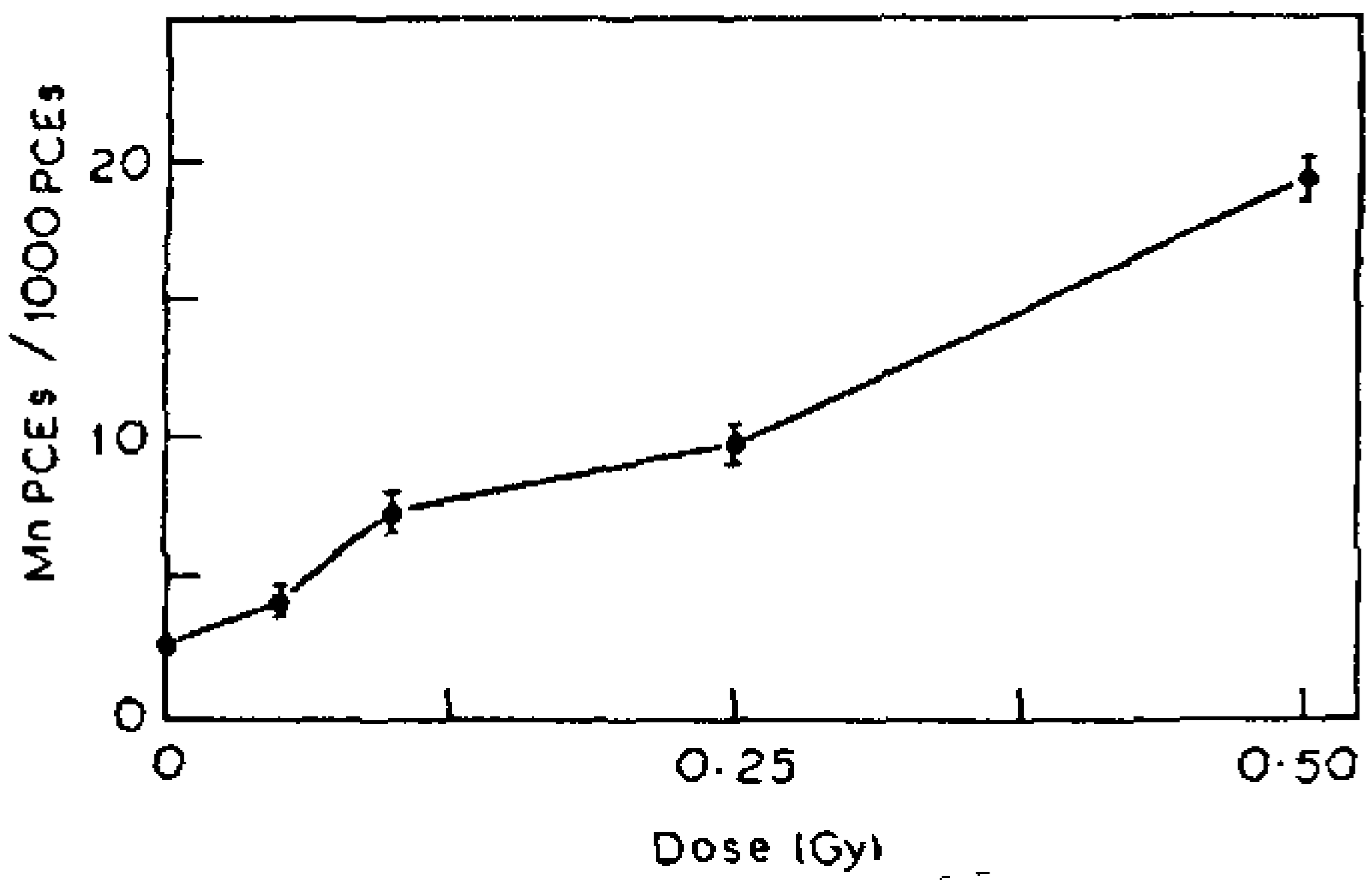

Figure 1. Frequencies of MnPCEs in bone marrow erythrocytes following whole-body exposure to low doses of γ-radiation at a dose rate of 0.28 Gy/min.

micronuclei. In particular, the presence of ascorbic acid does not abolish the radioprotective action of the combination(s) of the dietary agents. This indicates that these compounds continue to exert radioprotection when present together, as in a normal human diet. The magnitude of radioprotection afforded at the two radiation doses, 0.25 and 0.50 Gy is quite comparable. It would be even more interesting if these dietary constituents abolish the small but significant increase in the frequency of micronuclei observed in animals exposed to as small as 0.05 Gy. At such low doses, fluctuations in the frequency of MnPCEs are much greater, and therefore, the sampling size would have to be increased. Such studies are in progress. The doses of various dietary antioxidants used in the present study are those which can be achieved through the diet. Carrots, spinach, cabbage, guava and lemon are rich sources of ascorbic acid and β-carotene while almonds and peanuts contain large amounts of α-tocopherol. Chlorogenic acid is present in high concentrations in coffee. Curcumin is the main colouring principle of turmeric, an edible spice which is widely used in Indian foods. Therefore the present finding which suggests that the intake of a diet rich in 'natural' antioxidants can reduce the chromosomal damage induced by exposure to ionizing radiation has implications from the point of risk assessment.

1. Nambi, K. S. V. and Soman, S. D., *Health Phys.*, 1987, **52**, 653–657.
2. Hanson, G. P. and Komarov, E., Biological Effects of Low-Level Radiation, Proceedings of a symposium, Venice, April, 1983, IAEA, 211–230.
3. Ames, B., *Science*, 1983, **221**, 1256–1264.
4. Wattenberg, L. W., *Cancer Res.*, 1983, **43**, 2448–2453.
5. Stich, H. F., *Mutation Res.*, 1991, **259**, 307–324
6. Simic, M. G. and Bergtold, D. S., *Mutation Res.*, 1991, **250**, 17–24.
7. Sarma, L. and Kesavan, P. C., *Int. J. Radiat. Biol.*, 1993, **63**, 759–764.
8. Abraham, S. K., Sarma, L. and Kesavan, P. C., *Mutation Res.*, 1993, **303**, 109–112
9. Schmid, W., *Mutat. Res.*, 1975, **31**, 9–15.

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Tree ring evidences of the 1991 earthquake of Uttarkashi, Western Himalaya

R. R. Yadav and A. Bhattacharyya
Birbal Sahni Institute of Palaeobotany, 53 University Road, Lucknow 226 007, India

Tree-ring analyses of 'kail' pine (*Pinus wallichiana*) from Agora in Uttarkashi, Western Himalaya, were carried out to evaluate the effect of the 1991 earthquake event on tree growth. Tree rings were commonly found to be narrow in 1992, one year after the earthquake in most of the trees studied. The tilted trees showed eccentric growth, i.e. narrow rings on the upper side of the stem opposite to the lean in comparison to the wider contemporary rings of the lean side. The growth eccentricity was found to be synchronic in many trees and could be related to the 1991 earthquake event. Such tree ring studies along the active fault zones would help in the dating of palaeoseismic events.

In India reliable records of past earthquakes are limited to 200 years including 67 years of instrumental record. Proxy records could be utilized to date the past earthquake events. Longer records of earthquakes would help in seismic zoning by delimiting the areas experiencing frequent shocks.

Ring sequences of trees growing along the active fault zones offer the potential of dating the past earthquake events with the precision of actual year of their occurrence. Even in some cases tree rings have been found to provide the information to the level of months or seasons if the earthquake occurred in the growing season[1]. Strong seismic shocks cause intensive physical damage to trees such as severing of roots, tilting and sometimes even complete destruction. The trees surviving such shocks record the event in their annual growth rings with features such as narrow rings, growth eccentricity and increased proportion of reaction wood. Several studies[2–10] have demonstrated the applicability of tree rings in dating of palaeoseismic events.

This paper reports the response of the earthquake of 20 October 1991 in Uttarkashi on the growth of *Pinus wallichiana* (kail pine) from Agora in Uttarkashi, Western Himalaya.

Several places in Uttarkashi district in the Western Himalayan region were rocked by the devastating earthquake of 20 October 1991, which killed over a thousand people and flattened around 30,000 houses leaving several thousands homeless. This earthquake originated as a result of slipping on the segments of faults in the active zone of the Main Central Thrust[11]. The Main Central Thrust zone is made up of a succession of severely sheared and crushed rocks, split up by a large number of thrust planes into many tectonic slabs. The 1991 earthquake caused severe damage along the Munsiari Thrust extending south-east from Bankoli–Agora through Sainj, Lata, Saur in the Bhagirathi Valley. In Agora, the study area (38°51′ N and 78°29′ E), violent shaking due to the slipping of active segments of faults caused deep ground ruptures and rock falls. At many places, wide cracks on the mountain slopes and damaged buildings were still present during our field survey in November 1993 which remind the devastating effect of the earthquake in the area (Figure 1).

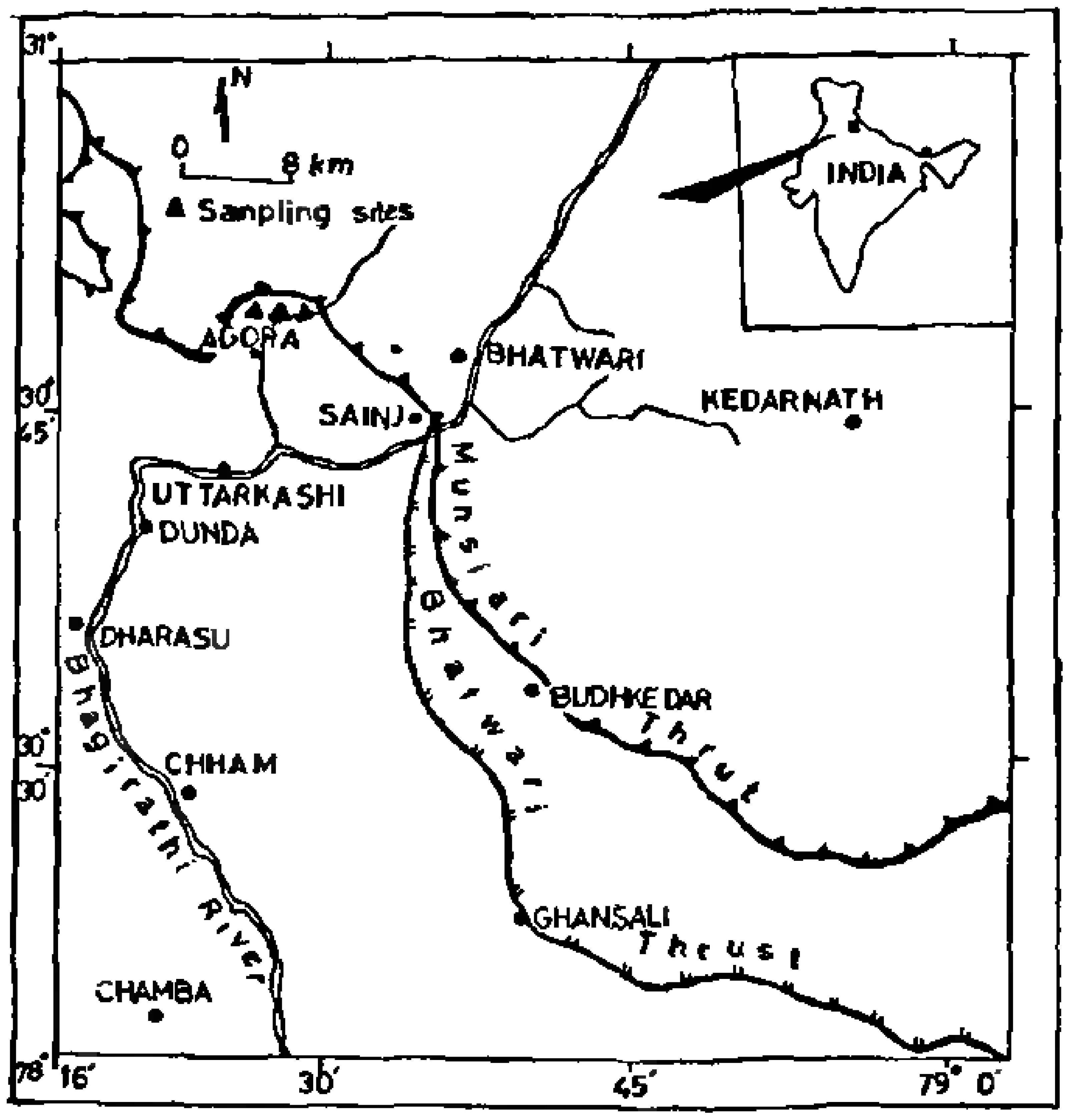

Figure 2. Kail pine trees growing in earthquake damaged area in Agora, Uttarkashi

To study the effect of earthquake on tree growth a reconnaissance was made in Agora, Uttarkashi during November 1993 (Figure 2) which faced severe damage due to this event. Kail pine (*Pinus wallichiana*) trees growing along the south and south-east facing mountain slopes were found much affected by this earthquake. These trees were recently planted on experimental basis by the Forest Department to stablize the slopes (Figure 3). Tree core samples were collected from 12 kail pine trees growing along the mountainous slopes over about 2 km distance. For the extraction of cores, Finish increment corer was used. The majority of the trees cored were found tilted towards the down hill slope. Attempts were made to take two cores, one each from up and down hill slope side of each tree. However, only one core was taken when the other side was not approachable due to steep slope. The tree cores were air-dried at room temperature and mounted on wooden frames. The cross surfaces were cut and smoothened with different grades of sand papers until the tracheidal cells became clear under the low power binocular microscope. As the trees are very young, simple ring counts coupled with matching of few signature rings were found satisfactory to date the tree rings. Dated tree ring sequences were measured with the Swedish Parker annual ring

Figure 1. Shows the devastating effect of the 20 October 1991 earthquake in Agora, Uttarkashi.

Figure 3. Sample collection sites near Agora, Uttarkashi

measuring machine model-3 with the accuracy of 0.01 mm. The age of the oldest tree estimated from the increment cores ranged from 1967 to 1993. Ring width measurement curves for two of the trees one each from undisturbed and disturbed condition are shown in Figure 4.

The analyses of tree ring samples collected from uphill slope side of 12 kail pine trees have shown abrupt growth reduction in 11 trees during 1992, the year subsequent to the earthquake event. Growth rings continued to be narrow in 1993 also but were slightly wider than of 1992. One tree which did not show the growth decline (Figure 4) was found to be growing on comparatively flat top with thick soil indicating that the trees growing on steep slopes with thin sheet of soil are prone to shaking. Vigorous shaking by the earthquake could have severed the fine root system besides tilting the trees. Severed root system greatly reduces the nutrient and water uptake of the trees resulting in poor growth. As the 1991 earthquake occurred in October when tree growth almost ceases completely in the Himalayan region, the 1991 ring size was not affected. The earthquake damage resulted in poor growth of the trees during the subsequent year. The tree growth recovers slowly as the new roots are formed to rebalance the root/shoot ratio in subsequent years. The narrow ring of 1992 in the majority of trees also had very small proportion of late wood in comparison to the neighbouring rings indicating short growing length during 1992.

Contrary to the narrow rings of 1992 and 1993 in many trees in the tree cores from uphill side, contemporary rings of the lean side were noted to be wider.

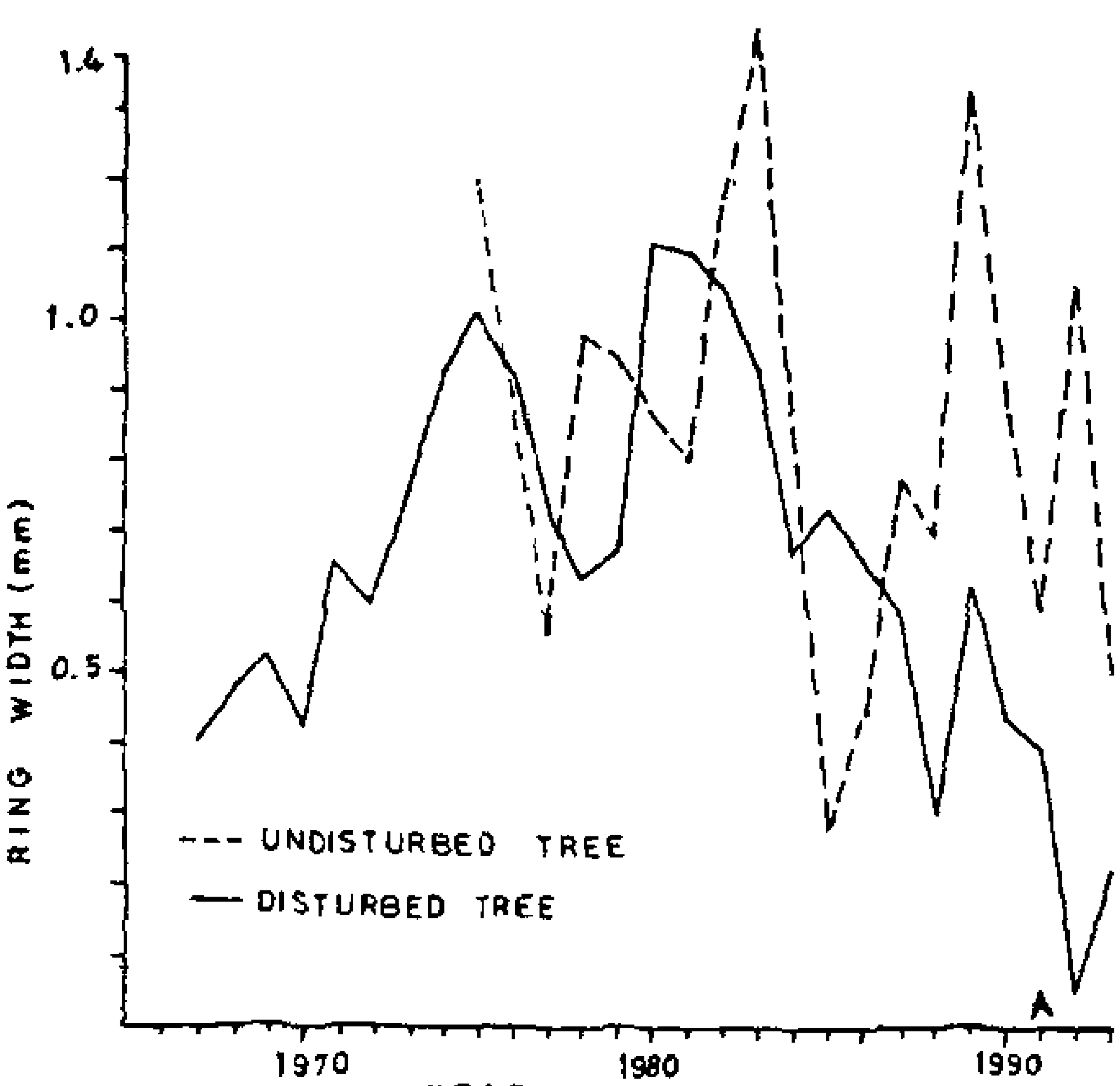

Figure 4. Raw ring width data from undisturbed and disturbed trees of kail pine The arrow head indicates the year of earthquake event.

Such eccentric growth occurs in gymnosperms in response to the tilting of tree. Trees growing on mountainous slopes with thin sheet of soil cover are prone to tilting. Tilting of trees is reflected in the production of eccentric growth rings which may continue to form for several years depending on the extent of tilt until the stem becomes straight. Such eccentricity in growth could also be used as a sensitive indicator of the physical forces causing the tilt of trees. Though several other geomorphological phenomena, viz. land slides, soil creeps, mass movements, etc. tilting the trees also produce similar event response like earthquakes but their effects are site-specific and localized. The presence of growth suppression and growth eccentricity of rings in many trees in a wide area indicates a common causal event that is the earthquake of 1991.

The present study has shown that the 1991 earthquake in Uttarkashi, Western Himalayan region caused intensive damage to kail pine trees. Synchronic alterations in ring width patterns such as abrupt growth decline and eccentricity noted in many trees of the area seem to be related to the 1991 earthquake event. The present findings indicate that extensive studies on trees growing in widespread areas along the active fault zones could be taken as an important criterion to identify the signatures of palaeoseismic events. However, for authenticity of the palaeoseismic dates, a large number of samples from different areas should be studied. Greater the number of tree samples showing disturbance, greater is the authenticity of tree ring date. Similarly, larger the area over which the disturbance occurs, greater is the chance that it has resulted from earthquake.

1. Shroder, J. F. and Butler, D. R., Proceedings of the International Symposium on Ecological Aspects of Tree-Ring Analysis (ed. Jacoby, G. C.), New York, 1987, pp. 186–212.
2. Page, R., *Geol. Soc. Am. Bull.*, 1970, **81**, 3085–3094.
3. LaMarche, V. C. and Wallace, R. E., *Geol. Soc. Am. Bull.*, 1972, **83**, 2665–2672.
4. Meisling, K. E. and Sieh, K. E., *J. Geophys. Res.*, 1980, **85**, 3225–3238
5. Ruzhich, V. V., Sankov, V. A. and Dneprovskii, Y. I., *Sov. Geol. Geophys.*, 1982, **23**, 57–63 (in Russian).
6. Jacoby, G. C. and Ulan, L. D., *J. Geophys. Res.*, 1984, **88**, 9305–9313.
7. Kaiser, K. E. and Kaiser-Bernhard, C., *Dendrochronologia*, 1987, **5**, 111–124.
8. Sheppard, P. R. and Jacoby, G. C., Proceedings of the International Symposium on Ecological Aspects of Tree-Ring Analysis (ed. Jacoby, G. C.), New York, 1987, pp. 281–289.
9. Jacoby, G. C., Richard, P. R. and Sieh, K. E., *Science*, 1988, **242**, 196–199.
10. Yadav, R. R. and Kulieshius, P., *Georgr. J.*, 1992, **158**, 295–299.
11. Valdiya, K. S., *Curr. Sci.*, 1991, **61**, 801–803.

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