 https://doi.org/10.3126/banko.v30i1.29177

Growth-climate relationship of *Pinus wallichiana* in three different parts of the Himalayas

S. Bhandari[1]* and J. H. Speer[1]

We have used six tree-ring width chronologies of *Pinus wallichiana* from the Himalayan region, which are available in the International Tree-Ring Data Bank (ITRDB), to determine their growth trends through time and the growth-climate relationship. Each of the chronologies downloaded from the ITRDB was detrended using an Age-dependent Cubic Smoothing Spline with a 20-year starting spline stiffness in the RCSigfree Software Program. We broke the six chronologies into three regions based on natural breaks between the sample sites. Altogether, three composite chronologies were made, one each from Bhutan, Nepal, and Pakistan. The average value for common periods was taken from each of those two chronologies to make a composite chronology. Across the three regions, the growth was lowest in the 1810s and has increased since 1980s. The growth showed a significant positive response to the winter temperature (November-February) in the eastern Himalayas in Bhutan. The chronology from Nepal showed that the growth of this species had a significant positive response to the self-calibrated Palmer Drought Severity Index of the previous year's December and the current year's January and March. In the western Himalayas of Pakistan, the growth of the same species is positively correlated to the annual self-calibrated Palmer Drought Severity Index. Winter temperature limits the growth of this species in the eastern Himalayas where there is enough moisture whereas the growth of this species is primarily limited by moisture in the western Himalayas.

Keywords: Drought, Moisture, *Pinus wallichiana*, Temperature, Tree-ring

The Himalayas are one of the largest mountain ranges in the word having distinctive landscapes, ecosystems, climatic variation, and geological features (Olson and Dinerstein, 2002). These mountains are one of the most sensitive and fragile ecosystems to climate change impacts (Shrestha *et al*., 2012). The regional climate of this mountain range is dominated by the Indian summer monsoon that extends from June to September and the western disturbance from December to March (Cannon *et al*., 2015). The eastern part of the region is mainly affected by the summer monsoon which arrives from the Bay of Bengal. The intensity of the summer monsoon decreases from the east to the west (Lang and Barros, 2004). On the other hand, the western part receives most of the rainfall in the winter because of the westerlies, which brings moisture from the Arabian, Mediterranean, and Caspian Seas (Ahmed *et al*., 2011). The availability of moisture greatly decreases from the east to the west because of this atmospheric circulation. These climatic patterns and availability of moisture affect the growth and distribution of the plant species in the region of the Himalayas (Sharma and Gupta, 1997).

We can use dendrochronological tools to understand the most limiting climatic factor for the growth of the species (Speer, 2010). Several studies have been done in the Himalayas to relate the growth of plants and climate (Dawadi *et al*., 2013; Aryal *et al*. 2018; Khan *et al*., 2018; Shah *et al*., 2018; Bhandari *et al*., 2019).

1. Department of Earth and Environmental System, Indiana State University, Terre Haute, Indiana, United States of America.
* E-mail: Sbhandari2@sycamores.indstate.edu

Pinus wallichiana, one of the native plant species to the Himalayas, has been frequently used in dendroclimatic studies (Yadav and Bhattacharyya, 1997; Cook *et al*., 2003; Cook *et al*., 2010; Asad *et al*., 2017; Gaire *et al*., 2019). This species, commonly known as Blue pine, is a large evergreen conifer distributed across the Himalayas, spanning from northeast Pakistan to Yunnan in southwest China (Devkota, 2013). This species usually prefers to grow on deep moist soils, in pure as well as mixed stands with *Cedrus deodara*, *Picea smithiana*, *Abies pindrow* and Quercus sps. At the higher altitude above 3,000 m, it is associated with birch and juniper (Yadav and Bhattacharyya, 1997). Generally, pine trees are sensitive to moisture, and have strong common signals compared to other species (Thapa *et al*., 2017). In this research, we have used six tree-ring chronologies of *P. walllichiana* from the Himalayas region, which are available in the International Tree-Ring Data Bank (ITRDB) to understand its growth trends and its climate response across the Himalayas.

Materials and methods

Chronology development

The International Tree-Ring Data Bank holds six chronologies of *P. wallichiana* with two from Bhutan, two from Nepal, and two from Pakistan (Table 1). Each of these chronologies were downloaded from the International Tree-Ring Data Bank and detrended using an Age-dependent Cubic Smoothing Spline with a 20-year starting spline stiffness followed by signal free standardization in the RC Sigfree Software Program (Melvin and Briffa, 2008). This detrending method retains the most low-frequency variability in the chronology while reducing the effects from juvenile growth (Melvin *et al*., 2007). The average value for common periods was taken from each of those two chronologies in each region to make a composite chronology. Altogether, three composite chronologies were made, one each from Bhutan, Nepal and Pakistan.

Growth-climate relationship

Temperature (1901−2017, CRU TS 4.02), precipitation (1901−2017, CRU TS 4.02), and the self-calibrating Palmer Drought Severity Index, scPDSI (1901−2016) Global 3.25 (Van Der Schrier *et al*., 2013) were taken from KNMI Climate Explorer (Trouet and Oldenborgh, 2013). These climatic parameters were correlated with each of the chronologies in the TREECLIM package in R (Zang and Biondi, 2015) to find the growth-climate relationship. The growth-climate relationship identifies the most limiting factor for the growth of the trees. Spatial correlation was carried out between each of the tree-ring chronologies and climate parameters in the KNMI Climate Explorer (Trouet and Oldenborgh, 2013).

Table 1: Brief description of *Pinus wallichiana's* chronologies in ITRDB

Sample location	Principal Investigators	Sample duration	Latitude	Longitude
Nangay, Bhutan	Edward Cook, Paul J Krusic and Dorji Dukpa (Cook *et al*., 2010)	1625−2003 AD	27.4	90.7
Pembu, Bhutan	Edward Cook, Paul J Krusic and Dorji Dukpa (Cook *et al*., 2010)	1741−2005 AD	27.2	89.3
Bhratang, Nepal	Edward Cook, Paul J Krusic, and Philip D. Jones (Cook *et al*., 2003)	1796−1994 AD	28.4	84.1
Alubari, Nepal	Edward Cook and Paul J Krusic, and Philip D. Jones (Cook *et al*., 2003)	1803−1993 AD	28.4	83.4
Astore-Rama, Pakistan	Edward Cook, Jonathan Palmer and Moinnudin Ahmed (PAGES 2k Consortium, 2013)	1317−2005 AD	35.3	74.8
Mushkin, Pakistan	Edward Cook, Jonathan Palmer and Moinnudin Ahmed (PAGES 2k Consortium, 2013)	1730−2007 AD	35.5	74.7

Results and discussion

We have constructed three composite chronologies one each from Bhutan, Nepal and Pakistan. Our composite *P. wallichiana* chronology from Bhutan in the eastern Himalayas spans over 263 years- from 1741 to 2003 AD based on the common period between the chronologies (Figure 1a). This chronology showed a sharp decline in the growth of this species in the early 1800s while the growth was higher during 1750−1800 AD, 1930−1960 AD and 1975−2003 AD. The growth of this species in Bhutan showed a significant positive correlation with winter temperature (Figure 2). The spatial correlation between the ring-width and CRU temperature also indicates a strong correlation with winter temperature in the eastern Himalayas (Figure 3).

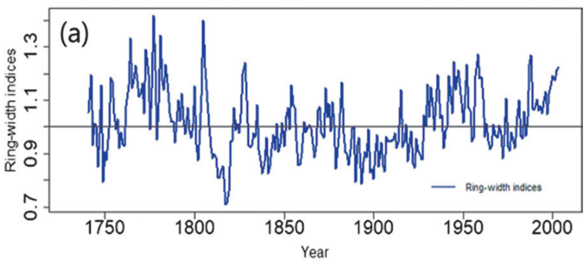
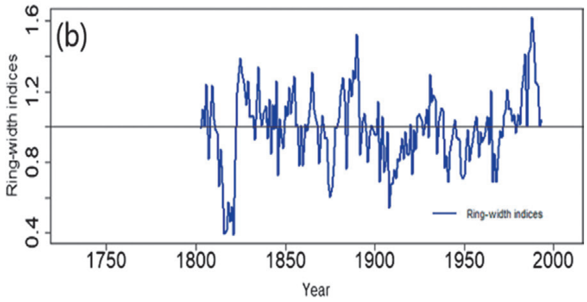


Figure 1: (a) A 263-year (1741−2003) long chronology of *P. wallichiana* from Bhutan



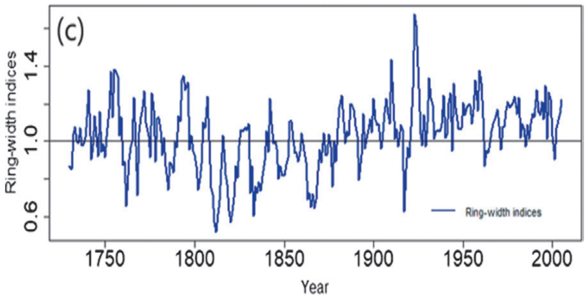


Figure 1: (b) A 191-year (1803−1993) long chronology of *P. wallichiana* from Nepal, and (c) A 276-year (1730−2005) long chronology of *P. wallichiana* from Pakistan

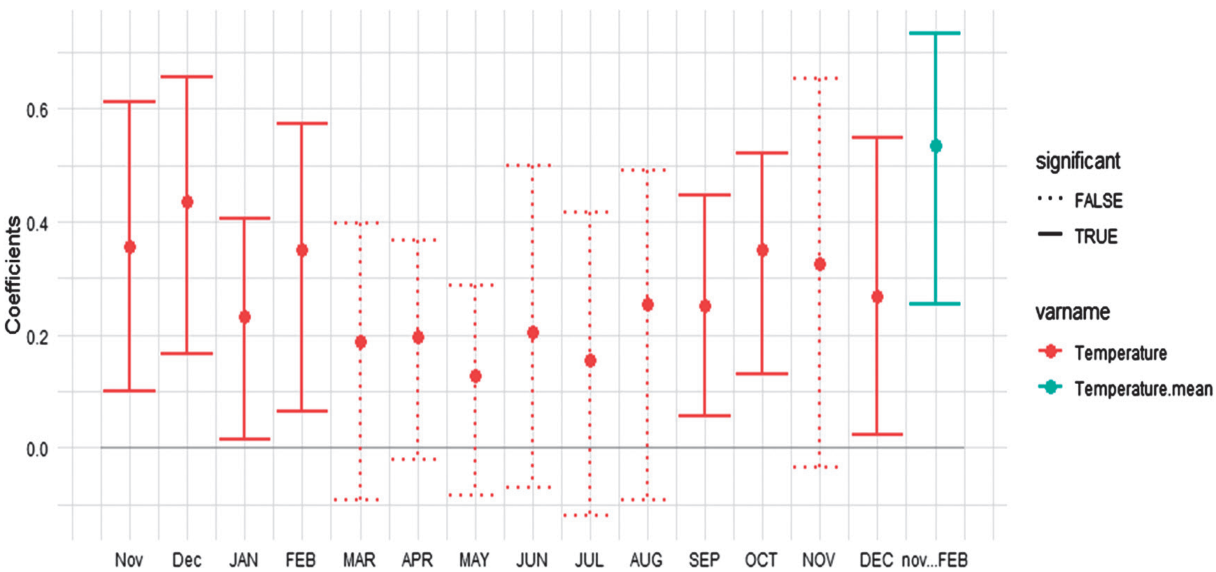


Figure 2: Correlation between the tree-ring width of *P. wallichiana* from Bhutan and CRU temperature

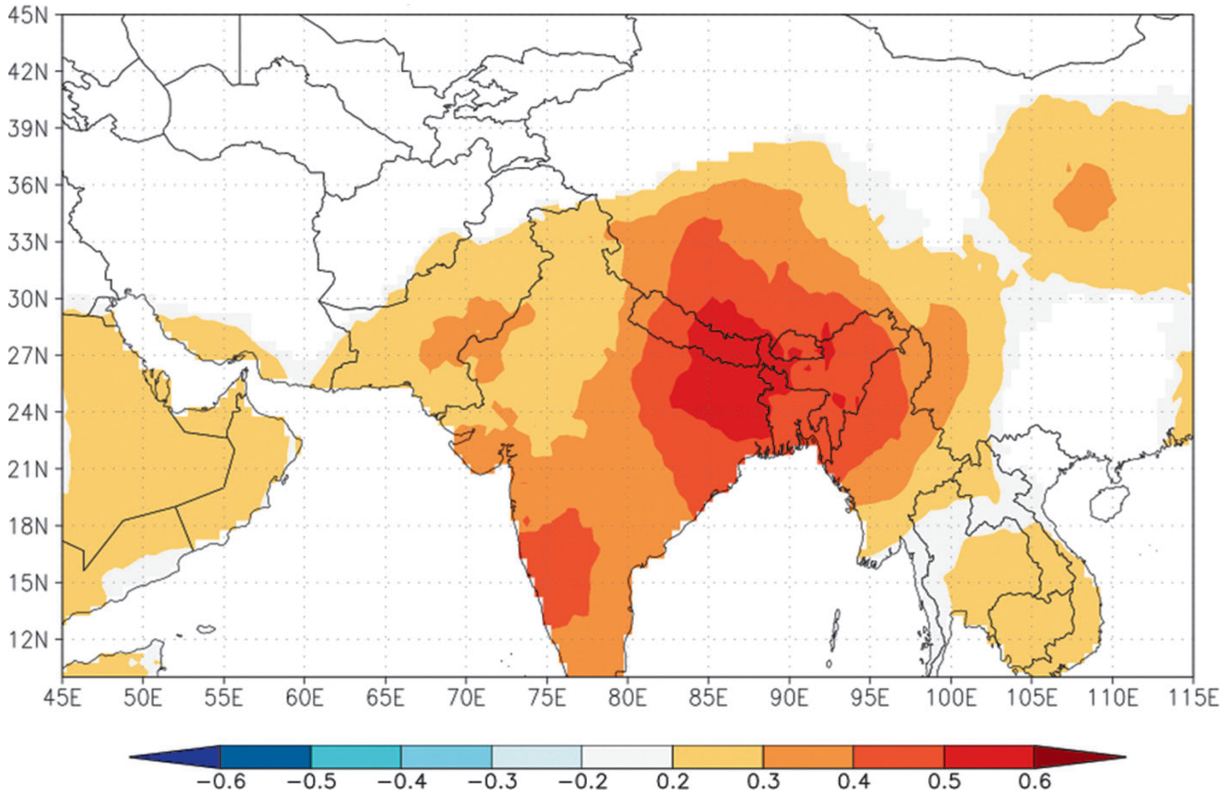


Figure 3: Spatial correlation between the tree-ring width of *P. wallichiana* from Bhutan and November-February average CRU TS4.02 temperatures during 1902−2003 (p<0.1%)

Similarly, a 191-year (1803−1993) long chronology of *P. walllichiana* was made from Nepal in the central Himalayas (Figure 1b). This chronology showed that the growth of this species was suppressed in the early 19th century and the growth has increased since the 1980s. The tree-ring chronology of *P. wallichiana* from the central Nepal Himalayas showed a positive correlation with the scPDSI of December of the previous year and January and March of the current year (Figure 4). This indicates that winter moisture limits the growth of this species in the central Himalayas of Nepal. Interestingly, the chronology of this species showed low spatial correlation with the scPDSI in the central Himalayas of Nepal (Figure 5).

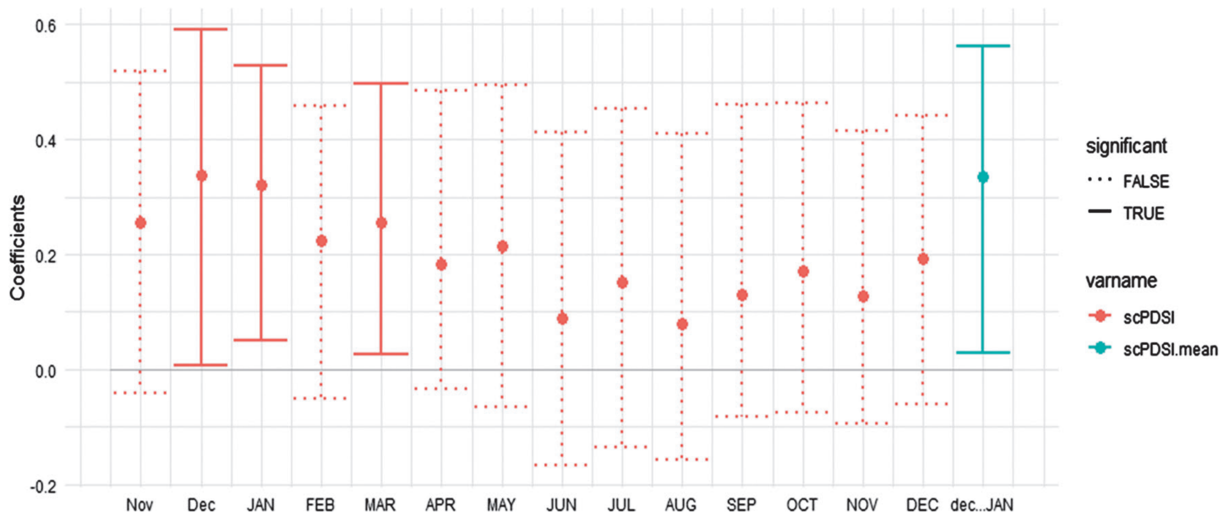


Figure 4: Correlation between the ring-width chronology of *P. wallichiana* from Nepal and CRU scPDSI

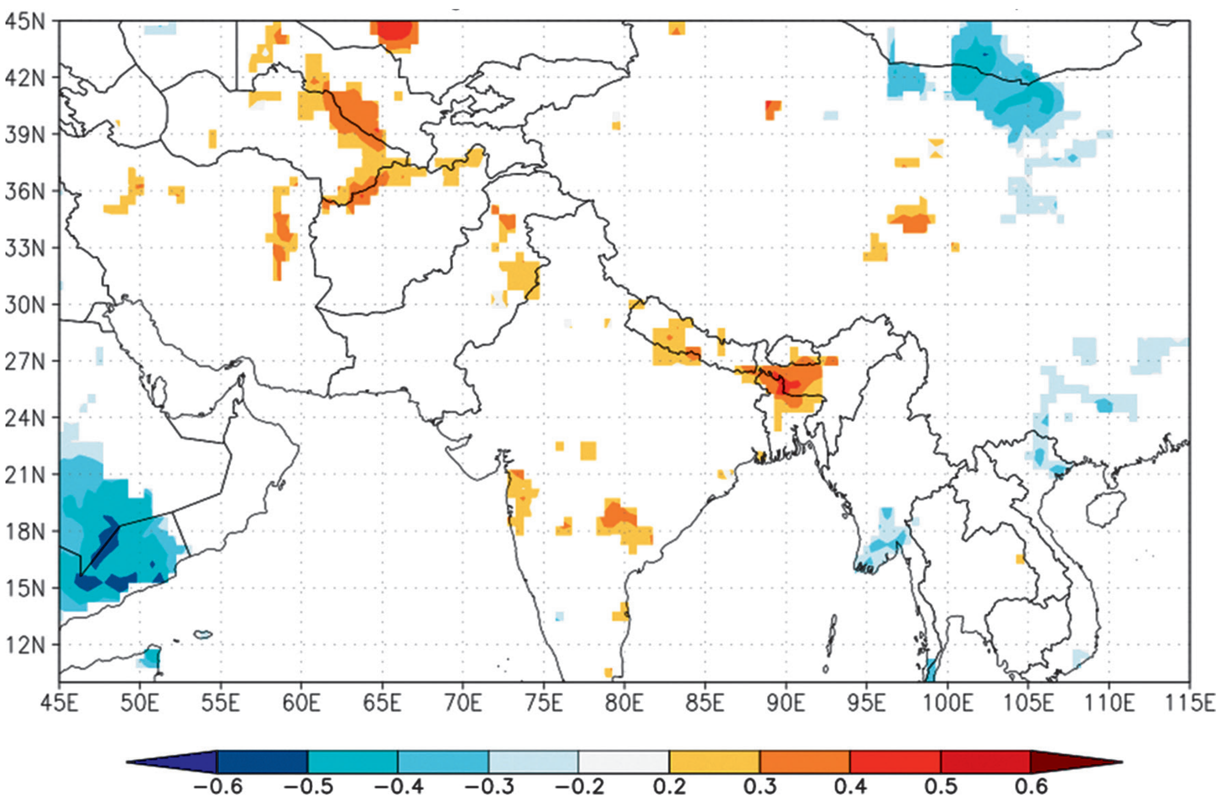


Figure 5: Spatial correlation between tree-ring width of *P. wallichiana* from Nepal and December−January average CRU scPDSI 3.26e during 1901−1993 (p<0.1%)

We also developed a 276-year long chronology of *P. wallichiana* from Pakistan (Figure 1c). The growth was suppressed in the 19th century while it was above average in the 20th century. This chronology was found to positively correlated with annual scPDSI (Figure 6) indicating that moisture availability affects the growth in western Himalayas of Pakistan. The spatial correlation between ring-width of the same species from Pakistan and January−June average CRU scPDSI showed a strong drought signal in the western Himalayas (Figure 7).

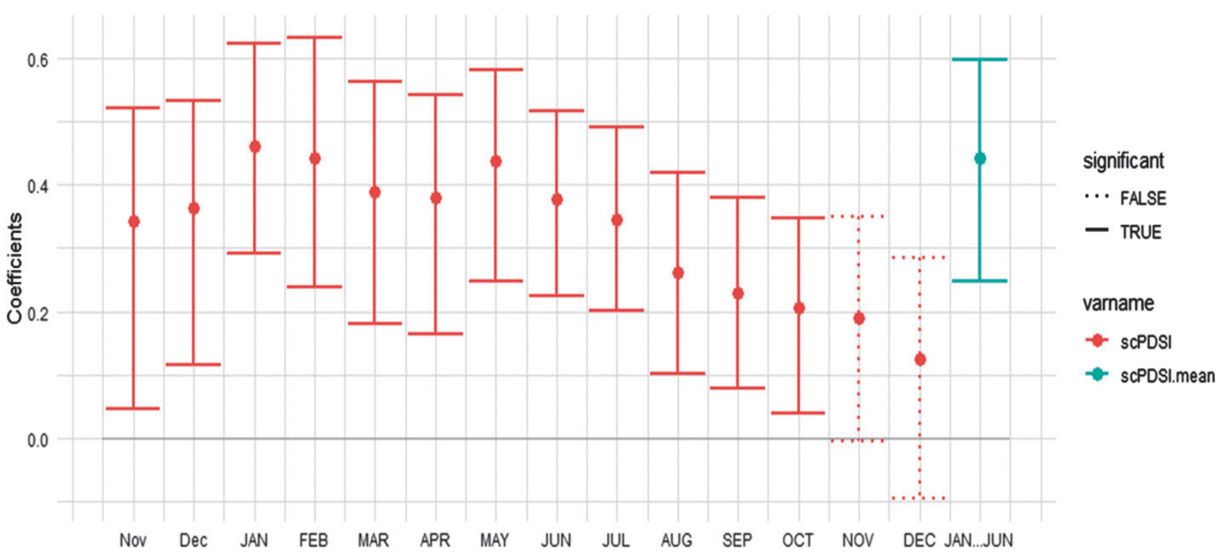


Figure 6: Correlation between a tree-ring width chronology of *P. wallichiana* from Pakistan and CRU scPDSI

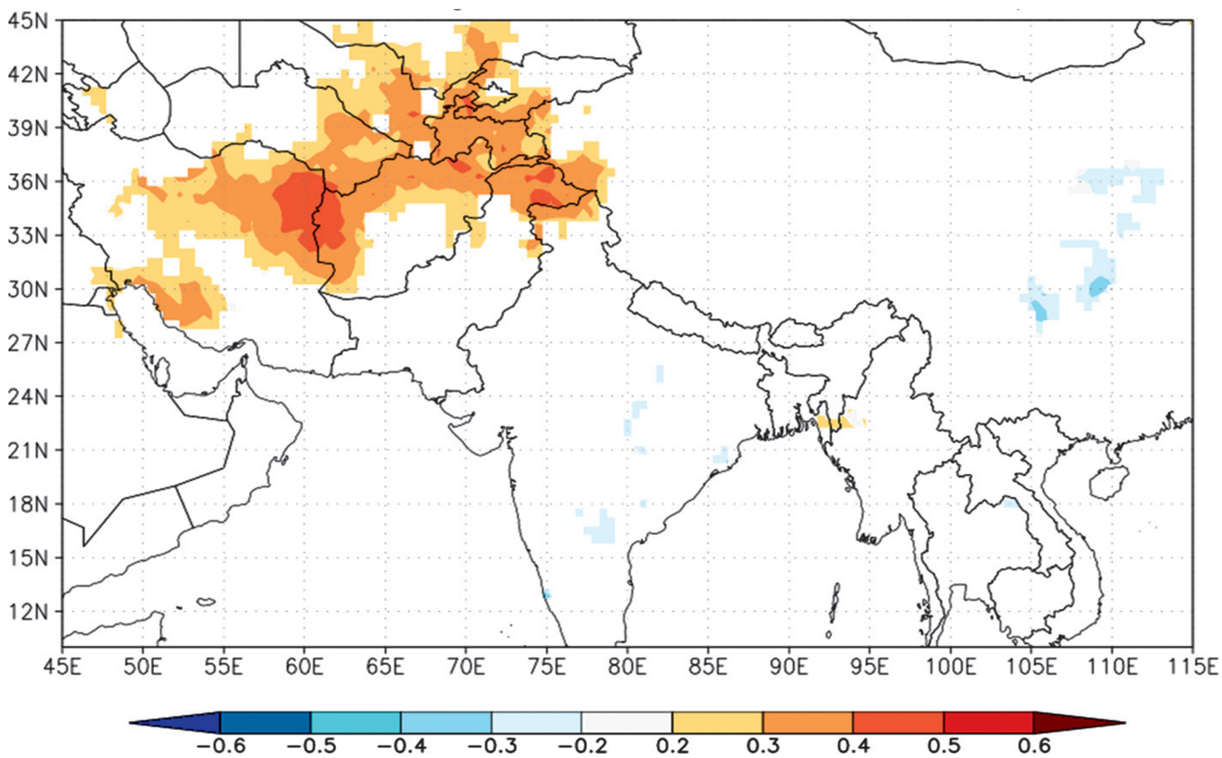


Figure 7: Spatial correlation between tree-ring width of *P. wallichiana* from Pakistan and January−June average CRU scPDSI 3.26e during 1901−2005 (p<0.1%)

All three chronologies of *P. wallichiana* from three different parts of the Himalayas showed a sharp decline in growth in the 1810s. This coincides with the eruption of an unidentified volcano in 1809 (Cole-Dai *et al*., 1997) and that of Mt. Tombara (Indonesia) in 1815. The decline in growth in this period might be because of extreme climate triggered by the explosion of these volcanoes. These eruptions may have caused the Asian monsoon failure for a few years after the events (Anchukaitis *et al*., 2010) and may have reduced moisture availability. The growth of conifer and Himalayan birch from the central Himalayas, Nepal (Thapa *et al*., 2017; Gaire *et al*., 2019; Liang *et al*., 2019), *Tsuga dumosa* from eastern Himalayas (Borgaonkar *et al*., 2018) and junipers from western central Asia (Esper *et al*., 2002) were also suppressed in the 1810s. The growth of this species is above average in the last decades of the 20th century. Several studies (Esper *et al*., 2002; Asad *et al*., 2017; Bhandari *et al*., 2019; Gaire *et al*., 2019) from the Himalayan region have also shown increased growth of different conifer species in the last decade of 20th century. The growth-climate relationship showed that winter temperature limits the growth of this species in the eastern Himalayas of Bhutan. The positive relation between tree-rings and winter temperatures may indicate that in the good winter months this species might experience photosynthesis and store carbohydrates for the subsequent growing season. The *P. wallichiana* trees of the central Himalayas in Nepal showed a positive correlation with winter moisture. In the winter season, the amount of rainfall is low in the region, which finally could not provide enough moisture for the growth of trees. Recently published articles (Sigdel *et al*., 2018a; Thapa and St. George, 2019) also indicated that the growth of pine in Nepal is limited by winter moisture. Precipitation in the form of snow or rainfall during the winter is an important source of moisture for plants during the following season (Borgaonkar *et al*., 2018). The ring-width of this species showed a strong positive correlation with the annual scPDSI in the western Himalayas of Pakistan. The total annual rainfall decreases from eastern to western Himalayas, causing the western part to have a moisture deficit (Cannon *et al*., 2015) which limits the growth of the species (Sharma and Gupta, 1997). In the dry and semi dry areas of the Himalayas, high moisture and cool temperature could be helpful for the growth of this species (Treydte *et al*., 2006; Sigdel *et al*., 2018b; Gaire *et al*., 2019).

Conclusion

The growth of *P. wallichiana* was sharply suppressed in the 1810s, and was increased in the late 20th century in the three different regions of the Himalayas. The sharp suppression of growth in the 1810s coincided with two volcanic eruptions. The growth of this species showed a winter temperature signal in the moist region of the eastern Himalayas in Bhutan and a drought signal in the dry to semi dry region of the western Himalayas. This species has a great potential for the study of both temperature and drought in the Himalayas. We will be able to have a better understanding of the growth-climate relations of this species in the Himalayan region if we can gather more chronologies from this species and collect the remnants from this species to extend its chronologies further back in time.

Acknowledgements

The first author is grateful to the Department of Earth and Environmental System, Indiana State University for providing a graduate teaching assistantship. We are thankful to Dr. Edward Cook, PAGES 2k Consortium, and their entire team for sharing their *P. wallichiana* chronologies to the International Tree-Ring Data Bank.

References

Ahmed, M., Palmer, J., Khan, N., Wahab, M., Fenwick, P., Esper, J. and Cook, E. (2011). The dendroclimatic potential of conifers from northern Pakistan. *Dendrochronologia* 29 (2) : 77−88.

Anchukaitis, K. J., Buckley, B. M., Cook, E. R., Cook, B. I., D'Arrigo, R. D. and Ammann, C. M. (2010). Influence of volcanic eruptions on the climate of the Asian monsoon region. *Geophysical Research Letters* 37 (22) : 1−5

Aryal, S., Bhuju, D. R., Kharal, D. K., Gaire, N. P. and Dyola, N. (2018). Climatic upshot using growth pattern of *Pinus roxburghii* from western Nepal. *Pakistan Journal of Botany* 50 (2) : 579−588.

Asad, F., Zhu, H., Zhang, H., Liang, E., Muhammad, S., Farhan, S. B., Hussian, I., Wazir, M. A., Ahmed, M. and Esper, J. (2017). Are Karakoram temperatures out of phase compared to hemispheric trends? *Climate Dynamics* 48 (9−10) : 3381−3390.

Bhandari, S., Gaire, N. P., Shah, S. K., Speer, J. H., Bhuju, D. R. and Thapa, U. K. (2019). A 307-year tree-ring SPEI reconstruction indicates modern drought in western Nepal Himalayas. *Tree-Ring Research* 75 (2) : 73−85.

Borgaonkar, H. P., Gandhi, N., Ram, S. and Krishnan, R. (2018). Tree-ring reconstruction of late summer temperatures in northern Sikkim (eastern Himalayas). *Palaeogeography, Palaeoclimatology, Palaeoecology* 504 : 125−135.

Cannon, F., Carvalho, L. M., Jones, C. and Bookhagen, B. (2015). Multi-annual variations in winter westerly disturbance activity affecting the Himalaya. *Climate Dynamics* 44 (1−2) : 441−455.

Cole-Dai, J., Mosley-Thompson, E. and Thompson, L. G. (1997). Annually resolved southern hemisphere volcanic history from two Antarctic ice cores. *Journal of Geophysical Research* 102 : 761−771.

Cook, E. R., Anchukaitis, K. J., Buckley, B. M., D'Arrigo, R. D., Jacoby, G. C. and Wright, W. E. (2010). Asian Monsoon Failure and Megadrought During the Last Millennium. *Science* 328 (5977) : 486−489.

Cook, E. R., Krusic, P. J. and Jones, P. D. (2003). Dendroclimatic signals in long tree-ring chronologies from the Himalayas of Nepal. *International Journal of Climatology : A Journal of the Royal Meteorological Society* 23 (7) : 707−732.

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

Devkota, A. (2013). Biodiversity : Gymnosperms. In : Jha, P. K., Neupane, F. P., Shrestha,

M. L. and Khanal, I. P. (eds.). Biological Diversity and Conservation. Nepal Academy of Science and Technology, Kathmandu, 127−134.

Esper, J., Schweingruber, F. H. and Winiger, M. (2002). 1300 years of climatic history for Western Central Asia inferred from tree-rings. *The Holocene* 12 (3) : 267−277.

Gaire, N. P., Dhakal, Y. R., Shah, S. K., Fan, Z. X., Bräuning, A., Thapa, U. K., Bhandari, S., Ayral, S. and Bhuju, D. R. (2019). Drought (scPDSI) reconstruction of trans-Himalayan region of central Himalaya using *Pinus wallichiana* tree-rings. *Palaeogeography, palaeoclimatology, palaeoecology* 514 : 251−64.

Khan, A., Ahmed, M., Siddiqui, M. F., Iqbal, J. and Gaire, N. P. (2018). Dendrochronological potential of *Abies pindrow* Royle from Indus Kohistan, Khyber Pakhtunkhwa (KPK) Pakistan. *Pakistan Journal of Botany* 50 (1) : 365−369.

Lang, T. J. and Barros, A. P. (2004). Winter storms in the central Himalayas. *Journal of the Meteorological Society of Japan* 82 (3) : 829−844.

Liang, E., Dawadi, B., Pederson, N., Piao, S., Zhu, H., Sigdel, S. R. and Chen, D. (2019). Strong link between large tropical volcanic eruptions and severe droughts prior to monsoon in the central Himalayas revealed by tree-ring records. *Science Bulletin*, 64 : 1018−1023.

Melvin, T. M. and Briffa, K. R. (2008). A signal-free approach to dendroclimatic standardization. *Dendrochronologia* 26 (2) : 71−86.

Melvin, T. M., Brifa, K. R., Nicolussi, K. and Grabner, M. (2007). Time-varying-response smoothing. *Dendrochronologia* 25 : 65−69.

Olson, D. M. and Dinerstein, E. (2002). The Global 200 : Priority ecoregions for global conservation. *Annals of the Missouri Botanical Garden* 89 : 199−224.

PAGES 2k Consortium. (2013). Continental-scale temperature variability during the past two millennia. *Nature Geoscience* 6 : 339−346.

Shah, S. K., Pandey, U. and Mehrotra, N. (2018). Precipitation reconstruction for the Lidder Valley, Kashmir Himalaya using tree-rings of *Cedrus deodara*. *International Journal of Climatology* 38 : 758−773.

Sharma, C. and Gupta, A. (1997). Vegetation and climate in Garhwal Himalaya during Early Holocene : Deoria Tal. *Palaeobotanist* 46 (3) : 111−116.

Shrestha, U. B., Gautam, S. and Bawa, K. S. (2012). Widespread climate change in the Himalayas and associated changes in local ecosystems. *PloS one* 7 (5) : 1−10.

Sigdel, S. R., Wang, Y., Camarero, J. J., Zhu, H., Liang, E. and Peñuelas, J. (2018b). Moisture-mediated responsiveness of tree-line shifts to global warming in the Himalayas. *Global change biology* 24 (11) : 5549−5559.

Sigdel, S., Dawadi, B., Camarero, J., Liang, E. and Leavitt, S. (2018a). Moisture-Limited Tree Growth for a Subtropical Himalayan Conifer Forest in Western Nepal. *Forests* 9 (6) : 340 doi : 10. 3390/f9060340.

Speer, J. H. (2010). Fundamentals of tree-ring research. University of Arizona Press.

Thapa, U. K. and George, S. S. (2019). Detecting the influence of climate and humans on pine forests across the dry valleys of eastern Nepal's Koshi River basin. *Forest Ecology and Management* 440 : 12−22.

Thapa, U. K., George, S. S., Kharal, D. K., and Gaire, N. P. (2017). Tree growth across the Nepal Himalaya during the last four centuries. *Progress in Physical Geography* 41 (4) : 478−495.

Treydte, K. S., Schleser, G. H., Helle, G., Frank, D. C., Winiger, M., Haug, G. H. and Esper, J. (2006). The twentieth century was the wettest period in northern Pakistan over the past millennium. *Nature* 440 (7088) : 1179−1182.

Trouet, V. and Oldenborgh, G. J. V. (2013). KNMI Climate Explorer : a web-based research tool for high-resolution paleoclimatology. *Tree-Ring Research* 69 (1) : 3−13.

Van Der Schrier, G., Barichivich, J., Briffa, K. R. and Jones, P. D. (2013). A scPDSI-based global data set of dry and wet spells for 1901−2009. *Journal of Geophysical Research Atmosphere* 118 : 4025−4048.

Yadav, R. R. and Bhattacharyya, A. (1997). Climate and growth relationship in blue Pine (*Pinus wallichiana*) from the western Himalaya India. *The Korean Journal of Ecology* 20 (2) : 95−102.

Zang, C. and Biondi, F. (2015). treeclim : an R package for the numerical calibration of proxy-climate relationships. *Ecography* 38 (4) : 431−436.