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Himalayan yew: stand structure, canopy damage, regeneration and conservation strategy

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Summary

Taxus baccata L. subsp. *wallichiana* (Zucc.) Pilger has come into prominence in recent times due to its uncontrolled harvesting from the Himalayan wilds for the extraction of the anti-cancer drug Taxol®. It is a very slow growing tree with poor regeneration, and the extent of canopy damage is likely to have serious consequences on biomass yield, plant survival and natural regeneration by affecting 'seed' output. The present study in the Jageshwar area of the Central Himalaya aimed to determine the stand and canopy structure, microsite characteristics, extent of canopy removal, and regeneration in human-disturbed and undisturbed sites. The number of trees, saplings and seedlings varied amongst plots. Leaf area index and canopy volume increased with increasing circumference at breast height. Of the total canopy volume, 57.4% was found to have been removed from the study area (9.54 ha; representing about 8% of the total *T. baccata* habitat). Regeneration of the species was found to be better in moist and shady microsites at undisturbed locations than in disturbed sites. Efforts made thus far for its conservation, and future strategies are discussed.

Keywords: Biomass removal, canopy structure, regeneration, stand structure, yew

Introduction

Amongst various high value medicinal plants of the Himalayan region, *Taxus baccata* L. subsp. *wallichiana* (Zucc.) Pilger (the only *Taxus* species in India) has gained considerable importance as a source of the anti-cancer drug Taxol® (paclitaxel), a diterpenoid which was first isolated from the stem bark of *T. brevifolia* Nutt. (Wani *et al*. 1971). Extracts of *T. baccata* are known to be a source of a drug, zarnab, which is prescribed in the ancient Unani system of Indian medicine (Anon. 1976) as a sedative, and for the treatment of bronchitis, asthma, epilepsy, snake bites and scorpion stings, besides application as an aphrodisiac (Beckstrom-Sternberg & Duke 1993).

Excessive harvesting of *T. baccata* from the forests all along the Indian Himalaya for Taxol (Nandi *et al*. 1994; Shukla *et al*. 1994) has caused substantial environmental concern. So far, there are no records of the estimation of canopy removal although visual estimates indicate substantial losses. The possible threat to *T. baccata* as a result of overexploitation because of the plant's traditional use for timber, religious purposes, bark mixed with tea, and bark/leaves exported to the plains for use as a medicine was recognized at the beginning of this century (Gamble 1922). In some areas, regeneration was a problem because 'seeds' along with the aril (a sweet, fleshy cup-like structure surrounding the 'seed') were eaten by birds, monkeys and children, and branches were used to make baskets. Gamble (1922) expressed the hope that this interesting tree would be protected in the Himalayan forest, both from being cut with the regular crops, and from being barked and otherwise damaged. The thin bark and low height suggest its extreme vulnerability to surface fires. As young plants require shelter and deep shade, *T. baccata* is unlikely to reproduce where forest has been cleared or canopy gaps are large. Though distributed widely in the Himalaya from Afghanistan in the west to Bhutan in the east at altitudes between 1800 and 3400 m, this undercanopy species never forms extensive cover, and commonly occurs in patches under *Quercus semecarpifolia*, *Abies pindrow*, and *Rhododendron* spp. The species is extremely slow growing in terms of girth increment (0.4−1.3 cm yr^{-1}; Anon. 1976) and ring counts (average of 8−12 rings cm^{-1} of radius; Gamble 1922).

Although much information exists on the major forest ecosystems of the Central Himalaya (Singh & Singh 1987), this does not include recent data on *T. baccata* trees. Therefore, this study was undertaken (i) to analyse the stand structure and micro-habitat characteristics of *T. baccata* subsp. *wallichiana* trees, (ii) to compare recruitment of seedlings and their establishment between human-disturbed and undisturbed sites, (iii) to quantify canopy characteristics and canopy removal due to uncontrolled harvesting, and (iv) to identify the possible steps that should be undertaken for conservation of the species. The identification of various tree species found in association with *T. baccata*, microsite requirements for its natural regeneration, establishment and growth of seedlings and saplings are necessary.

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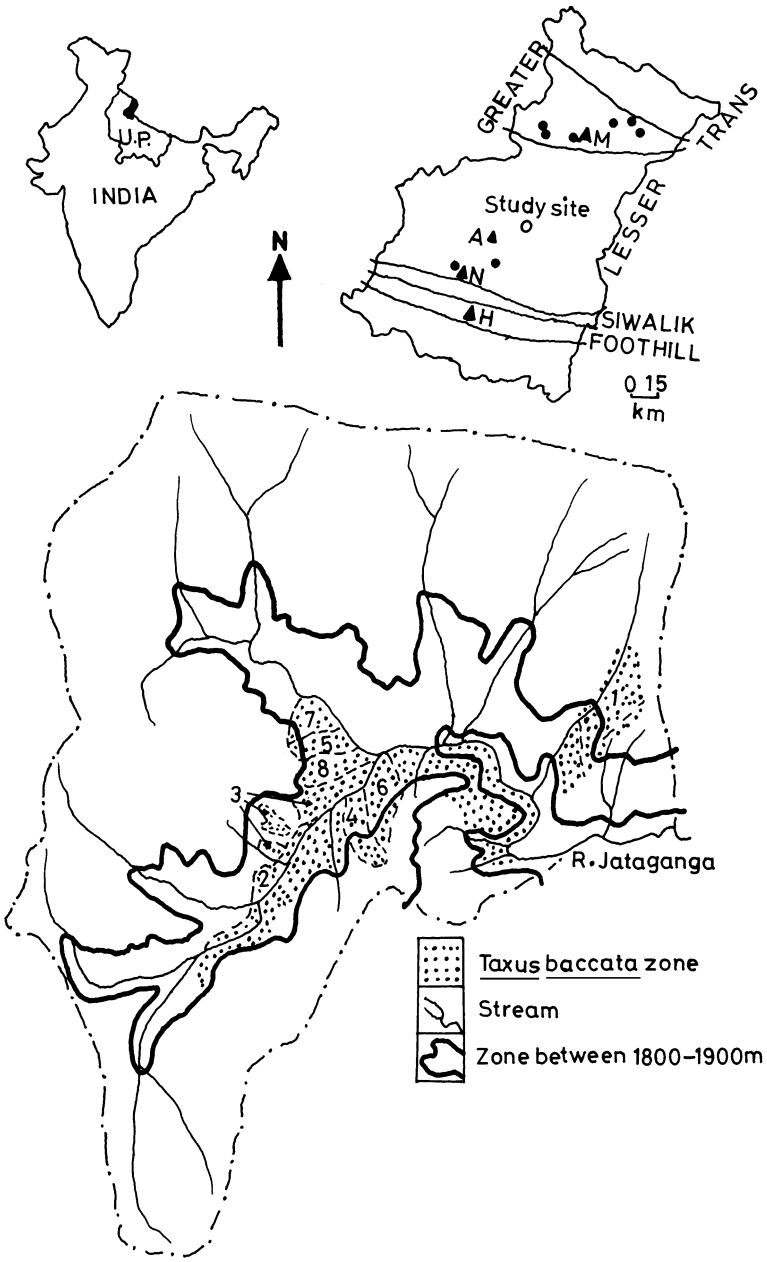


Figure 1 Location map showing distribution of *Taxus baccata* subsp. *wallichiana* (●) in different geological belts (Siwalik, Lesser, Greater and Trans Himalaya) of the Kumaun region in Central Himalaya. Prominent nearby towns (▲): M = Munsyari, A = Almora, N = Nainital, and H = Haldwani. Map of the Jageshwar area showing distribution of this species along water channels. Numbers 1–8 indicate plots; plot 3 was fragmented into three parts.

Furthermore, information on the possible effects of canopy removal on plant recovery and seed output, and the development of simple methods of propagation are a prerequisite for raising plants of different provenances for transplantation and projects involving afforestation. Steps undertaken to address these aims should result in the amelioration of some of the difficulties mentioned earlier, and in development of proper management and conservation strategy for this species.

Materials and methods

Plant and the study area

An evergreen, generally dioecious gymnosperm, *Taxus baccata* L. subsp. *wallichiana* (Zucc.) Pilger (family Taxaceae, order Taxales; local names *Thuner* and *Tallispatra*) occurs in the Central Himalaya (Fig. 1). A study area, Jageshwar (Almora district, between 29°35′−29°39′N and 79°59′−79°53′E; about 45 km from the Institute) was chosen for easy accessibility for frequent sampling and long-term studies. The exploitation of yew trees in this area started recently, and particularly large amounts of leaves and twigs

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Table 1 Site characteristics. Reserve forest is under the management of the Forest Department of the State Government whereas *Panchyat* forest is under the management of a local body governed by the villagers.

Plot No.	*Altitude (m)*	*Slope (°)*	*Aspect*	*Area (ha)*	*Type of forest management*
1	1770–1915	55–60	SW	1.50	Reserve
2	1800–1820	50–55	SE	1.22	Panchayat
3	1820–1850	50–60	SE	1.50	Panchayat
4	1805–1910	55–65	NE	0.81	Reserve
5	1805–1900	65–70	NE	1.00	Reserve
6	1805–1920	55–65	NW	2.00	Reserve
7	1830–1850	60–65	N	0.85	Reserve
8	1840–1880	70–75	NE	0.66	Reserve

(fresh) were harvested for commercial purpose in 1993, as reported by inhabitants from nearby villages during the survey. The total area under *T. baccata* in Jageshwar is approximately 120 ha.

Survey

A complete survey of the entire *T. baccata* habitat was carried out between July 1993 and October 1994. Different plots were selected for intensive study within the area (plots 1–8; representing about 8% of the total area of *T. baccata* habitat in the study area; Fig. 1). As a result of reckless cutting of trees and branches and other local practices including grazing by livestock, and based on the visual observations of the level of disturbance, plots 2, 3, 7 and 8 were classified as 'disturbed' (Fig. 1 and Table 1) and plots 1, 4–6 as 'relatively undisturbed'. Elevation, slope gradient and aspect were determined with the help of an altimeter, Avney level and compass, respectively. Photosynthetically-active solar radiation (PAR) in the open areas and under *Cedrus deodara* canopy was measured using a Quantum Radiometer (Licor Incorporated, Nebraska, USA).

Size class distribution and regeneration

Seedlings were counted in each plot by randomly placing quadrats of 10×10 m, and the age of each seedling (< 30 cm height) was estimated on the basis of internodes. Saplings (≥ 30 cm height but < 10 cm circumference at breast height (CBH) (i.e. 1.37 m above ground) were also counted in all eight selected plots. Girth of all trees with CBH >10 cm was measured in each plot. From these data, tree, seedling and sapling density, and tree basal cover were calculated on a per hectare basis. Population structures were prepared by establishing arbitrary size classes as reported by Upreti *et al.* (1985).

Canopy structure and removal

Canopy structure refers to the amount and organization of above-ground plant material, including size, shape and orientation of plant organs such as leaves, stems, flowers and fruits (Norman & Campbell 1989).

In order to understand the canopy structure and to determine the canopy damage because of uncontrolled harvesting of plant material, leaf area index (LAI) indicating the amount of foliage was measured; the volume was computed from the canopy profile coordinates. The drip line canopy area, and drip line leaf area index (DLLAI) of intact trees (undamaged crown with 100% canopy; total of 33 plants) for different CBH classes were also determined using a LAI-2000 Plant Canopy Analyzer (Licor Incorporated, Nebraska, USA) equipped with a fisheye light sensor. These measurements were made during the rainy season when there was a significant cloud cover. Different view caps, according to the size class, were used to restrict the view scope of the sensor (for details see: Nobel *et al*. 1993; Vertessy *et al*. 1995; Wang *et al*. 1995). Although this method is very effective, it may have overestimated LAI by 5–10% (Vertessy *et al*. 1995).

For volume calculation, the canopy profile of each tree was drawn in the field and the measurement of tree height, canopy depth and canopy width was taken. Later, x and y coordinates of each tree were identified and fed into a C-2000 programme (Licor Incorporated, Nebraska, USA). Expected volume was thus calculated from a regression developed between CBH and volume.

Visual observations for the removal of tree crown of all trees were made, and grouped as 0% removal (intact), 10–30% removal, 30–50% removal, 50–70% removal, 70–90% removal and $>$ 90% removal. The LAI and volume of 22 trees in each canopy removal class were also calculated, using the method described above, to standardize visual estimates for volume loss because it was not practically possible to determine the LAI and volume of all trees. Per cent volume loss was calculated for all 22 trees in each canopy removal class by subtracting the existing volume from expected volume and the values compared with the visual estimates of individual trees. The visual estimates of loss (% removal) were found to be underestimates by 7.2% for 10–30% removal class, 8.2% for 30–50% removal class, 10.7% for 50–70% removal class and 8.7% for 70–90% removal class. For each canopy removal class, expected values were converted into existing volume on the basis of average per cent removal. Plants placed in $>$ 90% removal class had only a few small twigs and leaves left, and were thus considered to have suffered 100% loss (for details see Nandi *et al*. 1997). The total existing volume was the sum total of the volume of intact trees plus trees of the above-mentioned removal classes. This method for the estimation of canopy

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Table 2 Number of seedlings, saplings and trees recorded in the study plots.

Plot No.	*Seedling (No ha^{-1})*	*Sapling (No ha^{-1})*	*Trees (No ha^{-1})*	*Tree basal area (m^2 ha^{-1})*	*Mean CBH (cm)*
1	204	5	55	2.90	66.69
2	3	11	143	1.10	31.06
3	5	3	65	0.69	36.43
4	0	0	65	4.67	93.33
5	0	0	31	1.71	83.20
6	28	10	80	2.10	57.40
7	0	0	99	1.79	47.65
8	0	0	123	1.12	33.61
Mean	30.0	3.6	82.6	2.01	56.17

removal can be used to quantify the crown loss of *T. baccata* in other parts of the Himalaya.

Statistical analysis

Regressions and correlations between tree canopy characteristics (volume and loss) and LAI with CBH were carried out (Snedecor & Cochran 1967). Comparison between disturbed and undisturbed plots was made using paired *t*-tests.

Results

Site characteristics

In the studied watershed, *T. baccata* trees grow under *C. deodara*, forming small groups of 5–10 trees (generally along main water channels) largely on north-west and north-east aspects (Fig. 1); the altitude varied between 1770 and 1920 m (Table 1). *T. baccata* was not observed on drier, south-facing slopes. Although some broadleaved tree associates (e.g. *Neolitsea pallens*, *Lyonia ovalifolia*, *Rhododendron arboreum*, *Aesculus indica*, *Quercus leucotrichophora* and *Q. floribunda*) were observed, such associations were uncommon. Average PAR during the day in October was 64.93 μmol m^{-2} s^{-1}, while available PAR under *C. deodara* canopy where *T. baccata* plants were found growing was about one-fifth of this value.

Stand structure and regeneration status

Amongst different plots, the stock density (number of trees) ranged from 31 to 143 trees ha^{-1} and the basal area varied from 0.69 to 4.67 m^2 ha^{-1} (Table 2). The mean tree number and basal area were found to be 82.6 trees ha^{-1} and 2.01 m^2 ha^{-1}. The mean CBH fluctuated between 31.06 and 93.33 cm. The largest tree had a girth of 204.4 cm (plot 4).

In general, seedlings and saplings were either absent or found in small numbers in most plots (Table 2). While plot 1 (undisturbed plot) had many (i.e. 204) seedlings and some individuals were also present in plot 6, seedlings and saplings were absent from the other two undisturbed plots (4 and 5). Very few seedlings (mean 58 vs 2; $t = 1.14$) and saplings (mean 3.8 vs 3.5; $t = 0.07$) were present in disturbed plots (2,3,7,8), and values were not significantly lower than in undisturbed plots. Seedlings and saplings were mostly found growing under the mother trees near gorges. The age structure of seedlings indicated a general decline in the number of seedlings with increasing age (Fig. 2).

The disturbed plots (i.e. 2, 3, 7, 8) had a population structure with a lower number of individuals both towards the lower and higher size classes and a higher number of individ-

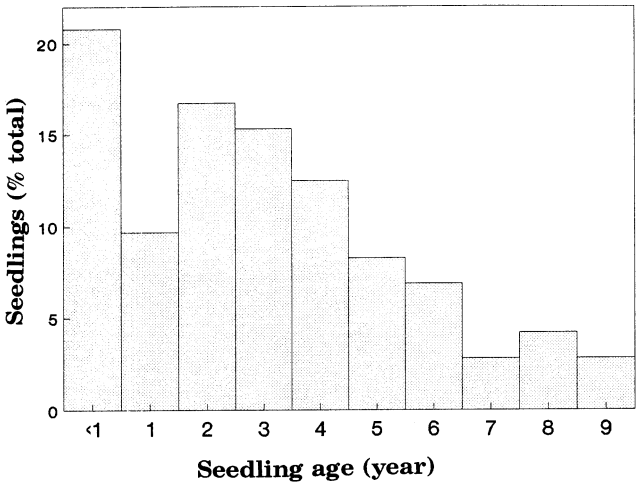


Figure 2 Distribution of *Taxus baccata* subsp. *wallichiana* seedlings in different age classes.

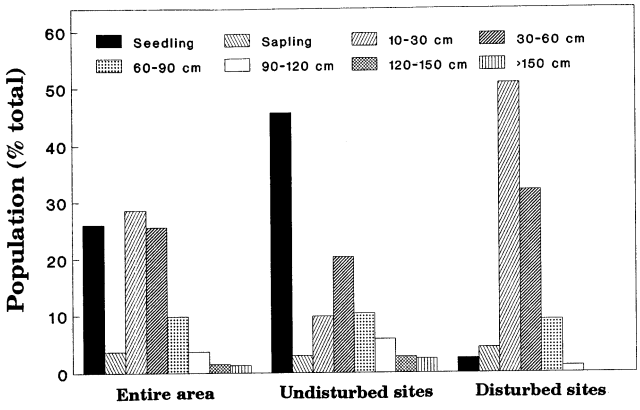


Figure 3 Population structure of *Taxus baccata* subsp. *wallichiana*. Undisturbed sites = plots 1, 4, 5 and 6; Disturbed sites = plots 2, 3, 7 and 8; Entire area = plots 1−8.

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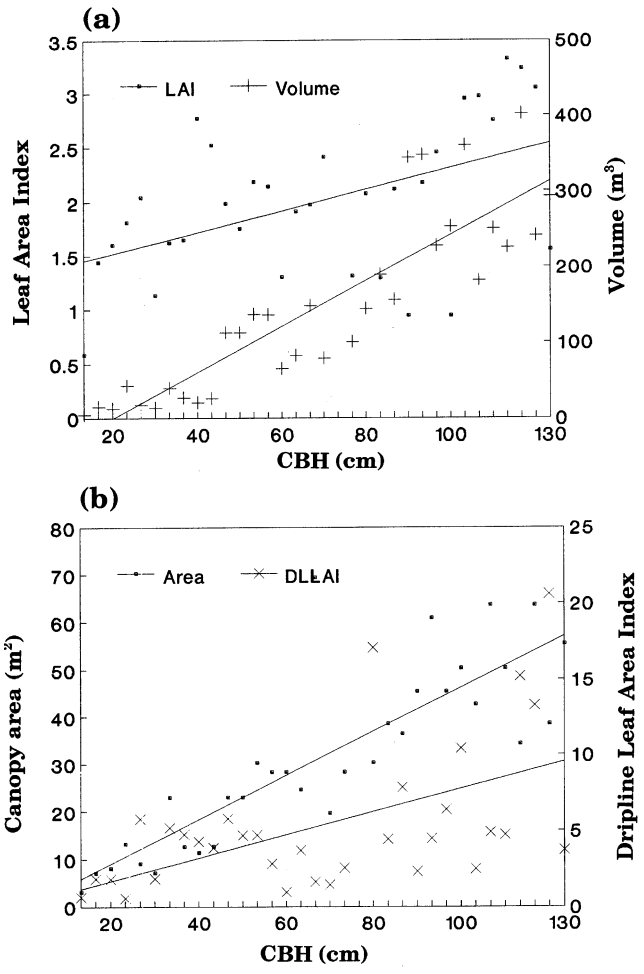


Figure 4 Relationships of (*a*) leaf area index (LAI) and volume (m^3), and (*b*) canopy area (m^2) and dripline leaf area index (DLLAI) with CBH (circumference at breast height).

uals in the intermediate size classes (Fig. 3). Undisturbed plots (1, 4, 5, 6) also showed a similar population structure; the seedlings were, however, more abundant than individuals of other size classes, although values were not significantly different ($t = 0.02$). The conversion of seedlings into saplings was still very poor (Fig. 3).

Canopy structure

The mean LAI across all CBH classes of *T. baccata* was 2.0. The girth was positively related ($p < 0.01$) to LAI ($Y = 1.35 + 0.0095X$; $r^2 = 0.487$) and volume ($Y = -55.655 + 2.9205 X$; $r^2 = 0.882$; Fig. 4*a*). Canopy area and DLLAI also increased with increasing girth (Fig. 4*b*), however, as expected the LAI decreased with increasing canopy loss ($Y = 2.03 - 0.01 X$; $r^2 = 0.640$; $p < 0.01$).

Biomass removal

It was necessary to obtain information on the exact number of trees in different removal classes in order to estimate biomass removal in terms of volume. Out of the total plants (763) examined, only 26% of the plants were found to be intact (representing 0–72% of total plants in different plots; most intact plants were found growing near or on cliffs which were out of reach), while 18.6% of trees had crowns which were entirely damaged (representing 0–100% of total plants in different plots); the remaining 55.5% of trees had 10–90% of the canopy damaged (Table 3).

The highest removal (100%) of tree crown was recorded from plot 8 (disturbed plot) and the lowest (23.7%) from plot 6 (undisturbed plot) (Fig. 5). Plot 1 which had the highest number of seedlings showed intermediate values for crown removal. Mean canopy removal was approximately 57%.

Discussion

This study indicated that specific microsites occur within the coniferous and broadleaved forest ecosystems in all aspects, except the drier south. The occurrence of most yew seedlings under the mother trees near gorges clearly indicates their preference for deeply-shaded, moist and sheltered sites in support of the empirical observation of Troup (1921) for this species. The higher number of seedlings from plot 1 was due to better protection, as the plot was located close to the Forest Department guest house. Like *T. baccata*, the American species, *T. brevifolia*, was also found to occur on wet or moist north- or east-facing slopes, typically with moderately deep, fine textured, well-drained soils on lower slopes or near drainage (Fites 1993). The shade-loving nature of this species is further supported by the reduced values for PAR recorded under *C. deodara* canopy where trees and seedlings of *T. baccata* were found growing.

Variations in mean CBH and total basal area from plot to plot indicate differences in the age of trees amongst plots. High mean CBH values for trees of plots 4 and 5 confirm the presence of older trees in comparison to other plots. Higher tree numbers for plot 2 indicate the preference of yew trees for moist and shady sites because this plot is located along the water channel. Campbell (1993) also reported a higher number of *Taxus* trees (264 trees ha^{-1}) in the wetter interior Cedar-Hemlock zone compared to the drier coastal Douglas-fir zone (60 trees ha^{-1}). The circumference of the largest tree (204.4 cm) in the present study is comparable to the lowest of the reported values for the Pacific yew (188–267 cm) in British Columbia, and is much smaller than the measurements of *T. baccata* in the Darjeeling hills and in parts of Himachal Pradesh in the Indian Himalayan region (450–600 cm girth; Gamble 1922).

A low recruitment for this species seems to be related to its poor seed germination (8–15% in the Institute nursery and field trials; S.K. Nandi & L.M.S. Palni, unpublished results). Other threats to species recruitment are consumption (for the aril part) and/or dispersal of 'seeds' to unfavourable sites by monkeys and birds; fallen 'seeds' are also destroyed by field rats. Moreover, the clipping of foliage for Taxol extraction may reduce pollen availability, which, in turn, would lower pollination and result in poor 'seed' set, even in relatively unharvested yew trees (Allison 1993). The decrease in

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Table 3 Current status of *Taxus baccata* trees (% of total trees) in the study plots at Jageshwar. Values in parentheses represent % removal (average for all trees) in a given removal class. na (not available) indicates that the information could not be collected due to complete damage of some trees; a dash (–) indicates not present, i.e. 'O'.

Plot No.	*Sex (%)*		*% trees (% canopy removal)*					
			Canopy removal classes (%)					
	Male	*Female*	*Intact*	*10–30*	*30–50*	*50–70*	*70–90*	*>90*
1	68.3	31.7	16.1 (0)	21.0 (26)	13.5 (47)	21.0 (65)	28.4 (85)	– (100)
2	na	na	22.5 (0)	28.3 (22)	7.5 (48)	13.3 (67)	17.9 (90)	10.4 (100)
3	na	na	3.1 (0)	15.6 (22)	7.3 (43)	7.3 (67)	39.5 (90)	27.0 (100)
4	52.8	47.2	28.3 (0)	26.5 (20)	17.0 (47)	11.3 (64)	15.1 (87)	1.9 (100)
5	71.0	29.0	12.9 (0)	32.3 (25)	6.5 (43)	29.0 (63)	19.4 (89)	–
6	63.1	36.9	71.9 (0)	20.6 (25)	4.4 (40)	2.5 (61)	0.6 (89)	–
7	na	na	52.4 (0)	3.5 (27)	6.0 (42)	8.3 (61)	20.2 (89)	9.5 (100)
8	na	na	–	–	–	–	–	100.0 (100)
Mean	63.8	36.2	25.9 (0)	18.5 (24)	7.8 (44)	11.6 (64)	17.6 (88)	18.6 (100)

the number of seedlings with increasing seedling / sapling age and their poor conversion into trees probably results from both biotic (grazing by goat and trampling by cattle and goats) and climatic (chilling temperatures, direct sunlight, warm summer without rains) factors. A relatively higher representation of trees in smaller girth classes indicates satisfactory conversion of saplings into trees in the past; a relatively higher number of seedlings in undisturbed plots was perhaps a result of harvesting restrictions.

Removal (legal and / or illegal) of *C. deodara* trees for commercial purposes (mainly for timber and furniture) has also considerably affected the habitat of *T. baccata*. Allison (1993) reported a marked reduction in the numbers of *T. brevifolia* in the Pacific region following extensive clear-cutting of old-growth forests. Colonization of this species has been reported to be slow even in potentially-suitable habitats (Busing *et al.* 1995). The amount of light penetrating the canopy is an exponential function of the cumulative leaf area (Kira *et al.* 1969). A decrease in LAI due to biomass removal from the canopy results in more light coming through canopy openings and this, in turn, adversely affects photosynthesis and, as a consequence, the total productivity decreases. Therefore, as a result of total or near-complete removal of crown, the trees in the present study site were seen to be gradually dying out due to termination of essential physiological activities.

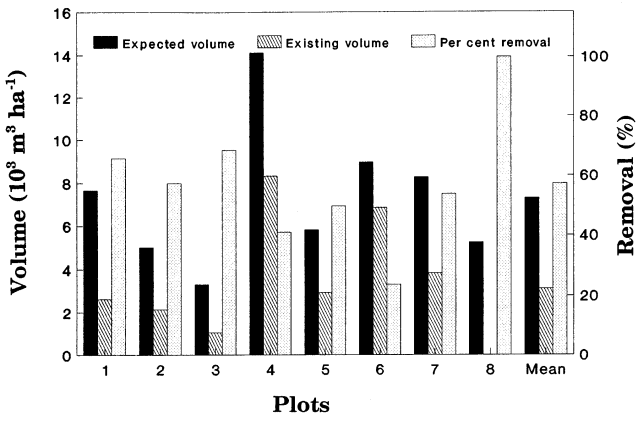


Figure 5 Estimated removal of *Taxus baccata* subsp. *wallichiana* canopy volume from plots 1–8 in Jageshwar area.

Possible techniques for propagation and steps towards conservation

Considerable canopy damage (57.4%) in the Jageshwar area and the extremely slow-growing nature of the species indicates very slow recovery of these trees. Therefore, some urgent measures are mandatory for conservation, reforestation and even cultivation of this species for commercial purposes. Modest efforts along these lines have already been initiated. These include: (1) Development of a simple and relatively cheap technique for clonal (vegetative) propagation using first year shoots and chemical treatments (Nandi *et al.* 1996); (2) Transfer of 130 vegetatively-propagated plants (cuttings taken from three well-established plants each of male and female in the study area) to the study site where approximately 50% survival has been recorded over a period of two years: this represents an 8% increment in the number of *T. baccata* plants in their natural habitat at Jageshwar (plots 1–8 which contain 763 trees); (3) Great enhancement (> 70%) of 'seed' germination (normally 8-15%) by various treatments (A. Pandey, M. Nadeem & L.M.S. Palni, unpublished results). Further, the techniques of clonal propagation and enhanced seed germination can be used to propagate selected clones from other parts of the Himalaya for conservation and afforestation of elite clones having high levels of Taxol. Activity (1) is being routinely used for large-scale propagation. Vegetative propagation from cuttings (2) is a significant step towards *in situ* conservation, while effort (3) is intended to maintain genetic diversity which can be assured through 'seed'. The results of the Jageshwar study are relevant to other parts of the Himalayan region where conservation efforts need to be intensified and reckless exploitation stopped.

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Legal and social aspects of conservation

Although the Government of India has now included *T. baccata* in a list of 'negative' exports, and the state forest department has placed severe restrictions on the removal of *T. baccata* from the Reserve Forest area, some illegal removal would seem to be still continuing. The restrictions were noted to be effective for plots 1, 4, 5 and 6 only (under the control of the state forest department) but in other sites which are under the control of villagers (*Panchayat* forest, i.e. forest land under the management of a local village body) or in close proximity to villages, felling of trees and canopy removal are still going on for various purposes (e.g. feeding of leaves to goats, fuelwood, tree trunks used as stakes, making of brooms, and cremation of dead bodies). The wood still continues to be used in house and furniture construction (Anon. 1976). More stringent laws and further restrictions in other zones need to be imposed. It must be added that public awareness has increased recently (S.K. Nandi & H.C. Rikhari, unpublished results) and a few locals have planted *T. baccata* seedlings near their houses. Greater awareness regarding the medicinal importance of this plant, and motivation of the local inhabitants to grow yew hedges for regular harvesting of leaves should reduce pressure on the wild populations. Non-governmental organizations, state forest departments, village committees and voluntary bodies should be encouraged to undertake conservation by planting clonally-propagated plants as well as plants of 'seed' origin in their natural habitat. A sanctuary and/or a yew park of representative size with plants from different ecozones should also be established. Care must be provided so that the specific microsites with recorded tree associations are maintained for proper recruitment of seedlings and also for plantation. This would ensure better growth and survival of the species. Based on studies in Western Oregon and Washington it has been suggested that conservation of *T. brevifolia* at the landscape level may require large, unmanaged reserves and proper maintenance of patches of old forest within managed forests (Busing *et al.* 1995). It must be mentioned that the *ex situ* conservation programme in British Columbia has created a collection of *T. brevifolia* cuttings from 500 clones (Campbell 1993). At present, Taxol is obtained from its natural source (i.e. plants) and this is likely to continue despite the reported chemical synthesis by Nicolaou *et al*. (1994) due to the very large number of steps involved in synthesizing Taxol and the increasing disinterest in synthetics. It is hoped, however, that large-scale vegetative propagation and cultivation for commercial purposes, as in the USA, would greatly reduce dependency on the natural stock (Wheeler & Piesch 1993) in the near future.

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