production. *Trop. Anim. Health Prod.*, 2020; https://doi.org/10.1007/s11250-020-02324-4

26. Sahoo, A., Sarkar, S., Lal, B., Kumawat, P., Sharma, S. and De, K., Utilization of fruit and vegetable waste as an alternative feed resource for sustainable and eco-friendly sheep farming. *Waste Manage.*, 2021, **128**, 232–242.
27. Kamra, D. N., Pawar, M. and Singh, B., Effect of plant secondary metabolites on rumen methanogens and methane emission by ruminants. In *Dietary Phytochemicals and Microbes* (ed. Patra, A. K.), Springer, Dordrecht, The Netherlands, 2012, pp. 351–370.
28. Hundal, J. S., Wadhwa, M. and Bakshi, M. P. S., Effect of supplementing essential oils on the *in vitro* methane production and digestibility of wheat straw. *J. Anim. Nutr.*, 2016, **1**, 14; doi:10.21767/2572-5459.100014.
29. Sarkar, S., Mohini, M., Nampoothiri, V. M., Mondal, G. and Pandita, S., Effect of tree leaves and malic acid supplementation to wheat straw based substrates on *in vitro* rumen fermentation parameters. *Indian J. Anim. Nutr.*, 2016, **33**, 421–426.
30. Valencia-Salazar, S. S., Jiménez-Ferrer, G., Arango, J., Molina-Botero, I., Chirinda, N., Piñeiro-Vázquez, A. and Kú-Vera, J., Enteric methane mitigation and fermentation kinetics of forage species from southern Mexico: *in vitro* screening. *Agrofor. Syst.*, 2021, **95**, 293–305.
31. Bhatta, R., Saravanan, M., Baruah, L. and Prasad, C. S., Effects of graded levels of tannin-containing tropical tree leaves on *in vitro* rumen fermentation, total protozoa and methane production. *J. Appl. Microbiol.*, 2015, **118**, 557–564.
32. Lee, H. J., Lee, S. C., Kim, J. D., Oh, Y. G., Kim, B. K., Kim, C. W. and Kim, K. J., Methane production potential of feed ingredients measured by *in vitro* gas test. *Asian–Aust. J. Anim. Sci.*, 2003, **16**, 1143–1150.
33. Valenciaga, D., Chongo, B., Herrera, R. S., Torres, V., Oramas, A. and Herrera, M., Effect of regrowth age on *in vitro* dry matter digestibility of *Pennisetum purpurecum* cv. CUBACT-115. *Cuban J. Agric. Sci.*, 2009, **43**, 79–82.
34. Shingfield, K. J., Ahvenjarvi, S., Toivonen, V., Vanhatalo, A., Huhtanen, P. and Griinari, J. M., Effect of incremental levels of sunflower-seed oil in the diet on ruminal lipid metabolism in lactating cows. *Br. J. Nutr.*, 2008, **99**, 971–983.
35. Hess, H. D., Monosalve, L. M., Lascano, C. E., Carulla, J. E., Diaz, T. E. and Kreuzer, M., Supplementation of a tropical grass diet with forage legumes and *Sapindus saponaria* fruits: effect on *in vitro* ruminal nitrogen turnover and methanogenesis. *Aust. J. Agric. Res.*, 2003, **54**, 703–713.
36. Patra, A. K. and Saxena, J., Dietary phytochemicals as rumen modifiers: a review of the effects on microbial populations. *Antone Van Leeuwenhoek*, 2009, **96**, 363–375.
37. Bhatta, R., Baruah, L., Saravanan, M., Suresh, K. P. and Sampath, K. T., Effect of medicinal and aromatic plants on rumen fermentation, protozoa population and methanogenesis *in vitro*. *J. Anim. Physiol. Anim. Nutr.*, 2013, **97**, 446–456.
38. Waghorn, G. C. and McNabb, W. C., Consequences of plant phenolic compounds for productivity and health of ruminants. *Proc. Nutr. Soc.*, 2003, **62**, 383–392.
39. Chaudhary, L. C., Srivastava, A. and Singh, K. K., Rumen fermentation pattern and digestion of structural carbohydrate in buffalo (*Bubalus bubalis*) calves as affected by ciliate protozoa. *Anim. Feed Sci. Technol.*, 1995, **56**, 111–117.
40. Ungerfeld, E. M., Shifts in metabolic hydrogen sinks in the methanogenesis-inhibited ruminal fermentation: a meta-analysis. *Front. Microbiol.*, 2015, **6**, 1–17.
41. Datt, C., Niranjan, M., Chhabra, A., Chatopadhyay, K. and Dhiman, T. R., Forage yield, chemical composition and *in vitro* digestibility of different cultivars of maize (*Zea mays* L.). *Indian J. Dairy Sci.*, 2006, **59**, 177–180.
42. Makkar, H. P. S., Sen, S., Blummel, M. and Becker, K., Effect of fractions containing saponins from *Yucca schidigera*, *Quillaja saponaria* and *Acacia auriculofprmis* on rumen fermentation. *J. Agric. Food Chem.*, 1998, **46**, 4324–4328.

ACKNOWLEDGEMENT. We thank the Director, ICAR-National Dairy Research Institute, Karnal for providing the necessary facilities and the Indian Council of Agricultural Research, New Delhi, for funds.

Received 5 December 2021; accepted 28 December 2021

doi: 10.18520/cs/v122/i3/322-327

Relationship between Cerambyciid borer (Insecta: Coleoptera) infestation and human-induced biotic interferences causing mortality of kharsu (*Quercus semecarpifolia* Smith in Rees) oak trees in Garhwal, Western Himalaya, India

Gaurav Chand Ramola* and Arun Pratap Singh

Entomology Branch, Forest Protection Division,
Forest Research Institute, Dehradun 248 006, India

Stem and wood boring beetles significantly damage kharsu oak trees leading to their mortality and decline in the Garhwal region of Western Himalaya, India. The relationship established between the prevalent biotic factors (extensive lopping and grazing) and the degree of borer infestation in Chakrata hills, Uttarakhand, revealed a strong correlation between the two. Density–girth class relationship in borer-infested oak stands revealed a higher degree of past disturbance compared to uninfested oak stands, with maximum infestation in girth class 61–80 cm and between 2601 and 2700 msl.

Keywords: Biotic interference, oak, stand composition, stem and wood borer, tree density.

OAKS are the dominant climax tree species of the moist temperate forests ecosystem in the Indian Himalayan region[1], where over 35 species of oak are reported spread along an elevation gradient of 800–3800 m amsl (ref. 2). Five species of evergreen oak, namely *Quercus leucotrichophora* (banj), *Quercus floribunda* (moru), *Quercus semecarpifolia* (kharsu), *Quercus glauca* (phaliyant/harimj) and *Quercus lanuginosa* (riyanj) grow naturally in the Western Himalaya[1], of which *Q. semecarpifolia*

*For correspondence. (e-mail: gauravramola30@gmail.com)

Figure 1. Adult (***a***) *Rosalia lateritia*, (***b***) *Xylotrechus basifuliginosus* and (***c***) *Anaglyptus fasciatus* (photograph: A.P.S.).

represents the climax community and forms extensive forests in the high-altitude zone of the region[3]. Recently, kharsu oak (*Q. semecarpifoilia*) forests have shown a decline in the region owing to overexploitation, mainly looping for fodder, fuelwood and grazing[3]. Kharsu oak is one of the most overexploited species in the sub-alpine zone of the Western Himalaya[4].

The kharsu oak tree and timber are attacked by a variety of insects. Stem and wood boring beetles have recently caused significant mortality of kharsu oak in the Garhwal region[5]. Among the cerambycid borers three species have been reported. (i) *Rosalia lateritia* (Hope, 1831) (Cerambycinae: Rosalini) is red longhorn beetle, 25–30 mm long, red from the above black from beneath, head is black with two red spots, elytra possesses small spots and antennae of male longer than the body whereas that of the female is equal to their body length. The beetle is distributed in India (Uttarakhand, Sikkim, Arunchal Pradesh, Assam), Myanmar and Indo-China (Figure 1 *a*). The larva of this beetle attacks live standing kharsu oak trees with adults occurring in May–September[5,6]. (ii) *Xylotrechus basifuliginosus* (Heller, 1926) (Cerambycinae: Clytini) is 14–15 mm in length, 4–5 mm in width, black to brownish in colour with yellowish pubescence on the head and prothorax region in female whereas head and prothorax are grey colour in male and forming three yellow-coloured transverse bands on the elytra in female and white in males. Larva of this beetle attacks the dead, standing and fallen kharsu oak trees which are initially infected by *R. lateritia.* This beetle is distributed in the Western and Central Himalaya in India (Himachal Pradesh and Uttarakhand) and Nepal (Figure 1 *b*)[5,6]. (iii) *Anaglyptus fasciatus* (Thomson, 1857) (Cerambyinae: Anaglyptini) is 10–12 mm in length, brown from the above with black transverse bands on the elytra; antennae are longer than the body in both sexes and larva mainly feeds on dead kharsu oak trees. The beetle is distributed in India (Himachal Pradesh, Uttarakhand, West Bengal and Sikkim) and Nepal[5,7,8] (Figure 1 *c*). These are three species of borers infesting kharsu oak trees in the study region having an annual life cycle, with the emergence of adults in summer when mating and egg-laying also take place[5,6].

It is not known if there is a relationship between biotic factors (lopping and grazing, and degree of past disturbance) and the degree of borer infestation and tree mortality of kharsu oak in the forest stands of this region. Basic data on stand composition, tree density and diameter class of kharsu oak trees in the borer infested sites are scanty[5].

We hypothesize that the degree of borer infestation and thereby kharsu oak tree mortality caused by them in the forest stands in Garhwal are directly related to the intensity of past disturbance. Hence greater the intensity of disturbance in kharsu oak forests, greater is the degree of borer infestation, and vice versa. The present study thus aims to establish a link between human-induced biotic disturbances, stand parameters and the degree of borer infestation on kharsu oak trees in Garhwal, so that the main cause of the recent oak mortality can be understood.

The present study was carried out during June 2018–July 2020. A major part of the Deoban Reserve Forest (N 30.74806; E 77.86639; 2600–2815 m amsl) in Chakrata hills, Uttarakhand, falls under the forest sub-type 12/C1d Western Mixed Coniferous Forests[9], covering an area of ~3301 ha in the Western Himalaya. A varying mixture of conifer species (*Abies pindrow*, *Picea smithiana*, *Cedrus deodara*, *Pinus wallichiana* and *Taxus baccata*) along with evergreen and deciduous broadleaved trees (*Q. semecarpifolia*, *Q. floribunda*, *Aesculus indica* and *Miliosma dilleniaefolia*) are found here. The understorey mainly consists of shrubs like *Vibernum cotinifolium*, *V. mullaha*, *Berberis aristata*, *Desomodium elegans*, *Daphne* spp., *Rosa macrophylla*, *Cotoneaster acuminate*, and dwarf bamboos like *Thamnocalamus spathiflorus* and *Arundinaria falcata*, which are characteristic of this forest type.

A total of 180 quadrates (10 × 10 m) were laid between 2500 and 2900 m amsl in kharsu oak forests in the study area. Ninety of these quadrates were laid out in borer-infested sites and 90 in borer uninfested sites. Enumeration of trees above 10 cm in girth was done by measuring GBH (girth at breast height) at 1.37 m above ground level for trees lying inside each quadrate.

The number of borer-infested kharsu oak trees in each plot in the study area was determined and marked on the basis of presence of their emergence holes as observed in the field by the authors in this study (10 mm in diameter by *R. lateritia*; 5 mm in diameter by *X. basifuliginosus* and 3 mm by *A. fasciatus*)[5]. Distribution of attack of these three borer species on kharsu oak trees in different diameter classes was determined in the present study in order to identify the most susceptible age class of kharsu oak.

Tree girth class distribution in the forest stands has been used as an indicator of forest stand quality[10]. A healthy forest stand will have an exponential girth class distribution of trees with clear preponderance to lower girth classes[11]. The forest stands characterized by an abundance of only mature canopy species and absence of seedlings and saplings can be due to persistent biotic pressure or outbreak of insect pests that are responsible for poor regeneration[12]. Analysis of size-class distribution of single species is more useful in the detection of disturbance than the analysis of stand size-class distribution[13]. The degree of past disturbance in kharsu oak forest was estimated by calculating the coefficient of determination (R^2) between regression of density and girth class relationship of trees in both borer infested and uninfested plots[14]. Lower values of R^2 indicate considerable disturbances and values close to 1.0 indicate a more balanced structure or relatively undisturbed stand[15,16]. Thus, tree density and GBH of each of selected plots were measured. The logarithmic number (log) of individuals per GBH class was plotted in size-class diagrams. The tree density of all quadrates of borer infested and uninfested plot was then compared in regression to determine the R^2 values.

Kharsu oak stands were also classified into four altitudinal distribution zones from 2500 to 2900 m amsl (2500–2600, 2601–2700, 2701–2800 and 2801–2900 m). These four classes were then evaluated for borer infestation and the number of lopped trees in order to establish a correlation between them.

Vegetation composition of kharsu oak stands, i.e. dominant trees was determined by laying down 180 quadrates (10 × 10 m) in the forest area to determine the tree density and shrub associates of kharsu oak.

The proportion of *P. smithiana* and *A. pindrow* was determined to be high in cooler aspects and gentle ground whereas *C. deodara* had a higher proportion in the lower limits and steeper slopes. Pure kharsu oak patches in this forest occupied the higher zone with an area of ~388 ha. Tree density in these forest stands was 1591 trees/ha; range 1383–1773 trees/ha and were dominated by the girth class 61–80 cm followed by 80–100, 41–60 and 101–120 cm. The number of trees with girth classes above 240 cm was negligible (Figure 2).

The population of *X. basifuliginosus* beetles was observed to be greater than *R. lateritia* and *A. fasciatus* at the time of emergence (June–July). A total of 1245 kharsu oak trees were surveyed in borer-infested sites, of which 337 trees were found to be borer infested due to the presence of emergence holes in these trees, which accounted for 27.06% of borer infestation in the area. It was observed that the attack of cerambycid borers was more in the middle girth classes of trees. Among all the girth classes in borer-infested sites, around 90% of infestation was recorded in the girth class 41–120 cm, with the highest number of borer-infested trees in the girth class 61–80 cm followed by 81–100, 41–60 and 101–120 cm (Figure 3).

In uninfested kharsu oak stands, a regression ($y = -0.169x + 2.828$, $P < 0.05$ highly significant at 1% level of significance) was also established in which the coefficient of determination (R^2) was high (0.70), because of the presence of lower girth classes of kharsu oak trees in these stands (Figure 4). This indicated a more balanced structure and the girth class distribution indicated a good regeneration of kharsu oak trees, which was also evident from the ground surveys.

A regression equation ($y = -0.109x + 1.612$) ($P < 0.05$ significant at 5% level of significance) was established based on a negative exponential model between the density (log) and girth class of kharsu oak trees in borer-infested stands[8]. This suggests that mortality rate of borer-infested kharsu oak trees decreases with increase in diameter class in these forest stands (Figure 5). The coefficient of determination (R^2) was 0.37 in borer-infested kharsu oak stands.

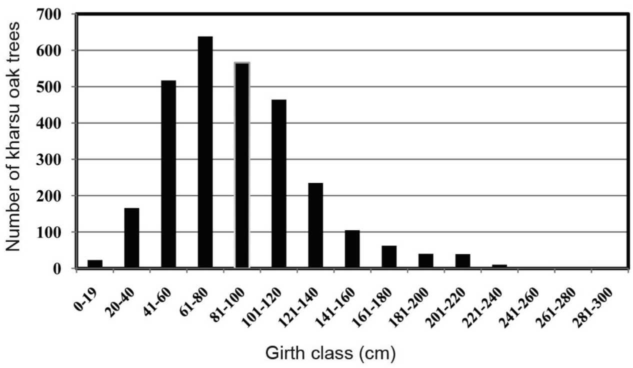

Figure 2. Population structure of different diameter classes of kharsu oak trees in the forest stands of Deoban Reserve Forest (RF), Chakrata hills, Uttarakhand, India.

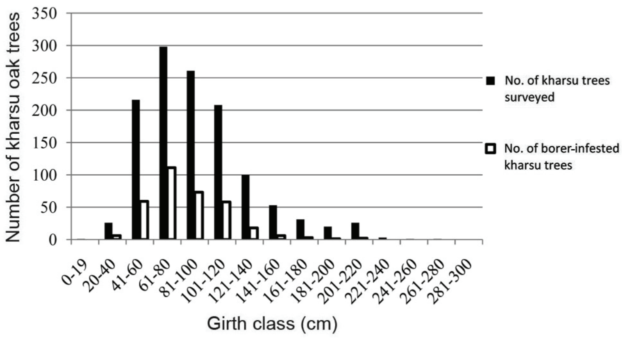

Figure 3. Population structure of different diameter classes of kharsu oak trees in relation to borer-infested trees in the forest stands of Deoban RF.

The low value of R^2 is not a good fit because girth-class distribution in borer-infested trees showed lack of young trees and bell-shaped girth-size class distribution is attributed to disturbed forest where regeneration has been hindered[15,16]. Thus, the low R^2 value in the present study suggests a high degree of past disturbance in borer-infested kharsu oak stands.

Borer infested and uninfested sites when overlaid on ArcGIS platform also indicated that the disturbance is mostly prevalent in the former sites (Figure 6). In Figure 6, disturbed (lopped and grazed) stands (orange circles) and borer-infested sites (red circles) overlap each other and can be clearly demarcated/separated from the borer uninfested sites (grey triangles) that lie outside this zone, in the Deoban RF.

Biotic factors in the form of lopping were more prominent in the Kharsu oak stands prone to borer infestation with tree mortality. Heavy lopping (50–75%) was observed in altitudinal class 2 (Figure 7, green circles). A highly significant correlation ($r = 0.7801$; $P < 0.05$ highly significant at 1% level of significance: $n = 180$ forest stands of $10 \text{ m} \times 10 \text{ m}$) was established between the number of lopped kharsu trees and the number of borer-infested kharsu oak trees in the forest stands of Deoban RF. Highest borer infestation (44.23%) was recorded in altitudinal class 2 (Figure 7) followed by altitudinal class 3, 1 and 4 respectively (Figure 8). The class 2 (2601–2700 m amsl) altitudinal zone was mostly dominated by tree species like kharsu oak, fir, spruce and deodar with a mean tree GBH of 0.79 m (range 0.27–2.71 m) and tree density of 1484 trees/ha.

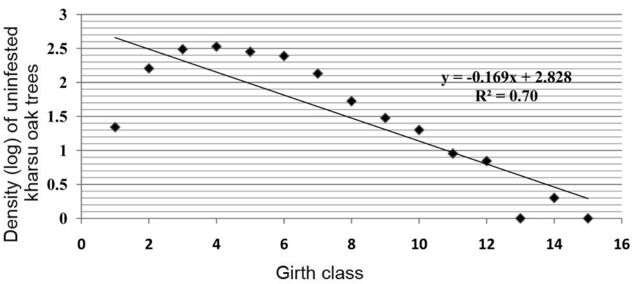

Figure 4. Graph showing the relationship between girth class and borer uninfested khasru oak trees in the forest stands of Deoban RF.

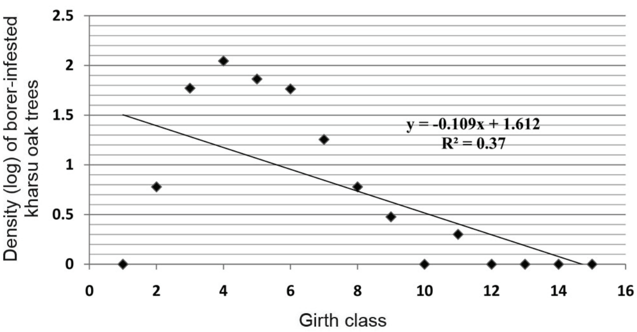

Figure 5. Graph showing relationship between girth class and borer-infested oak trees in the forest stands of Deoban RF.

The issues of anthropogenic disturbance, borer infestation and kharsu oak mortality have been persistent in the Chakrata Forest Division since the last several years. One of us (A.P.S.) had earlier (July–August 2008 and 2009) recorded infestation by the three borers in the forest stands of Deoban (compartments 6B; 9A and 9B) and Mundali blocks (2500–2740 m amsl), Chakrata hills, with 28% of kharsu oak trees infested by them at that time[5]. Biotic interferences in the form of lopping (>50% kharsu oak trees lopped) and heavy grazing were then identified as major factors responsible for degradation of these forest stands[5]. Biotic interferences recorded in kharsu oak forests during the present study were mainly extensive lopping and grazing by cattle (buffaloes, cows, goats, sheep and horses) belonging to the migratory and seasonal nomadic community of Van Gujjars and also local villagers who lived in the vicinity of Chakrata hills. Fresh green foliage of kharsu oak trees is lopped to feed the livestock, and the leftover green leaves are spread on the floor in the barn where these animals rest, while larger branches are used as fuelwood. Extensive lopping is the major cause of borer incidence in these forests as the wounds on oak branches after lopping attract stem borers like *R. lateritia* and *X. basifuliginosus* for oviposition and feeding. Lopping of trees is known to rapidly drain stored food reserves leading to a decline in tree growth[17] and lopped trees under environmental stress are generally prone to attack by stem borers[18]. Grazing during the summer (March–June) and monsoon (June–August) seasons directly effects regeneration of new oaks seedlings. If this process persists, it slowly eliminates the understorey and is one of the reasons for poor natural regeneration of kharsu oak in the study area. It is also known that grazing negatively affects herbivorous insects, thus limiting the effectiveness of natural enemies[18]. Insects are significantly more abundant in ungrazed areas than in grazed areas[19,20]. The understorey of flowering shrubs and herbs supports a large number of insect natural enemies of these cerambycid stem borers (mainly of family Braconidae, e.g. *Apanteles* sp.) and Ichneumonidae, e.g. *Rhyssa persuasoria himalayaensis* Wilkinson, 1927 of hymenopteran wasps), that are dependent on floral nectar. As these plants get eliminated with disturbance, it also disturbs the population dynamics of the insect pests causing them to multiply in geometric proportions and resulting in outbreaks that cause tree mortality.

The present study has established a relationship between borer infestation and human-induced biotic interferences causing mortality of kharsu oak trees in Garhwal. The findings of this study indicate an urgent need to check the spread of insect borers causing oak mortality using integrated pest management practices and restore the rapidly degrading kharsu oak forests across the Western Himalayan

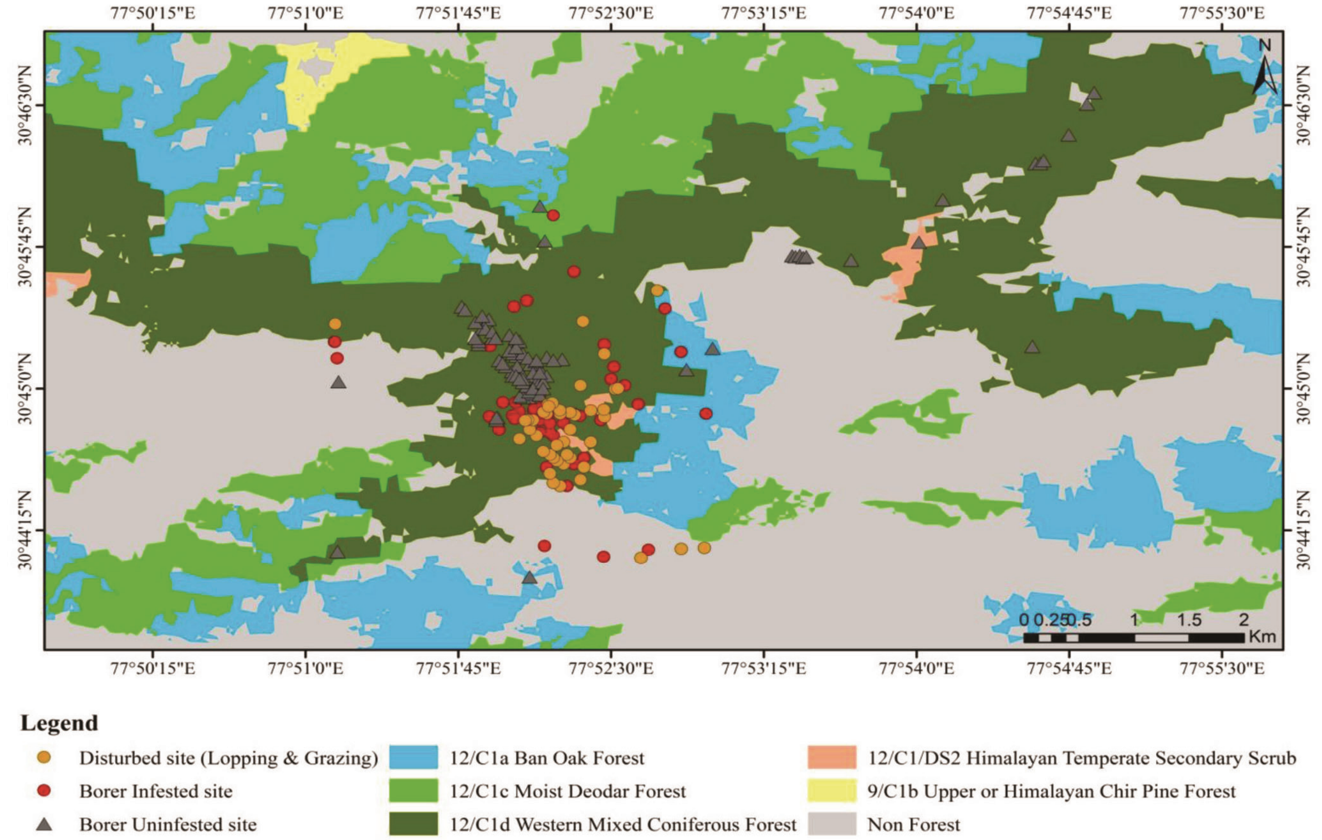

Figure 6. Borer infested and uninfested sites depicted in relation to disturbed sites in the kharsu oak forest stands of Deoban RF.

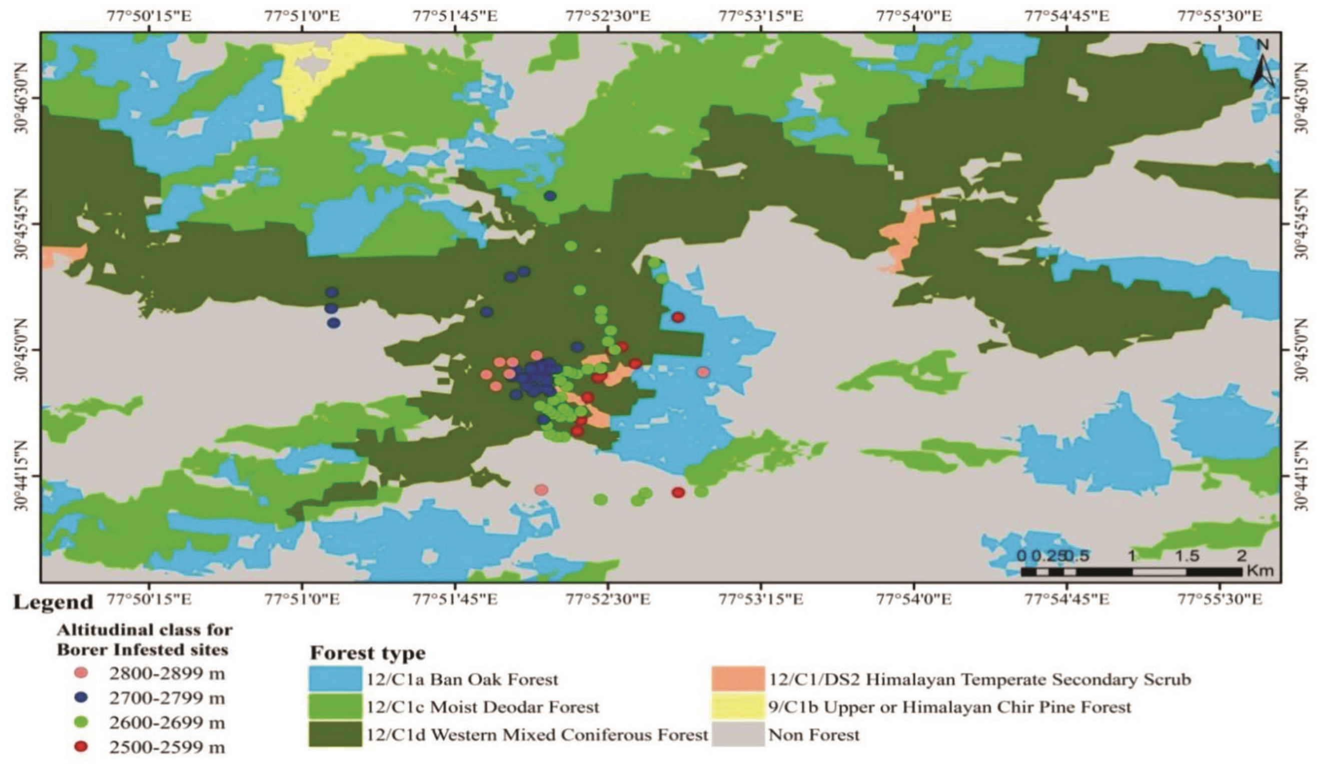

Figure 7. Borer infestation in the kharsu oak forest stands of Deoban RF along an altitudinal gradient of 2500–2899 m amsl.

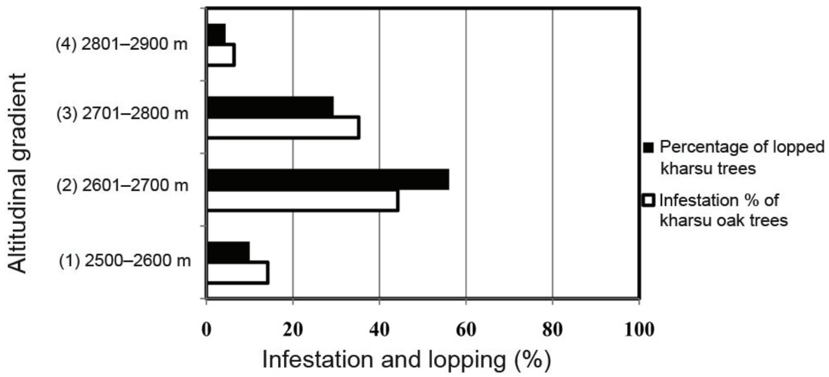

Figure 8. Borer infestation in comparison to lopping of kharsu oak trees in the forest stands of Deoban RF along an altitudinal gradient of 2500–2900 m amsl.

region. This can be done by raising kharsu oak nurseries and plantations, gap-filling of degraded and open oak forest patches protection of oak plantations and forests by fencing, exploring sustainable ways of harvesting and minimizing lopping of oak trees for fodder and fuelwood, checking livestock population, providing alternate trees species for fodder and fuelwood to villagers through afforestation programmes, providing alternate source of cooking fuelwood such as LPG cylinder, and increasing livelihood opportunities and income of the rural poor, thereby reducing their dependency on oak forests. All these steps are necessary to save these magnificent oak forests in the Himalayan region and will help in bringing back the kharsu oak forest stands to their original/natural state.

Conflicts of interest: None.

1. Troup, R. S., *The Silviculture of Indian Trees*, Clarendon Press, Oxford, UK, 1921, vols I–III.
2. Negi, S. S. and Naithani, H. B., *Oaks of India, Nepal and Bhutan*, International Book Distributors, Dehradun, 1995.
3. Shrestha, B. B., *Quercus semecarpifolia* Sm. in the Himalayan region: ecology, exploitation and threats. *Himalayan J. Sci.*, 2003, **1**(2), 126–128.
4. Gajendra, S., Rai, I. D. and Rawat, G. S., The year 2010 was 'mast seed year' for the Kharsu oak (*Quercus semecarpifolia* Sm.) in the Western Himalaya. *Curr. Sci.*, 2011, **100**(9), 1275.
5. Singh, A. P., Incidence of oak borers and oak mortality in Garhwal Himalaya, India. *Indian For.*, 2011, **137**(10), 1188–1193.
6. Beeson, C. F. C., *Ecology and Control of the Forest Insects of India and the Neighbouring Countries*, Government of India Publication, New Delhi, 1941.
7. Mitra, B., Bhaumik, S., Chakraborti, U. and Mallick, K., An update on the diversity, distribution and zoo-geographical notes on longhorn beetles (Cerambycidae: Coleoptera) of North-East India. *Biol. Forum – Int. J.*, 2017, **9**(2), 61–80.
8. Lazarev, M. A. and Murzin, S. V., Catalogue of Nepal Longhorn beetles (Coleoptera, Cerambycidae). *Humanity Space-Int. Almanac.*, 2019, **8**(6), 746–868.
9. Champion, H. G. and Seth, S. K., *A Revised Survey of the Forest Types of India*, Manager of Publications, New Delhi, 1968.
10. Chandrashekara, U. M., Assessment of level of human disturbance in village-adjacent natural forest plots in the Kerala part of Nilgiri Biosphere Reserve. *Int. J. Ecol. Environ. Sci.*, 2013, **39**(4), 211–221.
11. Richards, P. W., *The Tropical Rainforest: An Ecological Study*, Cambridge University Press, Cambridge, UK, 1952.
12. Bhuyan, P., Khan, M. and Tripathi, R., Tree diversity and population structure in undisturbed and human-impacted stands of tropical wet evergreen forest in Arunachal Pradesh, Eastern Himalayas, India. *Biodivers. Conserv.*, 2003, **12**, 1753–1773.
13. Johnson, F. L. and Bell, D. T., Size-class structure of three streamside forests. *Am. J. Bot.*, 1975, **62**(1), 81–85.
14. Schmelz, D. V. and Lindsey, A. A., Size-class structure of old-growth forests in Indiana. *Forest Sci.*, 1965, **11**(3), 258–264.
15. Parker, A. J. and Peet, R. K., Size and age structure of conifers forests. *Ecology*, 1984, **65**(5), 1685–1689.
16. Saxena, A. K., Singh, S. P. and Singh, J. S., Population structure of forests of Kumaun Himalaya: implications for management. *J. Environ. Manage.*, 1984, **19**(4), 307–324.
17. Kalisch, J. A. and Baxendale, F. P., *Insects Borers of Shade Trees and Woody Ornamentals*, EC1518, University of Nebraska-Lincoln Extension EC1580, 2010, pp. 1–8.
18. Guo, H., Guan, L., Wang, Y., Xie, L., Prather, C. M., Liu, C. and Ma, C., Grazing limits natural biological controls of woody encroachment in Inner Mongolia Steppe. *Biol. Open*, 2017, **6**(10), 1569–1574.
19. Rambo, J. L. and Faeth, S. H., Effect of vertebrate grazing on plant and insect community structure. *Conserv. Biol.*, 1999, **13**(5), 1047–1054.
20. Kruess, A. and Tscharntke, T., Contrasting responses of plant and insect diversity to variation in grazing intensity. *Biol. Conserv.*, 2002, **106**, 293–302.

ACKNOWLEDGEMENTS. We thank D. C. Arya, Divisional Forest Officer, Chakrata Forest Division, Uttarakhand for providing the necessary facilities during field surveys. The assistance of Tribhuwan Singh in generating GIS maps and Rohit Kumar (Forest Research Institute (FRI), Dehradun), during field surveys is acknowledged. We also thank the Director, FRI, Dehradun, and Head, Forest Protection Division, FRI for providing the necessary facilities to carry out this study. The study was part of a project funded by the Indian Council of Forestry, Research and Education, Dehradun.

Received 19 November 2021; accepted 28 December 2021

doi: 10.18520/cs/v122/i3/327-332