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Yield and household consumption of *Rhododendron arboreum* as a fuelwood species in Eastern Nepal

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ABSTRACT

Rhododendron arboreum Sm. is commonly used for fuelwood in mountainous regions of the Eastern Himalaya, however nothing is known about rates of extraction versus the annual increment capacity of the species in terms of biomass. In the study area, fuelwood is the major source of energy. We conducted household surveys and ecological surveys in and near two settlements to assess both fuelwood consumption and existing above ground biomass of *R. arboreum*. According to local residents, this species contributes 20–25% to household fuelwood requirements, while forest surveys and a survey of freshly cut stumps indicate that 15% of trees felled for fuelwood were *R. arboreum*. Trees were mostly young, comprised about 20% of all tree species in the forest, and accounted for 70.41×10^3 kg ha^{-1} biomass in average. The biomass of felled trees was calculated as 8.71×10^3 kg ha^{-1} at the time of study. Simulation based on the current rates of extraction and increment showed that the species will be in a critical condition in future at most of the monitored sites. In some places however, biomass was found to increase in spite of ongoing extraction. The results indicate that there is an urgent need of forest management which in a first step can be achieved through rotational harvesting that allows forest stands to regenerate and build up biomass. In addition, depletion of rhododendron stands can be reduced by economic development through ecotourism on the theme of rhododendrons, and by providing access to alternative sources of energy.

1. Introduction

Forest biomass is an important source of energy for rural livelihoods globally as well as in Nepal. Biomass ranks fourth as an energy source worldwide, and provides about 14% of the world's energy needs [1]. Fuelwood for cooking and heating is one of the most important products harvested from the forests of developing countries [2].

In Nepal, 68.4% of the population use wood as their main source of fuel for cooking [3]. Biomass use and especially the use of fuelwood affect the environment through deforestation, forest degradation, resource depletion, pollution, etc. In the 1970s, fuelwood use was thought to be the main cause of

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Fig. 1 – *Rhododendron arboreum* is a commonly used tree for fuelwood use in mountain settlements of Eastern Nepal a) Forest stand and cut stumps, b) Wood collected from forest (in the study area), c) Stack of *R. arboreum* wood in a village of Eastern Nepal (about 60 km from the study area).

deforestation in the Himalayas. While this one-dimensional explanation of a complex phenomenon has been largely refuted [4], fuelwood use does have a significant impact on forests, and there is still a need to better understand the links between fuelwood use and the condition of forests or of specific tree species, especially in remote locations, where so far not much research has been carried out.

This applies in particular to the high altitude regions of Nepal. People living in remote areas at high elevations consume more energy because of colder conditions. They rely more strongly on wood from the forest as an important source of energy [5–7] because other forms of energy like commercial fuel and electricity are beyond their reach due to lack of access, high prices, and low income. The proportion of people using wood as fuel is higher in the mountainous parts of Nepal (87.9%) than for the whole of the country [3].

In the mountainous areas of Nepal, local people prefer hardwoods like *Betula* and *Rhododendron* over softwood [8] as hardwood burns longer and produces a comparatively higher amount of heat. An ideal fuelwood species, according to the perspective of local people, must be heavy and dense, should have a low water content, and should not produce too much ash [9]. Rhododendrons meet all these requirements. Due to the presence of polyphenols and flavonoids, rhododendrons burn even when wet [10], which is especially important during the long and humid rainy season at high altitudes in Eastern Nepal.

Extensive use of fuelwood for domestic purposes and for the tourist sector has been exerting pressure on the forests, causing continuous decline in biomass [11]. As rhododendrons are also subject to these pressures, the natural populations of rhododendrons in the eastern Himalaya are gradually diminishing [12,13]. Among rhododendrons, *Rhododendron arboreum* is one of the most highly preferred and harvested species for use as fuelwood [14–16]. It has a high calorific value (19.7 kJ g^{-1}) and high fuelwood index value [9].

In the Eastern Himalayan region, *R. arboreum* is one of the most widespread rhododendrons. It occurs in the understory of high altitude forests, and forms pure stands in some places. It grows to a height of 25 m, and is capable of storing a large amount of biomass. The species is under much pressure due to excessive harvesting for fuelwood (Fig. 1) and ranks within the top ten collected species in mountainous regions in Nepal and adjoining regions [17].

Efforts to conserve rhododendrons and especially the slow growing *R. arboreum* [14] require a better understanding of the balance of extraction of *R. arboreum* as fuelwood and of its ability to replace biomass. The present study was carried out to assess above ground biomass change of *R. arboreum* against the current rate of household fuelwood consumption in a remote and high elevation area of Nepal.

2. Materials and methods

2.1. Study site

Research was carried out in the two settlements of Ghunsa (c. 3400 masl) and Pholey (c. 3100 masl) in Lelep Village Development Committee (VDC[1]) of Taplejung district (Fig. 2a) in the Kanchenjunga Conservation Area (KCA) of northeastern Nepal (Fig. 2b). The settlements are about 29 and 31 h walking distance from the headquarter of Taplejung district at *Phunling bazaar* (c. 1700 masl). Energy from gas, kerosene or electricity from the national transmission is not available because of high cost and remote location.

[1] VDC is the administrative level below district level.

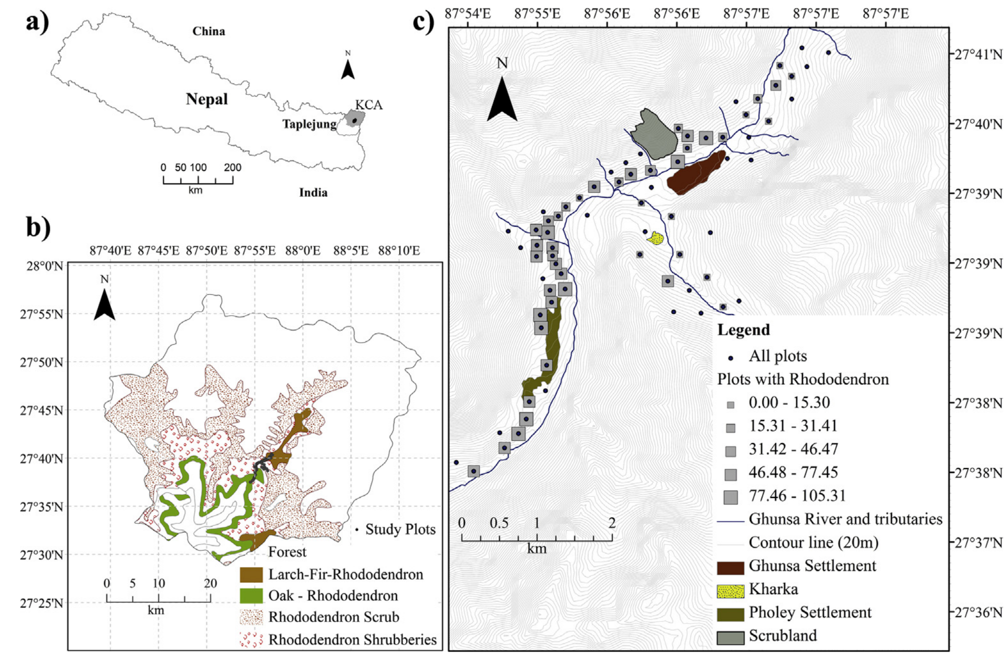

Fig. 2 – Study area a) outline of Nepal and location of Taplejung district and KCA, b) forests containing *Rhododendron* and study sites at Ghunsa river valley in Kanchenjunga Conservation Area, c) surveyed monitored plots and other land use. Size of plots with *R. arboreum* is indicative of AGB estimation, which was presented in legend with the range of estimated AGB.

The study area contains large parts of productive forest of the Kumbhakarna Conservation Community Forest (KCCF) and adjoining forest areas. Vegetation ranges from cool temperate (Mountain Oak-Rhododendron Forest) to sub-alpine (Birch-Larch-Fir-Rhododendron Forest) (Fig. 2b) ecological region types [18]. *R. arboreum* occurs in pure stands or in the understorey of forests containing *Larix griffithiana*, *Betula utilis*, *Tsuga dumosa*, *Abies spectabilis*, *Juniperus* spp., *Quercus* spp., mixed in with other *Rhododendron* spp.

The terrain of the study area is extremely mountainous with steep slopes within an altitudinal range from 2800 masl to 3800 masl. The climate is monsoonal with the maximum amount of rainfall during the summer monsoon season, which begins in June and ends in September [19]. While Ghunsa is located at the valley bottom, surmounted by and in the shadow of about 5000 m high mountains, Pholey is comparatively open with the surrounding mountains below 4500 m. Temperature inversions are common in such locations [20], especially in Ghunsa, where the proximity of high mountains leads to inversions causing very cold temperatures at the valley bottom every winter night. Daily mean temperatures recorded at Pholey and Ghunsa during the study period show a significant difference of winter temperatures between the two areas (Appendix A).

The total number of households (HHs) in the study area is 64 (43 in Ghunsa and 21 in Pholey) with an average of 4.34 individuals per HH. The major crop in this region is potato, which is exchanged for maize, rice and millet at *Phunling bazaar* (Source: field survey 2010/11). Occupations other than crop cultivation include animal husbandry, tourism (lodge, teahouse and porter services), carpet production, and small scale trade across the borders of Nepal with China and India. Yak as the most important domestic animal is kept for transportation as well as for dairy and meat products. The number of livestock owners was reported increasing while per household livestock holdings are decreasing [19].

During winter most of the residents of Ghunsa migrate to their winter residences at Pholey, or to lower settlements to avoid the cold temperatures at Ghunsa. During pre-monsoon and post-monsoon (the two tourism seasons) they migrate to a subsidiary settlement called Khambachen (above 4000 masl), which is situated above the tree line. During February/March to May residents of Ghunsa return back to their homes at Ghunsa.

2.2. *Household survey*

KCCF management allows felling of trees for fuelwood twice a year during March/April and October/November. Most fuelwood is collected during April/May because trees are then comparatively drier than in the post-monsoon season (Oct/Nov), and because residents of Ghunsa have just come back after having spent the winter elsewhere. Therefore, a household census was conducted in Ghunsa and Pholey settlements in the months of April/May.

Out of the total of 64 HHs in both sites, 14 HHs in Ghunsa and 7 HHs in Pholey (33% of total HHs) were randomly selected and interviewed. The purpose of interviewing was (1) to identify sites of wood collection, (2) to identify preferred species for fuelwood, and (3) to assess the amount of fuelwood consumption and the share of *R. arboreum*.

Weight surveys were conducted to estimate household consumption [21]. The sun dried wood stored in the surveyed households was divided into '*bharis*'[2], and weighed using a

[2] bhari = headload: a popular unit of measuring fuelwood in Nepal which, however, differs between villages.

spring balance of 100 kg capacity. Three '*bharis*' of sun-dried fuelwood were weighed and averaged in each one of the surveyed HHs, which altogether makes 63 '*bharis*'. Results on *R. arboreum* fuelwood use obtained from the household survey and from informal interviews were supplemented with visual estimation of the proportion of rhododendron wood in the fuelwood piles.

2.3. Secondary data from community forestry

The resulting estimates were combined with data from the KCCF logbook, which includes the five year (2009–2014) forest development plan (see Appendix B and Table B.1). These records contain the amount of wood expressed by number of '*bharis*' extracted in a fiscal year as well as the estimated wood requirement for the population residing in the area for the five year planning for forest management. Annual consumption of fuelwood was calculated by multiplying the weight equivalent to one '*bhari*' of wood that had been established from the HH weight survey with the number of '*bharis*' extracted from the forests that was recorded in the KCCF logbook.

2.4. Ecological survey and analysis

An ecological survey was conducted in March/April (2010), October/November (2010), January (2011) and April/May (2011). The sampling design was based on the distribution of *R. arboreum* and on information obtained from local people during the HH survey at wood collection sites. The survey area was divided into 11 sectors, each sector corresponding with wood collection sites that had been identified and assigned a local name by local residents (Table 1). Sectors are based on local identification and are therefore heterogeneous in size.

Simple random sampling [22] was used to select monitoring plots within each sector (see Fig. 2c and Appendix C). All sectors were divided into several 20 ha squares based on latitude and longitude grids on the satellite image of the study area, and random numbers were then used to generate the coordinates of the sample plots in ArcGIS. Each square has four randomly generated points, i.e., sample plots. The area outside the squares was not included. With the help of GPS, the coordinates of each point were located at the field site and 0.04 ha quadrats were plotted. Points that were located in other land use types (e.g. village, cultivated land, scrubland, etc.) were discarded.

Altogether 72 plots were monitored. Nested inside the 0.04 ha quadrats, which were used for sampling large trees, were 0.01 ha quadrats for small trees including large saplings, and 0.0025 ha quadrats for small saplings and seedlings. Out of a total of 2485 individual trees measured in the 72 plots, 499 live trees (20.08% of total tree spp.) of *R. arboreum* were recorded in 46 plots (Fig. 2c). In the monitoring plots, all *R. arboreum* trees $\geq$3 cm DBH (with height $\geq$ 2 m) were measured. The regenerating *R. arboreum* were counted and categorized as seedlings (height < 1 m) and small saplings (height < 2 m with diameter < 3 cm).

The rhododendrons measured in the observation plots were categorized into the following DBH size classes: large trees (DBH > 30 cm), medium sized trees (DBH = 20–30 cm), small trees (DBH = 10–20 cm), large saplings (DBH = 3–10 cm), and regenerating plants (seedlings and small saplings). Trees were categorized in class intervals of 5 cm to show density in each category.

Above ground biomass (AGB) as a function of diameter was estimated following the regression equation $\ln(W) = a + b \ln(\text{CBH})$ developed by Adhikari et al. [23]. In the equation, W is kg treepart^{-1} (Table 2), CBH is circumference at breast height in cm, *a* and *b* are regression coefficient (see Table 2). Regression coefficient values and regression statistics provided in Adhikari et al. [23] were used for estimation of biomass. Total AGB for each tree was estimated by adding up bole biomass, bole bark biomass, branch biomass and twig biomass as these four parts are used as fuelwood.

Table 1 – Forest sectors as locally identified and named by the residents.

Sector	Local name	Elevation range (m)[a]	Number of minutes walking to nearest Settlement[b]
1	Merak-Taga	3525	80 min to Ghunsa
2	Ghunsa pari	3500	45 min to Ghunsa
3	Kane	3410	20 min to Ghunsa
4	Tangthurma	3560	60 min to Ghunsa
5	Smriti Chautara	3390	30 min to Ghunsa
6	Yanmak samba	3365	45 min to Ghunsa
7	Chunda Ninba	3325	30 min to Pholey
8	Phole devisthan	3290	20 min to Pholey
9	Pholey	3260	15 min to Pholey
10	Tallo Pholey	3180	30 min to Pholey
11	Pholey phedi	2940	80 min to Pholey

[a] Figures are rounded and averaged for each sector.
[b] Distance recorded during field survey and approximate average for nearest and farthest distance for each sector, elevation difference between settlement and extraction site affect timing.

Table 2 – Constant values for calculating above ground biomass for *R. arboreum* based on Adhikari et al. (1995).

Tree part	Regression model	a	b	R^2	SE
Bole	$\ln(W_{bole}) = a + b \ln(\text{CBH})$	0.207	0.9638	0.904	0.123
Bole bark	$\ln(W_{bark}) = a + b \ln(\text{CBH})$	−3.5917	1.0207	0.922	0.117
Branch	$\ln(W_{branch}) = a + b \ln(\text{CBH})$	−0.1113	0.8288	0.903	0.107
Twig	$\ln(W_{twig}) = a + b \ln(\text{CBH})$	−0.4734	0.879	0.893	0.119

All values are significant at $p < 0.01$; *a* and *b* are regression coefficient for regression model; R^2 is coefficient of determination, and SE is standard error.

2.5. Measuring cut stumps and estimating DBH of cut trees

We recorded and measured stumps of *R. arboreum* trees that had been freshly cut[3] or felled within one year before the observation period. As trees are cut at a relatively low height, it was not possible to measure DBH; instead, basal diameter (at 20 cm) was measured and was used to predict DBH of cut or missing trees.

[3] old stumps can be easily distinguished from fresh cuts due to the decaying surface of the cut in older stumps.

Palander et al. [24] had described and used linear relation for an estimation of DBH of cut or missing trees. A linear relation DBH = 0.893 d_{base} − 0.911 ($R^2 = 0.978$, $p < 0.001$; see Appendix D) was developed to explain the relation of DBH and base diameter (at 20 cm) measured during the field survey using data from 97 trees. In the relation d_{base} is base diameter (20 cm) and DBH is diameter at breast height. The DBH (and CBH) of missing trees were calculated using this linear relation and these values were then regressed to obtain estimates of the felled biomass (unit is $\times 10^3$ kg ha^{-1} year^{-1}).

2.6. Tree rings and annual width increment

In each sector, tree cores were collected from selected *R. arboreum* trees from the monitoring plots. Altogether 194 cores were collected from 97 trees. The sample comprised large saplings of 3–10 cm DBH and trees of 10–20 cm DBH which had been selected because of their abundance in the study area. The data from 112 cores from 56 trees were used for analysis. Tree cores showing false rings, incomplete rings and unclear rings were not used.

The tree ring increment was averaged for each sector and the mean increment value was used to calculate DBH change. The mean annual growth rates (i.e., the annual increment) of the trees were estimated by measuring the distance between two annual rings. Ring widths were measured to the nearest 0.01 mm using a dissecting microscope in conjunction with J2X software. The annual increment was used to calculate annual growth per year. As the cores were from breast height (1.37 m) of trees, annual increment can be regarded as DBH change. The change in DBH as measured in terms of tree ring width was estimated by averaging annual increments.

2.7. Simulation of biomass change

Caspersen et al. [25] define change in biomass (ΔAGB) as difference between biomass added by growth rate and biomass reduced by mortality, i.e., ΔAGB = *Biomass (growth)* - *Biomass (mortality)*. Change in biomass can vary through time because of species composition, age structure, browsing by livestock, defoliation, competition, developmental stage, disturbances, etc. [26]. We use disturbance (human harvest) as factor affecting change in biomass, hence change in biomass was calculated as ΔAGB = *Biomass* (*growth$_i$*) - *Biomass* (*harvested$_i$*), i = sector 1 to 13. The tree growth and harvest parameter estimates were used, together with the initial plot tree biomass calculations [27], in the Simile package (Version 5.8) [28] to simulate changes in *R. arboreum* biomass (see Appendix E and Fig. E.1).

Biomass (growth) was estimated based on the annual increment in DBH. Average annual increments of representative trees were determined and used to calculate change in biomass over time as *Biomass (growth$_i$)* = *Increment$_i$* × *Biomass$_i$* × (1 - *Biomass$_i$/Biomass threshold$_i$*) with i = sector 1 to 13. In the equation *Increment* represents average of annual biomass increase (unit is 10^3 kg ha^{-1} year^{-1}) determined as described in sub-Section 2.6; *Biomass* represents current AGB (unit is 10^3 kg ha^{-1}) estimated as described in sub-Section 2.4; *Biomass threshold* represents maximum biomass set for the calculation based on 0.95 percentile of all cumulative *Biomass* (unit is 10^3 kg ha^{-1}). The purpose of the threshold is to turn off the biomass growth rate below a certain limitation value. *Biomass (harvested)* was considered as annual consumption and estimated as described in sub-Section 2.5. We used this simulation to estimate the change of *R. arboreum* biomass in the forest sectors over one decade, and to distinguish between sustainable and non-sustainable harvests.

3. Results

3.1. Fuelwood consumption

Inhabitants of the study area depend heavily on energy from biomass. A micro-hydro station established in 2008/09 provides a small amount of energy, while the remaining energy demands can be fulfilled by fuelwood only. Fuelwood is used to prepare food for the family and fodder for cattle as well as for heating rooms. Beside cooking and heating, there are various traditional activities, e.g. '*tomba*' and '*churpi*' making, for which fuelwood is used, and which are included in daily household activity (see Appendix F for details). The exact amount of wood harvested and consumed for tourism purposes could not be assessed as field research was not carried out through the full length of the year. Interviewing hotel owners provides information only on the consumption of tourists staying in the hotel/lodge, but not of the porters and others who accompany or assist the tourists.

3.2. Share of rhododendron arboreum in fuelwood consumption

The weight survey showed that one '*bhari*' is equivalent to an average of 34.5 ± 0.64 kg within a range of 39 kg maximum and 30 kg minimum. The annual amount of fuelwood collected per household was between 3.5 and 15.72 × 10^3 kg, with an average of 9.36 ± 0.43 × 10^3 kg (Source: fieldwork 2010/11 and KCCF, see Appendix B). Per capita per day consumption of fuelwood was 5.9 kg. The consumption measured during the survey period April/May was 35.79 kg per day per household, which is higher than the annual average calculated on the basis of KCCF data: 25.66 kg per day per household. The total annual amount of fuelwood collected from the forest in the two settlement areas was estimated at c. 17087 '*bharis*' (590.12 × 10^3 kg) in 2009/2010 (Source: KCCF).

Birch (*B. utilis*) followed by junipers (*J. recurva* and *J. indica*) are the most preferred fuelwood species (Table 3) by local residents. *Rhododendron*, despite its superior fuelwood qualities, is the least preferred fuelwood species in this area (Table 3) mainly because the predominantly young trees yield only small wood, which, according to local residents, burns off and is used up quickly. Moreover, KCCF/KCA management permits the collection of *Juniper* spp. and *B. utilis* for woodfuel purposes, but discourages people to collect *R. arboreum* or other rhododendrons (Source: KCCF).

However, as both birch and juniper are not available near Pholey, local residents of the Pholey area are forced to rely on *R. arboreum*, despite the official discouragement, and in spite of the small size of most plants. Field research showed that extraction

Table 3 – List of the tree species preferred and collected as fuelwood in the study area based on household and ecological survey.

Sn	Collected species	Ghunsa		Pholey		Stump
		Preference	Occurrence	Preference	Occurrence	Count
1	*Acer* sp.	6	Y	6	Y	10
2	*Betula utilis*	1	Y	1	N	58
3	*Juniperus indica*	2	Y	3	Y	100[c]
4	*Juniperus recurva*	2	Y	3	Y	
5	*Lyonia ovalifolia*	3	Y	2	Y	17
6	*Rhododendron arboreum*[a]	4	Y	4	Y	58
7	*Rhododendron barbatum*[a]	4	Y	4	Y	51
8	*Rhododendron campanulatum*[a]	4	Y	4	Y	
9	*Rhododendron campylocarpum*[a]	4	Y	4	Y	
10	*Sorbus microphylla*	5	Y	5	N	6
11	*Viburnum* sp.	7	Y	7	Y	11
12	*Abies spectabilis*[b]	10	Y	9	Y	–
13	*Larix griffithiana*[b]	8	Y	8	Y	–
14	*Pinus wallichiana*[b]	9	Y	11	N	–
15	*Tsuga dumosa*[b]	11	N	10	Y	–

[a] Rhododendrons are collected because of absence of highly preferred species and cut stump count was done based on *R. arboreum* and other rhododendrons.
[b] Cone, branches and other remaining pieces after separation for timber. Preference comes from interview with local residents and occurrence from forest sampling.
[c] Count for both *Juniperus* spp.

of *R. arboreum* is high, and that it is higher than extraction of other rhododendrons. Both, data from the forest survey as well as visual assessment of wood stored in each household showed that rhododendrons are one of the most extensively collected fuelwood species (Table 3). Local residents reported that rhododendrons contribute about 30–35% (about 20–25% for *R. arboreum*) of their fuelwood needs. According to our estimation based on the record book of the community forest user group and our field survey, total annual fuelwood consumption is 590.12×10^3 kg, to which *R. arboreum* contributes 118.02 to 147.53×10^3 kg (20–25%) of the total consumption.

3.3. Distribution of *Rhododendron arboreum*

Up to an altitude of 3630 masl, *R. arboreum* is one of the major components in more than 50% of the surveyed plots. Regenerating individuals occur up to c. 3750 masl. Out of 46 plots, three plots contain only regenerating plants while the remaining plots consist of plants of varying size.

The average density (expressed as ha^{-1}) of *R. arboreum* was 212 for trees with DBH 10–15 cm, 101 for trees (15–20 cm), 40 for (20–25 cm), 24 for trees (25–30 cm) and 7 for trees with DBH $>$ 30 cm (Fig. 3). The density of saplings with 3–10 cm was 266 and of saplings $<$ 3 cm was 850. The density of seedlings was 2176 (see Fig. 3). The proportion of larger trees was comparatively higher in lower elevation plots, whereas the distribution of small trees and large saplings was almost equal in all plots, which accounts for an average increment in diameter of 0.134 ± 0.01 cm $year^{-1}$. Occurrence density of *R. arboreum* was higher in sectors 2, 6, 7, 8, 9, 10 and 11, and lower in sectors 1, 3, 4 and 5.

The base diameter of stumps ranged between 7 and 39 cm with a maximum of trees around 16 cm. Most stumps were of rhododendron, juniper and birch trees (Table 3). About 15% of the stumps recorded in the surveyed plots were of *R. arboreum* trees. Signs of lopping and cut stumps of *R. arboreum* were found in almost the whole area of its occurrence with the exception of the religious forest, where there were no signs of tree felling or lopping.

3.4. Available biomass, simulation of growth and extraction

Based on the forest survey, average AGB estimated for *R. arboreum* in the study sites was $54.44 \pm 0.64 \times 10^3$ kg ha^{-1} (5.07–105.31×10^3 kg ha^{-1}). Variations in biomass density between the sites indicate different stages of stand development. The density of cut stumps of *R. arboreum* showed that logging was highest in sectors between the two settlement areas, which are accessed and used by residents from both settlements. The average density of cut stumps was 139.07 ± 32.58 ha^{-1} in the study area, on the basis of which we estimate $13.95 \pm 2.99 \times 10^3$ kg ha^{-1} of mean biomass extraction during the study period.

The simulation based on biomass growth and biomass extraction revealed a mixed pattern of biomass increment in some sectors and biomass decline in others. Based on the

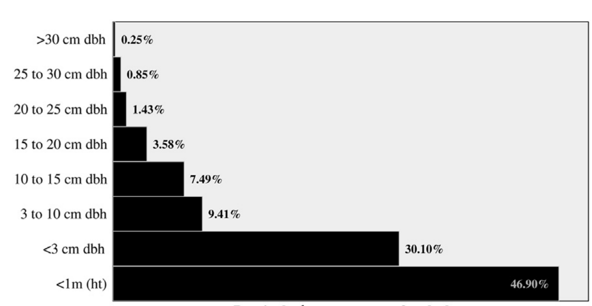

Fig. 3 – Size classes of *Rhododendron arboreum* in the surveyed plots, indicating the decline in plant density toward maturity, seedling > sapling > tree life-form.

simulation results, decline in *R. arboreum* biomass was higher in sectors 1, 4, 5 and 7 (Fig. 4). In sectors 2, 3 and 6, decline occurred at a slower pace and could be stopped or reversed quite easily by managing extraction. At sectors 9, 10 and 11, biomass was increasing slowly despite ongoing extraction, while in sector 8, increments were slow in places without extraction (see Fig. 4).

4. Discussion

Our study shows that biomass of *R. arboreum* stands in the study area is declining, and that a further decline is to be expected. Some of the reasons for this situation can be linked to the physical environment and to the physiology of *R. arboreum*, others are grounded in socio-economic parameters such as access, patterns and intensity of using *R. aboreum,* as well as demographic patterns, e.g. migration. It is the second set of parameters that provides an entry point for measures to conserve and sustainably use *R. arboreum*.

According to our data, fuelwood consumption in the area is high, though less than the use of fuelwood in Sagarmatha National Park and Buffer Zone (SNPBZ) [27], and the amount of wood extraction determined by our research is equivalent with the lower amount extracted in SNPBZ [27]. It is similar, to consumption in Northeast India (3.90–5.81) and Bhutan (4.7) [29,30], both situated in the Eastern Himalayan region, and higher than in lowland areas of western India [31] located at the same latitude as our study area.

The intensive use of *R. arboreum* as a fuelwood species in the study area can be explained partly by the generally high consumption of fuelwood at high altitudes, partly by the fact that in the study area, *R. arboreum* is more heavily used as a fuelwood species than in other areas, where more preferred species such as birch and juniper are available in greater quantity.

Households located at higher elevations where temperatures are lower and the cold season longer require more fuelwood to fulfill greater heating requirements [29,32] but also because of the longer time required for cooking the same amount of food as at lower elevations. Fuelwood consumption

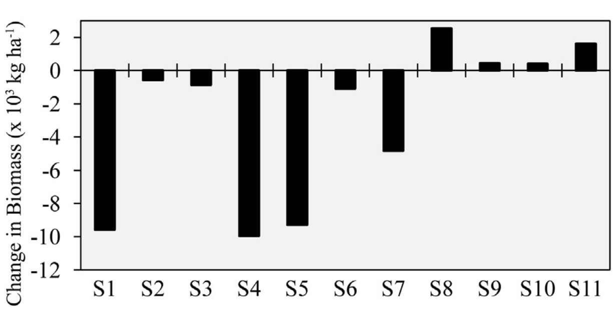

Fig. 4 – Change in biomass of *Rhododendron arboreum* as calculated based on simulation. With existing rate of increment and removal of biomass projected into the future there could be rapid decline, slow decline or increase in biomass in the different forest sectors (Sec 1 to Sec 11). Upright bars indicate improvement in biomass condition and inverted bars indicate reduction in biomass. Reduction of biomass is high in between the two settlements.

can also be higher in areas frequented by tourists requiring facilities such as hot showers as shown by research in the Sagarmatha (Everest) [27] and Sikkim regions [6]. Fuelwood consumption is also affected by occupation, economic status of family, type of stove used (traditional stove or fireplace) and availability of other energy sources.

Fuelwood consumption in the study area is mainly determined by the lack of other energy sources and by heating requirements almost throughout the year. In this research we did not collect quantitative data on fuelwood consumption from all seasons, which must be considered as a limitation of the study. As explained in methods, we measured fuelwood consumption in April and May, and assessed annual consumption by combining our data with data from the KCCF logbook. The higher consumption of fuelwood during April/May as compared to the annual consumption can be explained by the fact that this period coincides with the spring collecting season when most of the fuelwood supply for the rest of the year is collected because the wood is dry at the end of the long dry season, and because people who have spent the cold months at lower altitudes return to their homes by this time.

Migration can also be the cause of some local variation. The KCCF report (statistical summary in Appendix B) confirms that local residents living in a village throughout the year with agriculture as their main occupation require more wood than those who work as porters or who are engaged in trade, and are therefore away from the village for extended periods.

Migration can locally increase fuelwood consumption and pressure on forests. In winter, residents from Ghunsa move to their second homes in Pholey, increasing the fuelwood consumption in this settlement. In summer, as noted by Ikeda [33] herders from Ghunsa valley collect their fuelwood supply between Pholey and Ghunsa, and around Ghunsa and bring it with them to higher elevation areas that are lacking in trees. These two seasonal activities create pressure especially on the forests between these two settlements. Our result concerning the greater density of cut stumps in the sectors between the villages concurs with the observation of Ikeda [33]. Most of the forests between the two settlements have *R. arboreum* as the major forest component. Collecting of *R. arboreum* for fuelwood was less near settlements where villagers watch over their resources, but more intense along the routes between the two settlements.

During the official collecting periods, *R. arboreum* fuelwood is collected by cutting rhododendron trees. Outside the official collecting periods, fuelwood is extracted from *R. arboreum* mainly through lopping and breaking off branches. An important reason for the heavy use of *R. arboreum* as fuelwood, despite the small size of the young plants, is the fact that the wood can be burned without prior drying [10] and the limited availability of other preferred fuelwood species.

Most *R. arboreum* trees in the study site are young. The total amount of above-ground biomass estimated in our work is therefore significantly below that of adjoining regions in Eastern Nepal [34]. The predominance of young *R. arboreum* individuals may be due to felling and clearing the forest in the past, which has opened up the canopy and thus improved the conditions for regeneration.

Slow increment in biomass is mainly caused by low growth rate as indicated by growth ring analysis. Low growth rate, in turn, is partly caused by the dry and cold winters in this region. Availability of soil moisture is lower during the dry period and even lower when frost locks up what moisture is available in the soil. The lack of soil moisture intensifies the water stress of trees, thereby limiting their growth and resulting in the formation of narrow growth rings [35].

Under conditions of water stress, *Rhododendron* can vigorously produce reproductive buds at the expense of vegetative growth [36]. The seeds are minute, amounting to about 12 million in 1 kg, and can be dispersed to several 100 m [14]. The profusion of reproductive buds under stressful conditions may thus contribute to more seed production and dispersal, and help to explain both, the prevalence of new colonies in previously unoccupied areas, and the slow vegetative growth. Growth of *R. arboreum* seedlings is slow. They grow only a few millimeters in height during 1–2 years [14], which can be further slowed by low temperatures and reduced light availability.

Under the canopy of *R. arboreum* stands, seedling establishment is jeopardized by the thick layer of *R. arboreum* leaf litter [8]. *Rhododendron* leaves decompose slowly [37], even more slowly in colder regions, adding to the build-up of the litter layer which prevents seedling establishment [38]. Trampling of young plantlets due to the movement of animals and people, especially near settlement areas, threatens the survival of seedlings that have managed to get established.

Slow growth and low seedling survival rate in addition to the removal of biomass by forest users can deplete the tree biomass of forests in high mountains as indicated by the findings of Salerno et al. [27] for *A. spectabilis* in SNPBZ, which concurs with our results. Likewise, to continue extracting fuelwood in the study area at the rate established through our survey could lead to the rapid reduction in biomass of *R. arboreum* in some sectors and jeopardize the efforts of KCA management for conservation of *R. arboreum*. However, our simulation results indicate that while biomass declines in some sectors, there is biomass increment in other sectors. This is mainly due to only moderate extraction of *R. arboreum* [27]. In one sector, however, increment of *R. arboreum* biomass is due to the presence of a sacred forest where cutting is prohibited.

It is not possible to precisely assess the energy supply-demand situation, because this depends on demographic change, availability of alternative sources, change in climatic condition and proper forest management. In the Eastern Himalayas, conservation of rhododendrons requires the development of alternative sources of energy supply that suit the socio-economic conditions of high mountain settlements, i.e., they should be cheap, and easily accessible. Managing extraction could be another solution, since our simulation results indicate that forest would recover in many places if extraction is lowered by only a margin. This could be achieved by shifting extraction from more pressurized forest sectors to less pressurized sectors, and by rotation within sectors.

5. Conclusion

Fuelwood constitutes a considerable part of the forest biomass currently used in the study area. Slow growth rate of seedlings and more mature plants was identified as a constraint to biomass addition which may contribute to the depletion of *R. arboreum* in future if the current rate of extraction continues.

Improving access to transportation facilities for exchanging goods, developing eco-tourism by establishing *Rhododendron* trails as planned by KCA management, and an increase in the number of tourists could be factors changing the figure of wood extraction, which we were not able to consider in this study. While this must be regarded as a limitation of the present study, the simulation is capable of providing important information on *R. arboreum* biomass change, which could be useful in decision making processes regarding forest management and harvest.

Within the present context, the relatively slow rate of degradation could be reverted by forest management measures such as rotational sector-wise extraction, and by a complete restriction of use in those sectors, where biomass loss due to extraction is highest. In addition, promotion of alternative sources of energy, such as hydropower, solar and wind energy at a price that is affordable for local residents could reduce the pressure of wood extraction on the forest in general, and on *R. arboreum* in particular.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.biombioe.2013.12.016.

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