Fir (*Abies densa*) forests in Central Bhutan: a model-based approach to assess a suitable utilization

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Summary

A model which was developed to describe uneven-aged forests is further advanced and is used here to assess some possible effects of the utilization of fir (*Abies densa* Griff.)-dominated forests in Bhutan. Because the structure and species composition of these forests should not be altered to any great extent, in order to maintain the protective and ecological function of the forest, a utilization involving modern harvesting equipment is not economically viable. A traditional utilization, e.g. shingle production for the local market, as a single tree or a small group selection forest, is possible without changing the forest in an undesirable way.

Introduction

East Himalayan fir (*Abies densa* Griff.) is found throughout the eastern Himalayas at altitudes between 3000 and 4200 m a.s.l. (Troup, 1926), i.e. up to the timberline. It often forms pure stands (Grierson and Long, 1983; Negi, 1989), but is quite frequently associated with hemlock (*Tsuga dumosa* (D. Don) Eichler) and spruce (*Picea spinulosa* (Griff.) Henry), and sometimes with juniper (*Juniperus recurva* D. Don) and larch (*Larix griffithiana* Carrière). Bamboos are common as undergrowth, and often rhododendrons (*Rhododendron* spp.), birch (*Betula utilis* D. Don), maple (*Acer* spp.) and other broadleaved species are found growing in the lower and middle canopy strata.

Fir-dominated forests cover more than 7 per cent of the total area of Bhutan or 11.5 per cent of the forest area (Wangchuk, 1991), extending mainly between 3400 and 4000 m a.s.l. They cover the upper parts of most of the big watersheds and therefore have an important protective function. Many of these forests are little utilized or almost untouched, since they are in remote areas with little infrastructure development. However, there is a strong pressure on timber resources in southern Asia and the question has arisen of how these forests, which have to be considered as sensitive ecosystems due to their proximity to the upper timberline, could be utilized without affecting their protective function. The approach to finding a suitable method for the utilization of these forests was to remain as close as possible to the natural structure, species composition and dynamics of these forests while actively managing the stands.

Study site and method

The study was carried out in the Chumi Valley in Bumthang District, Central Bhutan, at an altitude between 3340 and 3800 m a.s.l., covering the potential belt of utilization. Geologically the area consists of meta-sediments and gneisses of the main crystalline belt of the High Himalaya (Gansser, 1983).

The mean annual precipitation amounts to 1300–1500 mm a^{-1}, of which 80 per cent falls from May to October during the monsoon season (IFDP, 1991, 1992). The mean minimum temperature in January is –8.3°C, the mean maximum temperature in July is +14.6°C, and the mean annual temperature is +4.6°C. The meteorological data were recorded at an altitude of 3400 m a.s.l.

In order to assess structure, productivity and regeneration of this type of forest in Central Bhutan, three transects (series) of five plots of 50 × 50 m each were measured and analysed. The first transect was on a north-facing slope with deep and quite acid soils (pH 4.5–5.5), the second on a south-facing slope with superficial, rocky and relatively dry soils, and the third was on a ridge with soils similar to the south-facing slope. The slope varied between 20 and 80 per cent.

No signs (cuttings, cattle tracks) of human activity were found within the study region. The forest can therefore be described as a 'virgin' forest.

On each of the 15 plots of 2500 m^2, the tree species and the diameter at breast height (d.b.h.) of all trees with d.b.h. ≥4 cm were recorded (living trees only, most broadleaved species were recorded by genus and not by species). In addition, within a 10 m-wide diagonal of the plot (657 m^2), all firs were bored with an increment borer to obtain cores from which to analyse the increment and to detect stem rots. On seven subplots of 1 m^2 on the diagonal of each plot the amount of regeneration (number of seedlings and saplings <1.30 m tall) was recorded.

The standing volumes (*V*) of spruce and hemlock were calculated using tariffs based on section-wise measurements done within the region (IFDP, unpublished results) but reduced by 25 per cent due to the observation of trees with broken tops and the high altitude. The equations used were:

Hemlock (*Tsuga dumosa*),

$$V\,[m^3] = 0.75\ (0.0002246 \times dbh[cm]^{2.3673911})$$

Spruce (*Picea spinulosa*),

$$V\,[m^3] = 0.75\ (0.0001717 \times dbh[cm]^{2.4938206})$$

For fir, the tariff from the pre-Investment survey (cited in Laumans, 1991) was used:

Fir (*Abies densa*),

$$V\,[m^3] = (-0.050899 + 3.087220 \times dbh[m])^2$$

No tariffs are available for the broadleaved trees in this area. The volume was estimated using functions derived from the tariffs for the smallest trees for the Canton of Lucerne, Switzerland (Schweizerischer Forstkalender, 1992, p. 193):

Betula utilis, *Acer* spp.,

$$V\,[m^3] = 0.0001406 \times dbh[cm]^{2.422625543}$$

Other broadleaved trees,

$$V\,[m^3] = 0.0000836247 \times dbh[cm]^{2.4879305188}$$

Results

A summary of the number of stems, the basal area and the standing volume is given in Table 1. More detailed results are presented in Bürgi *et al.* (1992).

Roughly 90 per cent of the standing volume was fir, whereas almost 90 per cent of the number of stems were broadleaved trees. The number of stems, between 1100 and 1500 trees per ha, is very high compared with spruce-dominated virgin forests in Europe (Korpel, 1995). As an example, the distribution of the number of stems and the basal area for the first series of plots (average of five plots) is given in Figures 1 and 2.

The maximum diameter of fir was just under 140 cm in diameter. The shape of the distribution is very flat, whereas the stem distribution of the broadleaved trees is very steep and has a maximum of only ~40 cm diameter; 87 per cent of the basal area is from trees with 54–122 cm d.b.h.

The data measured were very similar to those for uneven-aged multi-storey forests, such as the single-tree selection forests in Switzerland.

The proportion of fir in the regeneration is similar to the proportion in number of stems (Table 2). The regeneration is not evenly distributed over the whole area.

Table 1: Summary of number of stems, basal area and standing volume (means and standard deviations of the three series; figures per ha)

	Abies densa	*Tsuga dumosa*	*Picea pinulosa*	*Rhododendron* spp.	*Betula utilis*	*Acer* spp.	*Sorbus* spp.	*Viburnum* spp.	*Prunus* spp.	Other Broadl.	Total conifers	%	Total broadl. spp.	%
Series 1														
No./ha	187.2	–	–	932.0	14.4	107.2	141.6	114.4	30.4	20.8	187.2	12.1	1360.8	87.9
SD	43.2			577.5	13.4	96.1	67.0	132.0	11.2	46.5	43.2		491.1	
m^2/ha	61.8	–	–	7.9	1.5	1.7	1.9	0.5	0.9	0.2	61.8	80.8	14.7	19.2
SD	9.8			5.7	1.8	1.9	1.1	0.5	0.7	0.5	9.8		4.3	
m^3/ha	717.9	–	–	29.7	13.4	11.2	8.5	1.5	4.5	0.9	717.9	91.2	69.6	8.8
SD	114.0			22.7	16.9	13.4	6.0	1.4	4.2	18.2	114.0		27.0	
Series 2														
No./ha	166.4	9.6	1.6	1221.6	56.8	39.2	135.2	20.8	27.2	10.4	177.6	10.5	1511.2	89.5
SD	67.3	7.3	3.6	662.4	23.6	37.7	51.5	21.2	20.1	19.1	71.4		664.6	
m^2/ha	52.0	5.1	0.0	13.6	3.5	1.0	2.7	0.3	0.6	0.2	57.1	72.3	21.8	27.7
SD	15.1	7.0		5.9	2.4	1.4	0.9	0.2	0.5	0.4	11.7		8.0	
m^3/ha	601.4	64.9	0.1	55.0	30.3	6.7	12.7	1.1	2.7	0.9	666.5	85.9	109.5	14.1
SD	177.3	89.3	0.3	24.7	23.3	10.2	5.8	0.9	2.7	2.1	135.6		50.9	
Series 3														
No./ha	215.2	6.4	–	713.6	24.0	56.8	163.2	70.4	48.0	18.4	221.6	16.8	1094.4	83.2
SD	94.5	14.3		241.9	20.4	52.6	83.2	30.5	27.6	25.9	87.6		147.9	
m^2/ha	56.9	1.3	–	6.1	2.0	0.8	1.5	0.5	0.7	0.2	58.2	83.1	11.8	16.9
SD	9.5	2.9		2.4	2.3	0.7	0.9	0.4	0.4	0.5	7.8		4.9	
m^3/ha	659.3	13.2	–	23.0	18.1	4.9	6.0	1.9	2.8	0.9	672.5	92.1	57.6	7.9
SD	112.0	29.5		11.0	21.9	4.4	4.1	1.7	2.0	1.9	93.6		36.7	

Broadl. = broadleaved species, SD = standard deviation.

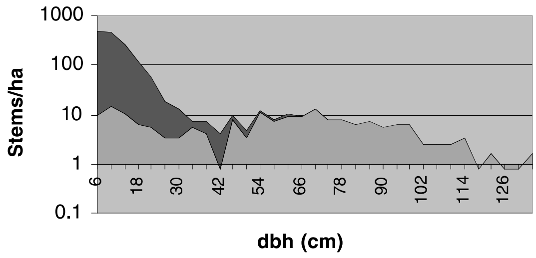

Figure 1. Stem distribution, Series 1.

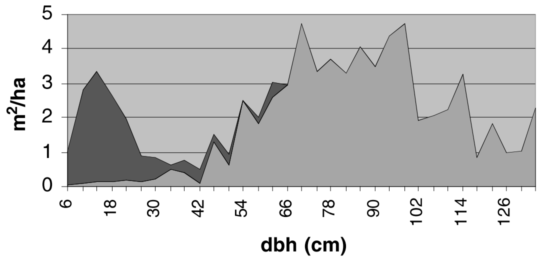

Figure 2. Basal area distribution, Series 1.

The model

In order to assess the utilization possibilities of the measured fir forest, a model was developed, based on the formula of Meyer (1933), which was developed for selection forests:

$$N = k \times e^{-a \times dbh} \quad (1)$$

where N = number of stems, dbh = diameter at breast height, e = basis of the natural logarithm, and k, a are constants describing the distribution.

With this formula it is possible to describe the distribution of all the stems, including the broadleaved trees (Figure 3). The model was fitted in such a manner that the total number of stems, the basal area and the standing volume were similar to those measured in the stands. In addition, the maximum diameter to be attained was set at 90 cm, in order to increase the number of young firs. Moreover, the amount of rotten firs, which increases with diameter, will also be reduced. The fit gave the following values for the constants k and a:

$$k = 405.03827$$

$$a = 0.07505$$

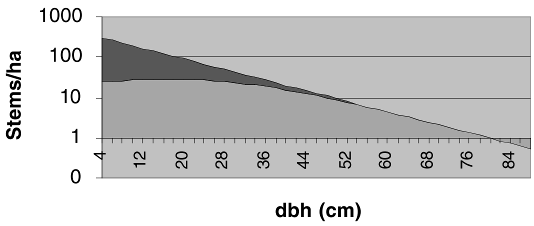

Figure 3. Model forest, stem distribution.

To obtain the stem distribution of the firs alone, the formula for the stem distribution has to be multiplied by a factor that describes the proportion of the broadleaved trees as a part of the whole stem distribution. This factor is again a function of the d.b.h. and needs to be exponential. A suitable function for this factor is:

$$F = \frac{c}{(1/e^{dbh \times d}) + c} \quad (2)$$

Table 2: Regeneration (means and standard deviations of the three series, figures per hectare)

	Conifers		Broadleaves	
	Seedl./sapl. per ha	%	Seedl./sapl. per ha	%
Series 1	3992	11	31 891	89
SD	4379		23 328	
Series 2	3857	28	9 905	72
SD	5430		11 144	
Series 3	6095	13	42 667	87
SD	7336		56 895	

Seedl./sapl. = seedlings and saplings, SD = standard deviation.

where *F* = factor 1, *dbh* = diameter at breast height, e = basis of the natural logarithm, and *c*, *d* are constants describing the distribution.

The constants *c* and *d* were fitted in such a manner that the basal area and the standing volume of the firs did not significantly exceed the measured values in the plots and so that the number of stems of the broadleaved trees and their basal area were comparable with the measured values. Since the maximum diameter is limited to 90 cm for fir and 50 cm for broadleaved trees in the model, there will be a few more trees in the lower and middle strata. This is reflected in the model.

Suitable values for the constants *c* and *d* are:

$$c = 0.06$$

$$d = 0.1$$

The resulting stem distribution is shown in Figure 3 and the distribution of the basal area (to avoid uncertainties by tariffs) in Figure 4. The relevant figures for the model stand are given in Table 3.

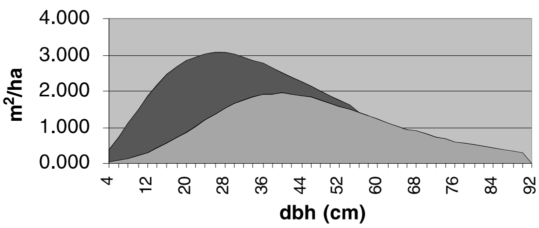

Figure 4. Model forest, basal area distribution.

Discussion

Comparison of the model with the measured stands in the three series suggests several topics for discussion.

Number of stems

Due to the limitation of the exploitable diameter to 90 cm, there was a decrease in the bigger diameter firs. This leads to less shady conditions in the lower and middle canopy strata. The additional light will encourage regeneration. For sustainability of the forest, the regeneration needs to be firs and not broadleaved trees, otherwise the forest will become a broadleaved forest. In fact, the value for the number of stems of fir according to the model is almost three times those recorded for the measured series, whereas the number of stems for the broadleaved trees is similar in the model and in the plots.

A weak point of the model is that we currently do not know whether it is possible to guide the regeneration in such a manner that a sufficient number of regenerating firs become established. However, there are examples in the Lame Gömpa Research Forest on comparable sites, in areas where shingles are produced, indicating that this is likely to happen.

Basal area

While the basal area of the broadleaved trees in the model is slightly higher than that in the measured series, with a similar distribution of the

Table 3: Relevant figures for the model stand

Diameter class	Conifers = Fir			Broadleaved trees		Total	
	(stems/ha)	(m^2/ha)	(m^3/ha)	(stems/ha)	(m^2/ha)	(stems/ha)	(m^2/ha)
4–15 cm	158	1.18	10.20	1120	6.59	1278	7.77
16–23 cm	111	3.18	32.28	284	7.73	395	10.91
24–35 cm	142	9.33	100.76	142	8.63	284	17.96
36–51 cm	107	14.83	166.24	30	3.78	137	18.61
52–90 cm	53	16.75	192.94	1	0.26	54	17.01
>90 cm	0	0.00	0.00	0	0.00	0	0.00
Total	571	45.28	502.41	1577	26.98	2148	72.26

Volume of the broadleaved trees is not calculated.

Table 4: Increment per diameter class in the model

	Diameter class	Stems (ha^{-1})	Rotten (vol %)	Standing volume ($m^3\ ha^{-1}$)	Standing volume (%)	Standing volume Rotten ($m^3\ ha^{-1}$)	Increment ($m^3\ ha^{-1}\ a^{-1}$)	Increment (%)	Sound increment ($m^3\ ha^{-1}\ a^{-1}$)	Sound increment (%)
Model	4–15 cm	158	3.1	10.2	2.0	0.3	0.340	7.5	0.330	
North-facing	16–23 cm	111	44.6	32.3	6.4	14.4	0.591	13.1	0.327	
slope	24–35 cm	142	31.3	100.8	20.1	31.5	1.205	26.6	0.828	
	36–51 cm	107	36.5	166.2	33.1	60.7	1.355	29.9	0.861	
	52–90 cm	53	55.3	192.9	38.4	106.7	1.035	22.9	0.462	
	>90 cm				0.0					
	Total	571		502.4	100.0	213.6	4.526	100.0	2.808	62.0
Model	4–15 cm	158	3.1	10.2	2.0	0.3	0.266	7.7	0.258	
South-facing	16–23 cm	111	44.6	32.28	6.4	14.4	0.450	13.1	0.249	
slope	24–35 cm	142	31.3	100.76	20.1	31.5	0.914	26.6	0.628	
	36–51 cm	107	36.5	166.24	33.1	60.7	1.026	29.8	0.651	
	52–90 cm	53	55.3	192.94	38.4	106.7	0.782	22.7	0.349	
	>90 cm				0.0					
	Total	571		502.41	100.0	213.6	3.438	100.0	2.136	62.1
For comparison the averages of the three series:										
Series 1	Total	187.2	84.1	717.87	100.0	603.7	3.227	100.0	1.459	45.2
Series 2	Total	166.4	82.0	601.40	100.0	493.1	2.244	100.0	0.357	15.9
Series 3	Total	215.2	59.6	659.30	100.0	392.9	3.110	100.0	0.860	27.7

d.b.h., the basal area of the firs is reduced by about 25 per cent, mainly because of the elimination of trees with large diameters.

Standing volume

A reduction of 25 per cent of the standing volume for the firs and a shift of the maximum of the distribution from around 90 to 40 cm are the obvious changes. More important than these figures is the proportion of sound and rotten standing volume. If it is assumed that the percentage of rotten firs remains the same per diameter class, then the share of rotten firs in the standing volume is reduced from 60–85 per cent to 43 per cent as a result of the reduction in the large diameter trees.

Increment

The increment for the model was calculated for the northern slope and for the southern slope separately, with the tree ring width derived from the tree ring analysis (Table 4). This estimation is most probably a conservative one; a greater amount of younger trees in the model could lead to a slight increase in the average tree ring width, resulting in a slightly higher increment than calculated.

For fir, the most important change in the model compared with the measured stands takes place in quantity and quality of increment. Because of the increase of the number of stems in the small and medium diameters, the amount of increment produced in the small and medium diameters increases sharply, leading to an overall increase in increment of ~50 per cent (4.5 m^3 ha^{-1} a^{-1} on the north-facing slope, 3.4 m^3 ha^{-1} a^{-1} on the south-facing slope).

The model also shows an improvement in the amount of increment of sound firs: 62 per cent of the increment is produced on sound firs, reaching 2.8 m^3 ha^{-1} a^{-1} on the north-facing slope and 2.1 m^3 ha^{-1} a^{-1} on the south-facing slope. However, this increment of sound timber is still less than half as much as that occurring in mixed conifer forests in the same region (Rosset, 1999).

Conclusion

It seems possible to fit realistic models developed for uneven-aged forests to *Abies densa* virgin forests. It is even possible to derive figures for a sustainable utilization of these forests from such a model. The precondition is that the forest is treated accordingly, i.e. as a selection forest. This sort of selection cutting was traditionally carried out by shingle makers; they cut only those trees that were suitable for their purpose, and the result is a sort of selection forest. The main problem in the fir forest is the low increment and the high percentage of rotten trees. There is hardly enough sound increment for an economically viable timber harvest with modern equipment (e.g. cable cranes, skidders). The recommendation for the utilization of these forests is therefore twofold:

1 The fir forests in this region are economically not suitable for a utilization with modern harvesting equipment, which needs an expensive opening up by building forest roads. Economically viable harvesting operations would lead to changes in the structure and the species composition and might affect the protective function of the forests.
2 Utilization in a traditional manner as a single tree or small group selection forest is possible and this would maintain the protective function of the forest as long as it is carried out on a sustainable basis. These recommendations are confirmed by an Austrian forest ecology project carried out in another area in central Bhutan (Gratzer *et al*., 1997).

References

Bürgi, A., Rinchen and Dorji, T. 1992 Structure, productivity, regeneration and possible utilization of the fir (*Abies densa* Griff.) forests in Chumi Valley, Central Bhutan. IFDP, Lame Gömpa, Bhutan, 47 pp.

Gansser, A. 1983 *Geology of the Bhutan Himalaya* (Denkschriften der Schweizerischen Naturforschenden Gesellschaft, Vol. 96). Birkhäuser, Basel, Switzerland, 181 pp.

Gratzer, G., Rai, P.B. and Glatzel, G. 1997 *Ecology of* Abies densa *forests of the IFMP – Ura, Bhutan.*

Research Report, Forest Ecology Unit at IFMP, 219 pp.

Grierson, A.J.C. and Long, D.G. 1983 *Flora of Bhutan, Volume 1, Part 1*. Royal Botanic Garden, Edinburgh, 186 pp.

IFDP 1991 *The Weather in Bumthang 1990*. RGOB/Helvetas, Lame Gömpa, Bhutan, 15 pp.

IFDP 1992 *The Weather in Bumthang 1991*. RGOB/Helvetas, Lame Gömpa, Bhutan, 19 pp.

Korpel, S. 1995 *Die Urwälder der Westkarpaten*. G. Fischer, Stuttgart, 310 pp.

Laumans, P. 1991 *Using PIS Volume Equation* (Working Document No.11). FO:DP/BHU/85/016. RGOB/FAO, Thimphu, Bhutan, 3 pp.

Meyer, H.A. 1933 Eine mathematisch-statistische Untersuchung über den Aufbau des Plenterwaldes. *Schweiz. Z. Forstwes.* **84**, 33–46, 88–103, 124–131.

Negi, S.S. 1989 *Forest Types of India, Nepal and Bhutan*. Periodical Expert Book Agency, Delhi, 322 pp.

Rosset, J. 1999 *Temperate Conifer Forests of Bhutan: A Review of Forestry Research Activities until June, 1998* (Special Publication No 3). RNR-RC Jakar, Bhutan, 87 pp.

Schweizerischer Forstkalender, 1992 Huber, Frauenfeld, Switzerland, 246 pp.

Troup, R.S, 1926 *The Silviculture of Indian Trees*, 3 Vols. Oxford University Press, Oxford, 1195 pp. (Reprinted 1986 by International Book Distributors, Dehra Dun)

Wangchuk, S. 1991 The natural resources of the Himalayan Kingdom. In *Bhutan and its Natural Resources*. Vikas Publishing House, Kanglung/New Delhi, pp. 44–52.