growing season climate factors of *Abies spectabilis* on a mesic north-facing slope in Langtang National Park and of *Pinus wallichiana* on a dry south-facing slope in Manang. The study did not reveal any significant variation in *A. spectabilis* and *P. wallichiana* treeline elevation over the past six decades and in the timing of the current treeline establishment. Another recent study (Gaire et al. 2014) investigated tree-rings of *Abies spectabilis* and *Betula utilis* from the treeline ecotone of Manaslu Conservation Area. *A. spectabilis* showed a high percentage of individuals younger than 50 years, indicating a high recruitment rate. Population structure along the elevational gradient indicated a distinct upward shift of *A. spectabilis*. In contrast, the upper limit of *B. utilis* occurrences did not change in the past decades. In general, the stand density increased. More recruits of *A. spectabilis* compared to *B. utilis* were found, pointing to a change in dominance patterns. Gaire et al. (2014) also established a negative correlation of the increment of *A. spectabilis* with monthly mean and minimum temperatures from June to September of the current and of the previous year. Regeneration of the same species was favoured positively by precipitation and maximum temperature of current year's August. Moisture stress during the pre-monsoon season was found to limit the growth of *B. utilis*. Regeneration of *A. spectabilis* correlated positively with the above-average monthly maximum temperature during most of the months and with above-average precipitation during dry warm summer months.

In conclusion, the use of dendrochronological/-ecological methods contributes to a better understanding of age structures, regeneration patterns, and dynamics of treeline ecotones. Most of the cited studies point to distinct growth responses of treeline trees to climate change with *A. spectabilis* showing mainly positive correlations with climate warming, and *B. utilis* showing negative response in particular to pre-monsoon warming. The low number of hitherto published studies restrict the drawing of wider conclusions regarding the correlations of climatic and other environmental factors with upper species limits, changing treeline ecotone species compositions and altitudinal shifts of species for the Nepal Himalaya. Comprehensive respective research programmes are badly needed.

The project TREELINE

State of the art and TREELINE objectives

While at global scale plant growth limitation by low-temperature determines the position of natural alpine treelines (e.g., Troll 1973; Stevens & Fox 1991; Holtmeier 2009; Körner 2012), factors and mechanisms influencing treeline position and dynamics at smaller scales are not well understood. Recent studies on the world's alpine treelines give evidence of both advancing treelines and rather insignificant treeline responses to climate warming (e.g., Baker & Moseley 2007; Hofgaard et al. 2009; Wieser et al. 2009; Lv & Zhang 2012). The inconsistency of findings on changing treeline spatial patterns points to considerable research deficits concerning the sensitivity to climate changes. It is widely accepted that climate exerts a top-down control on local ecological processes at the treeline (e.g., Batllori & Gutiérrez 2008). It is not well understood, however, how landscape scale and local scale abiotic and biotic factors and processes interact and influence the treeline and its response to climate. Moreover, effects of climate warming often mix up with impacts of land use (Malanson et al. 2007; Batllori et al. 2009). In consequence, complex research approaches at local and landscape scales at natural treelines are needed (e.g., Malanson et al. 2011).

The new research scheme "Sensitivity and Response of the Treeline Ecotone in Rolwaling Himal, Nepal, to Climate Warming" (TREELINE) aims at investigating treeline sensitivity and response using a landscape approach. The project focuses on spatially differentiated patterns and processes by correlating varied treeline responses to landscape- and local-scale site conditions and mechanisms (geomorphic controls, soil physical and chemical conditions, plant interactions associated with facilitation, competition, feedback systems). This approach will allow inferences on how the region-wide climate warming input and finer-scale modulators interact to govern non-uniform treeline response patterns.

The near-natural treeline ecotone in Rolwaling extends from the closed subalpine forest via timber- and treeline to the lower alpine vegetation belt. The near-natural status of the treeline can be attributed to the remote location without connection to the road network (3 days walking distance), to the small human population and to the fact that plants and animals in Rolwaling are protected to a certain extend by the recurring Buddhist theme of a sacred hidden valley (Sacherer 1979). The study slopes show no signs of fire or of grazing by cattle. The Rolwaling River separates the uninhabited north facing study site slope from the very sparsely populated south facing slope where human activities take place, albeit to a limited extent.

Vegetation analyses include the sampling of tree individuals along elevational transects across the treeline ecotone with regard to growth rates, age structures, tree physiognomy, stand densities, and tree recruitment. Moreover, we measure/analyse standard soil physical and chemical parameters, altitude, slope, exposition and microrelief (percentage and size of rocks, stones and soil covering the ground), composition of ground vegetation, leaf area index, air temperature, solar radiation, soil moisture, and soil temperature. We also sample naturally established seedlings of the treeline tree species, and correlate recruitment patterns with microhabitat conditions (vegetation and substrate cover, species composition, shelter elements, edaphic conditions) to analyse requirements for successful recruitment. To assess the impacts of ongoing temperature enhancement on seedling establishment, we install open top chambers at and above the treeline ecotone and replant seedlings of *A. spectabilis* to sites of experimental warming. Scenarios of treeline dynamics under climate warming will be based on the assessed interactions. Amongst others, we will apply statistical and forest growth models including data gained by dendrochronological methods (cf. Schickhoff et al. 2014).

The objective of the dendroecological approach in TREELINE is to detect changes in age structures and recruitment of treeline stands and in radial increment of trees in order to evaluate whether the Rolwaling treeline advances or remains stable under the influence of climate warming. We collect and analyse tree-ring cores of treeline tree species with a focus on the dominant species *Abies spectabilis* and *Betula utilis*, and correlate tree-ring parameters with modelled climate variables (Gerlitz et al. 2014; Gerlitz 2014). Our sampling design stratifies each altitudinal transect (2 NE-exposed, 1 NW-exposed) in four belts of distinct vegetation patterns (named A to D). The lowest belts (A, B) contain mixed forest stands with the upper limits of tall, upright growing individuals of *Acer caudatum* in A and of *Abies spectabilis* and *Betula utilis* in B. The third belt (C) represents the krummholz belt with dense and largely impenetrable *Rhododendron campanulatum* thickets and the species limit of *B. utilis*, while the uppermost belt (D) contains alpine vegetation with only small (DBH < 7 cm) and stunted individuals of *A. spectabilis*, *Sorbus microphylla* and *Rh. campanulatum* (Fig. 1).

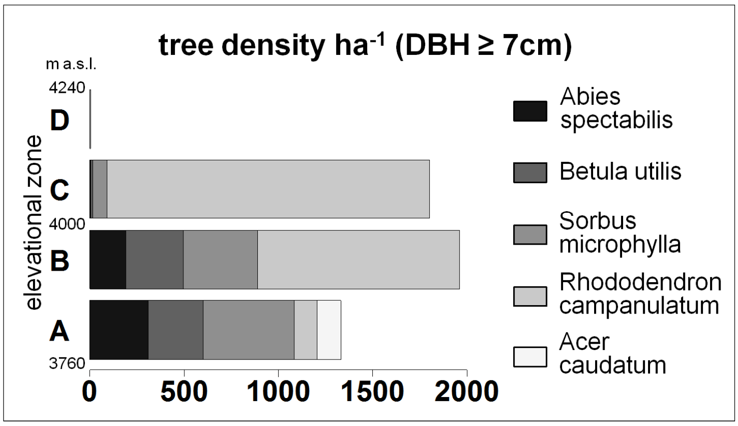

Figure 1: Tree species density in four altitudinal vegetation zones (A, B, C, D), forming the treeline ecotone in Rolwaling valley.

Intensive tree-ring sampling, accompanied by comprehensive recording of tree growth parameters and spatial patterns, started in 2013 and was completed in September 2014. We sampled a total of c. 280 individuals of *Abies* and *Betula* each, c. 160 *Sorbus* trees and c. 40 trees of *Acer* and *Rhododendron* of all diameter classes. We extracted two increment cores from each tree. We analyse all increment cores and test in particular the suitability of *A. caudatum*, *S. microphylla* and *Rh. campanulatum* for dendrochronological analyses since these species have hardly been sampled to date. Tree-ring cores are prepared according to standard dendrochronological procedures (Pilcher 1990; Stokes & Smiley 1996). Annual rings are counted, measured and cross-dated in the recently initialised dendro-laboratory at the Institute of Geography, University of Hamburg using a LINTAB 6 measuring system and TSAP-Win software (Rinntech, Heidelberg). We apply standard methods for cross-dating, detrending and correlating of annual radial increment with climatic variables (Fritts 1976; Cook 1985; Cook & Briffa 1990; Fang et al. 2014). Measured raw series of *A. spectabilis* cores point to the potential of establishing a 50 year long chronology covering the period of 2012 – 1962. The longest series from our sample measured so far dates back 200 years, but many trees are affected by heart rot causing substantial loss of the number of cores in the chronology already after about 50 years. An initial crossdating attempt of all measured raw series resulted in a mean Gleichlaeufigkeit value (GLK%, Eckstein & Bauch 1969) of about 50 % (max: 67 %, min: 39 %) indicating the need for checking for missing and double rings. We will continue with exact cross-dating, accuracy checking, discarding of poorly correlated samples, detrending and standardisation of the ring-width series, and identification of pointer years. We found promising results for the crossdating suitability of *Rh. campanulatum*: The longest measured series comprises 136 years and 20 of the collected cores date at least 50 years back. Mean initial GLK calculated within the sites accounts for about 55 % (min: 36 %, max: 72 %) which is possible to improve by checking for missing and double rings and discarding of poorly correlated series. The wood is little infested by heart rot but the rings are difficult to measure precisely due to low visibility and small ring widths.

More detailed results from dendrochronological/-ecological studies in TREELINE will be included in forthcoming publications. Preliminary findings point to complex growth and spatial patterns dominated by the altitudinal gradient but influenced by environmental factors, e.g. soil properties and microclimate, at the small scale.

Acknowledgements

The authors are indebted to an anonymous reviewer, to the German Research Foundation for funding (DFG, SCHI 436/14-1), to Nepalese authorities for research permits, and to the community in Rolwaling for assistance in fieldwork and willingness to cooperate.

Appendix

Overview of published and/or online available dendrochronological studies from Nepal. There are few studies with an explicit dendroecological background. RW: ring width, MLD: maximum latewood density, n.s.: not specified.

authors + year published	study area	altitude [m] sampling site	tree-ring research domain	studied species	studied parameters
Suzuki 1990	Jumla District	3060 / 3100	chronology + climate response	*Abies spectabilis, Picea smithiana , Pinus wallichiana*	RW
Bhattacharyya et al. 1992	25 sites across Nepal	1320 – 3720	chronology building	*Pinus roxburghii, Tsuga dumosa, Abies spectabilis, Cedrus deodara, Picea smithiana, Larix potanini, Juniperus recurva, Pinus wallichiana*	RW
Schmidt 1992	South Mustang	n.s.	chronol. building with dendroarchaeol ogical background	*Pinus sp.*	RW
Gutschow 1994	Kagbeni / South Mustang	n.s.	dendroarchaeol ogy	*Pinus sp.*	RW
Romagnoli & Lo Monaco 1995	Western Nepal	n.s.	chronology building	*Betula utilis, Abies spectabilis , Juniperus sp., Picea smithiana, Pinus wallichiana*	RW

DOI: 10.2312/GFZ.b103-15069

authors + year published	study area	altitude [m] sampling site	tree-ring research domain	studied species	studied parameters
Schmidt et al. 1999	Mustang, Manang, Khumbu	n.s.	chronol. building with dendroarchaeol ogical background	*Abies spectabilis , Pinus wallichiana, Picea smithiana*	RW
Schmidt et al. 2001	Kagbeni / South Mustang	n.s.	dendroarchaeol ogy	*Pinus wallichiana, Cupressus torulosa*	RW
Cook et al. 2003	25 sites across Nepal	1830 – 3630	climate reconstruction (temperature)	*Abies spectabilis, Tsuga dumosa, Pinus wallichiana, Juniperus recurva, Picea smithiana, Ulmus wallichiana*	RW
Zech et al. 2003	Gorkha Himal	n.s.	climate reconstruction, glacial history	*Abies spectabilis*	RW
Bräuning 2004	Mugu and Dolpo	3500 / 3850 / 4020	chronol. building + climate response	*Abies spectabilis, Betula utilis, Pinus wallichiana*	RW, MLD
Sano et al. 2005	Humla District	3850	climate reconstruction (temperature)	*Abies spectabilis*	RW, densities
Chhetri 2008	Langtang National Park	n.s.	chronol. building + climate response	*Abies spectabilis*	RW
Udas 2009	Mustang District	3415 – 3242 3220 – 3092	chronol. building + climate response	*Abies spectabilis*	RW
Bhuju et al. 2010	Sagarmatha National Park	3850 / 4050	dendroecology	*Abies spectabils, Betula utilis*	RW
Chhetri & Thapa 2010	Langtang National Park	3309 / 3444	chronol. building + climate response	*Abies spectabilis*	RW
Sano et al. 2010	Humla District	3850	chronol. building + climate response	*Abies spectabilis*	RW, $\delta^{18}O$
Suwal 2010	Manaslu Conservation Area	3624 - 3841	dendroecology	*Abies spectabils*	RW
Tenca & Carrer 2010	Khumbu	3800 - 4100	chronol. building + climate response	*Abies spectabils, Betula utilis*	RW
Bräuning et al. 2011	upper Dolpo	n.s.	chronol. building with dendroarchaeol ogical background	*Pinus wallichiana*	RW, ^{14}C dating
Gaire et al. 2011	Langtang National Park	3730 - 3950	climate response, dendroecology	*Abies spectabilis*	RW
Sano et al. 2012	Humla District	3850	climate reconstruction (precipitation)	*Abies spectabilis*	RW, densities, $\delta^{18}O$

authors + year published	study area	altitude [m] sampling site	tree-ring research domain	studied species	studied parameters
Dawadi et al. 2013	Langtang National Park	3780 / 3950	chronol. building + climate response	*Betula utilis*	RW
Scharf et al. 2013	Dolpo	n.s.	chronol. building with dendroarchaeological background	*Pinus wallichiana*	RW, ^{14}C dating
Shrestha 2013	Manang, Langtang National Park	3770 - 4180	climate response, dendroecology	*Abies spectabils, Pinus wallichiana*	RW
Shrestha et al. 2013	Dolakha District	900 - 1750	construction of allometric model	*Pinus roxburghii*	RW
Gaire et al. 2014	Manaslu Conservation Area	3690 - 3996	climate response, dendroecology	*Abies spectabilis, Betula utilis*	RW
Liang et al. 2014	Sagarmatha NP, Langtang NP, Manaslu CA	3900 - 4150	climate response, dendroecology	*Betula utilis*	RW

References

Baker, B.B., Moseley, R.K. (2007): Advancing treeline and retreating glaciers: Implications for conservation in Yunnan, P.R. China. Arctic, Antarctic, and Alpine Research 39: 200–209.

Batllori, E., Camarero, J.J., Ninot, J.M., Gutiérrez, E. (2009): Seedling recruitment, survival and facilitation in alpine *Pinus uncinata* tree line ecotones. Implications and potential responses to climate warming. Global Ecology and Biogeography 18: 460–472.

Batllori, E., Gutiérrez, E. (2008): Regional tree line dynamics in response to global change in the Pyrenees. Journal of Ecology 96: 1275–1288.

Bhattacharyya, A., LaMarche, V.C., Hughes, M.K. (1992): Tree-ring chronologies from Nepal. Tree-Ring Bulletin 1992, 52: 59–66.

Bhuju, D.R., Carrer, M., Gaire, N.P., Soraruf, L., Riondato, R., Salerno, F., Maharjan, S.R. (2010): Dendroecological study of high altitude forest at Sagarmatha National Park, Nepal. In: Jha, P. K. & Khanal, I. P. (eds.): Contemporary Research in Sagarmatha (Mt. Everest) Region, Nepal: An Anthology. Nepal Academy of Science and Technology, Kathmandu, Nepal. 119–130.

Bräuning, A. (2004): Tree-ring studies in the Dolpo-Himalya (western Nepal). In: Jansma, E.; Bräuning, A.; Gärtner, H. & Schleser, G. (eds.): TRACE - Tree Rings in Archaeology, Climatology and Ecology, Vol. 2. Schriften des Forschungszentrums Jülich, Reihe Umwelt Vol. 44, Forschungszentrum Jülich. 8–12.

Bräuning, A., Scharf, A., Kretschmer, W., Gierl, S., Leichmann, K., Burchardt, I. (2011): The development of a long pine (Pinus wallichiana) chronology from western Nepal from living trees and 14C-dated historic wood samples. In: van der Maaten-Theunissen, M., Spiecker, H., Gärtner, H., Heinrich, I. & Helle, G. (eds.): TRACE Tree Rings in Archaeology, Climatology and Ecology, Vol. 9. Scientific Technical Report 11/07, GFZ German Research Centre for Geosciences. 110–113.

Chhetri, P.K. (2008): Dendrochronological analyses and climate change perceptions in Langtang National Park, Central Nepal. In: Aryal, K. R. & Gadema, Z. (eds.): Climate Change and Disaster Impact Reduction. n.p. 28–32.

Chhetri, P.K., Thapa, S. (2010): Tree ring and climate change in Langtang National Park, Central Nepal. Our Nature 8:139-143.

Cook, E.R. (1985): A Time Series Analysis Approach to Tree Ring Standardization. PhD thesis, The University of Arizona, USA. 171 pp.

Cook, E.R., Krusic, P.J., Jones, P.D. (2003): Dendroclimatic signals in long tree-ring chronologies from the Himalayas of Nepal. International Journal of Climatology 23: 707–732.

Cook, E., Briffa, K. (1990): Data analysis. In: Cook, E. & Kairiukstis, L. (eds.): Methods of Dendrochronology: Applications in the Environmental Science. Kluwer. 97-162.

Dawadi, B., Liang, E., Tian, L., Devkota, L. P., Yao, T. (2013): Pre-monsoon precipitation signal in tree rings of timberline Betula utilis in the central Himalayas. Quaternary International 283: 72–77.

Eckstein, D., Bauch, J. (1969): Beitrag zur Rationalisierung eines dendrochronologischen Verfahrens und zur Analyse seiner Aussagesicherheit. Forstwissenschaftliches Centralblatt 88: 230–250.

Fang, K., Wilmking, M., Davi, N., Zhou, F., Liu, C. (2014): An ensemble weighting approach for dendroclimatology: Drought reconstructions for the Northeastern Tibetan Plateau. PLoS ONE 9: e86689.

Fritts, H. C. (1976): Tree Rings and Climate. Academic Press. 567 pp.

Gaire, N.P., Dhakal, Y.R., Lekhak, H.C., Bhuju, D.R., Shah, S.K. (2011): Dynamics of Abies spectabilis in relation to climate change at the treeline ecotone in Langtang National Park. Nepal Journal of Science and Technology 12: 220–229.

Gaire, N.P., Bhuju, D.R., Koirala, M. (2013): Dendrochronological studies in Nepal: Current status and future prospects. FUUAST Journal of Biology 3: 1–9.

Gaire, N.P., Koirala, M., Bhuju, D.R., Borgaonkar, H.P. (2014): Treeline dynamics with climate change at the central Nepal Himalaya. Climate of the Past 10: 1277–1290.

Gerlitz, L., Conrad, O., Thomas, A., Böhner, J. (2014): Warming patterns over the Tibetan Plateau and adjacent lowlands derived from elevation- and bias-corrected ERA-Interim data. Climate Research 58: 235–246.

Gerlitz, L. (2014): Using fuzzified regression trees for statistical downscaling and regionalization of near surface temperatures in complex terrain. Theoretical and Applied Climatology 1–16, online first, doi:10.1007/s00704-014-1285-x.

Gutschow, N. (1994): KAGBENI: Structural analysis of dendrochronological data. Ancient Nepal , Journal of the Department of Archaeology 136: 23–50.

Hofgaard, A., Dalen, L., Hytteborn, H. (2009): Tree recruitment above the treeline and potential for climate-driven treeline change. Journal of Vegetation Science 20: 1133–1144.

Holtmeier, F.K. (2009): Mountain Timberlines. Ecology, Patchiness, and Dynamics. Springer, Dordrecht.

Körner, C. (2012): Alpine Treelines : Functional Ecology of the Global High Elevation Tree Limits. Springer.

Liang, E., Dawadi, B., Pederson, N., Eckstein, D. (2014): Is the growth of birch at the upper timberline in the Himalayas limited by moisture or by temperature? Ecology 95: 2453-2465.

Lv, L.-X., Zhang, Q.-B. (2012): Asynchronous recruitment history of Abies spectabilis along an altitudinal gradient in the Mt. Everest region. Journal of Plant Ecology 5: 147–156.

Malanson, G., Butler, D., Fagre, D., Walsh, S., Tomback, D., Daniels, L., Resler, L., Smith, W., Weiss, D., Peterson, D., Bunn, A., Hiemstra, C., Liptzin, D., Bourgeron, P., Shen, Z., Millar, C. (2007): Alpine treeline of Western North America: Linking organism-to-landscape dynamics. Physical Geography 28: 378–396.

Malanson, G.P., Resler, L.M., Bader, M.Y., Holtmeier, F.-K., Butler, D.R., Weiss, D.J., Daniels, L.D., Fagre, D.B. (2011): Mountain treelines: A roadmap for research orientation. Arctic, Antarctic, and Alpine Research 43: 167–177.

Pilcher, J. R. (1990): Sample preparation, cross-dating, and measurement. In: Cook, E. & Kairiukstis, L. (eds.): Methods of Dendrochronology: Applications in the Environmental Science. Kluwer. 40-51.

Romagnoli, M., Lo Monaco, A. (1995): Dendrochronological studies of samples from Jumla forest, Himalayas, Nepal. Annali Accademia Italiana di Scienze Forestali 44: 95–112.

Sacherer, J. (1979): The high altitude ethnobotany of the Rolwaling Sherpas. Contributions to Nepalese Studies 6: 45-64.

Sano, M., Furuta, F., Kobayashi, O., Sweda, T. (2005): Temperature variations since the mid-18th century for western Nepal, as reconstructed from tree-ring width and density of Abies spectabilis. Dendrochronologia 23: 83–92.

Sano, M., Sheshshayee, M. S., Managave, S., Ramesh, R., Sukumar, R., Sweda, T. (2010): Climatic potential of δ18O of Abies spectabilis from the Nepal Himalaya. Dendrochronologia 28: 93–98.

Sano, M., Ramesh, R., Sheshshayee, M.S., Sukumar, R. (2012): Increasing aridity over the past 223 years in the Nepal Himalaya inferred from a tree-ring δ18O chronology. The Holocene 22, 7: 809–817.

Scharf, A., Bräuning, A., Kretschmer, W., Wegner, B., Darragon, F. (2013): 14C AMS Dating of wooden cores from historic buildings for archaeological and dendrochronological research in High Asia. Radiocarbon 55: 1358–1365.

Schickhoff, U. (2005): The upper timberline in the Himalayas, Hindu Kush and Karakorum: A review of geographical and ecological aspects. In: Broll, G. & Keplin, B. (eds.): Mountain Ecosystems. Studies in Treeline Ecology. Springer: 275–354.

Schickhoff, U., Bobrowski, M., Böhner, J., Bürzle, B., Chaudhary, R.P., Gerlitz, L., Heyken, H., Lange, J., Müller, M., Scholten, T., Schwab, N., Wedegärtner, R. (2014): Do Himalayan treelines respond to recent climate change? An evaluation of sensitivity indicators. Earth System Dynamics Discussions 5: 1407-1461.

Schmidt, B. (1992): Dendrochronological research in South Mustang. Ancient Nepal, Journal of the Department of Archaeology 130-133: 20–33.

Schmidt, B., Wazny, T., Malla, K., Höfs, E., Khalessi, M. (1999): Chronologies for historical dating in High Asia/Nepal. In: Wimmer, R. & Vetter, R. E. (eds.): Tree-ring Analysis: Biological, Methodological, and Environmental Aspects. CAB International: 205–211.

Schmidt, B., Gruhle, W., Thomalla, E., Khalessi, M., Malla, K. (2001): Dendrochronological dating of timber: A contribution to the architectural history and settlement processes at Kagbeni. In: Pohle, P. & Haffner, W. (eds.): Kagbeni - Contributions to the Village's History and Geography (= Gießener Geographische Schriften 77): 161–167.

Shrestha, K. B. (2013): Treeline and Vegetation Dynamics in Response to Environmental Changes in Nepal, the Central Himalaya. PhD thesis, University of Bergen, Norway.

Shrestha, S., Karky, B. S., Gurung, A., Bista, R., Vetaas, O. R. (2013): Assessment of carbon balance in community forests in Dolakha, Nepal. Small-scale Forestry 12: 507–517.

Stevens, G. C., Fox, J. F. (1991): The causes of treeline. Annual Review of Ecology and Systematics 22: 177–191.

Stokes, M.A., Smiley, T.L. (1996): An Introduction to Tree-ring Dating. University of Arizona Press.

Suwal, M. K. (2010): Tree Species Line Advance of Abies spectabilis in Manaslu Conservation Area, Nepal Himalaya. MSc. thesis, Tribhuvan University, Kathmandu, Nepal. 43 pp.

Suzuki, E. (1990): Dendrochronology in coniferous forests around Lake Rara, West Nepal. The Botanical Magazine (= Shokubutsu-gaku-zasshi) 103: 297–312.

Tenca, A., Carrer, M. (2010): Growth climate response at high elevation: comparing Alps and Himalayas. In: Levanic, T., Gricar, J., Hafner, P., Krajnc, R., Jagodic, S., Gärtner, H., Heinrich, I. & Helle, G. (eds.): TRACE - Tree Rings in Archaeology, Climatology and Ecology, Vol. 8. Scientific Technical Report 10/05, GFZ German Research Centre for Geosciences. 89-97.

Troll, C. (1973): The upper timberlines in different climatic zones. Arctic and Alpine Research 5: A3–A18.

Udas, E. (2009): The Influence of Climate Variability on Growth Performance of Abies spectabilis at Tree Line of West-Central Nepal. MSc. thesis, Ernst Moritz Arndt University of Greifswald, Germany.

Wieser, G., Matyssek, R., Luzian, R., Zwerger, P., Pindur, P., Oberhuber, W., Gruber, A. (2009): Effects of atmospheric and climate change at the timberline of the Central European Alps. Annals of Forest Science 66: 402–402.

Zech, W., Glaser, B., Abramowski, U., Dittmar, C., Kubik, P. W. (2003): Reconstruction of the late quaternary glaciation of the Macha Khola valley (Gorkha Himal, Nepal) using relative and absolute (14C, 10Be, dendrochronology) dating techniques. Quaternary Science Reviews 22: 2253–2265.