Above-ground biomass models for Seabuckthorn (*Hippophae salicifolia*) in Mustang District, Nepal

R. Rajchal[1] and H. Meilby[2]

Seabuckthorn (*Hippophae salicifolia* D. Don.), an important multi-purpose tree, is found at altitudes of 2000–3600 m amsl in Nepal, but so far no models have been developed for estimating the biomass of this species, thus hampering resource assessment and management planning. Hence, the objective of this study was to develop local biomass models for wood, fruit, and leaves of Seabuckthorn. In November 2006, a diameter-stratified sample of 30 trees was harvested in Lete and Kunjo Village Development Committees at an altitude of about 2300 m amsl in the lower part of Mustang District, Nepal. The fresh weight of fruit and oven-dry weight of wood (stem and branches) and leaves were measured and used as a basis for developing biomass models. Diameters of the trees were measured at 30 cm above ground whereas the heights were measured in terms of the total tree height (m). Among several models tested, the models suggested for local use were: ln(woody biomass, oven-dry, kg) = -3.083 + 2.436 ln(diameter, cm), ln (fruit biomass, fresh, kg) = -3.237 + 1.346 ln(diameter, cm) and ln(leaf biomass, oven-dry, kg) = -4.013 + 1.403 ln(Diameter, cm) with adjusted coefficients of determination of 0.99, 0.73 and 0.91 for wood, fruit, and leaves, respectively. The models suggested for a slightly broader range of environmental conditions were: ln (woody biomass, oven-dry, kg) = -3.277 + 0.924 ln(diameter^2 × height), ln(Fruit biomass, fresh, kg) = -3.146 + 0.485 ln(diameter^2 × height) and ln(leaf biomass, oven-dry, kg) = -4.121 + 0.532 ln(diameter^2 × height) with adjusted coefficients of determination of 0.99, 0.68, and 0.92 for wood, fruit, and leaves, respectively. The models can be used in assessment of Seabuckthorn resources and above-ground carbon and in the management of these resources by communities and others.

Key words: Allometric models, biomass functions, wood, foliage, fruit, leaves

Seabuckthorn is a general name for a group of shrubs or small trees belonging to genus *Hippophae* Linn., under Elaeagnaceae family. All species of the genus *Hippophae* are dioecious, deciduous, thorny and willow-like woody plants (Lu, 1992). Seabuckthorn is a fast-growing multipurpose species which has an extraordinary capacity to grow and survive under extreme conditions (-40 to +40º C), and has an extensive rooting system with strong soil binding capacity, making the species useful for soil stabilization, river bank control and water retention (TISC, 2001). Seabuckthorn berries and leaves are rich sources of vitamins, antioxidants, and other nutrients and are widely recognized for their medicinal value (Maertz, 2006). For farmers living in the mountains, Seabuckthorn offers opportunities to maintain sustainable livelihoods by providing fuelwood, fodder, healthy foods, and medicinal products and protecting the land from soil erosion (Lu, 1992; Ansari, 2003).

Two species of *Hippophae* are native to the mountain regions of Nepal, *H. salicifolia* D. Don and *H. tibetana* Schlecht. (Lu, 1990; Lu, 1992; Kharel, 1999; Vaidya, 1999). According to Gupta *et al.* (2000), *H. salicifolia* is found between 2000 m and 3600 m altitudes amsl, whereas *H. tibetana* is found at slightly higher elevations of 3300 – 4500 m amsl (Ansari, 2003). The two *Hippophae* species have been reported from the mountain areas of Baglung, Darchula, Dolakha, Dolpa, Humla, Jajarkot, Jumla, Kaski, Manang, Mugu, Mustang, Ramechhap, Rasuwa, Solukhumbu and Taplejung Districts (Vaidya, 1999; Gupta *et al*., 2000; TISC, 2001; Baral, 2002). In Mustang District, the species emphasized in this study, *H. salicifolia*, grows along the banks of rivers and

[1] US Geological Survey, Denver, Colorado, USA. E-mail: rrajchal@hotmail.com
[2] Department of Food and Resource Economics, University of Copenhagen, Denmark.

streams, on flood plains, steep slopes, alluvial soils, and newly eroded colluvial deposits of Lete, Kunjo, and Kobang Village Development Committees (VDCs).

Despite widespread use of Seabuckthorn and considerable worldwide attention, only few studies on the species have been conducted so far in Nepal. Some initiatives have increased local utilization of the fruit of Seabuckthorn by promoting juice making, and it appears that local communities and development organizations are mainly concerned with product utilization issues. However, for commercial utilization and proper management of natural populations of the species, estimation of available resources is crucial. Because of the strong allometric relationship typically observed between biomass and diameter/ height of a tree species, the use of regression estimates offers a reasonable, efficient and non-destructive approach to biomass estimation. Additionally, because of the growing interest in above ground biomass estimation triggered by the need for assessment of carbon stocks in forests, biomass functions for Seabuckthorn offers a useful tool for estimating carbon retention in other similar species for which only few studies have been made.

Therefore, the primary objective of this study was to develop local above ground biomass models for wood, fruit and leaves of Seabuckthorn (*H. salicifolia*) in Mustang District, Nepal. The study should be useful not only to academic communities for estimating and comparing the biomass of Seabuckthorn forests/thickets but also to the local communities of Mustang District for assessing the current resource status as a basis for planning their resource extraction.

Materials and methods

Study area

Mustang is one of the main districts of the Annapurna Conservation Area that covers most of the Annapurna Himal complex and the Kali Gandaki Valley. The district, with Jomsom as its headquarters, covers an area of 3,573 km², and has a population of about 15,000 (HMG/N, 2001). It extends from 28º24′ to 29º20′ N latitudes and from 83º30′ to 84º10′ E longitudes. The terrain is rugged and ranges from 1372 m to 8167 m amsl, thus representing sub-tropical to alpine types of climate. The district is characterised by a very

large biodiversity, unique landscapes and rich cultural heritage, and has, therefore, become one of the most important tourist destinations in the nation.

The study area is located in Lete and Kunjo VDCs in Lower Mustang, and covers about 61 ha of Seabuckthorn forest/thicket, the majority of which is located along the Kali Gandaki River (Rajchal, 2007) (Fig. 1).

Data collection

Selection of trees and measurements

In November 2006, thirty Seabuckthorn trees were selected on the banks of the Kali Gandaki and Lete Rivers, both in Lete and Kunjo VDCs. The trees were evenly distributed across nine diameter classes (each 5 cm wide); the diameters of the selected sample trees ranged from 1.4 cm to 43.2 cm at 30 cm above ground. The total height of the selected trees ranged from 1.8 m to 15.2 m. Due to the shrub-like character of *H. salicifolia* and the occurrence of small individuals, the stem diameters were measured 30 cm above ground. Dead, dying or malformed individuals were avoided while selecting the sample trees. The direction of felling was determined before felling the trees; the ground was cleared for shrubs and other obstacles, and a 20 m × 10 m Tarpaulin was laid out in the direction of felling to prevent loss of leaves or dead branches. Tree height, crown diameter, bark thickness and number of annual rings 30 cm above ground were measured after felling. At the analysis stage, these measurements were included in our search for the most suitable biomass model. Tree height and crown diameters were measured to the nearest 10 cm, and diameter 30 cm above ground was measured to the nearest 1 mm. Finally, the thickness of the bark was measured to the nearest 0.5 mm.

Fresh (green) weight measurement

The thirty sample trees were cut both at 30 cm above ground and as close as possible to the ground to include the stump. All branches with leaves and fruit were separated, and the trunk and branches were cut into short, manageable segments. All the leaves were clipped off, and the fruit were collected safely from the branches which were added to the wood biomass. The woody parts were weighed to the nearest 0.1 kg in the fresh (wet) condition using a Spring Balance,
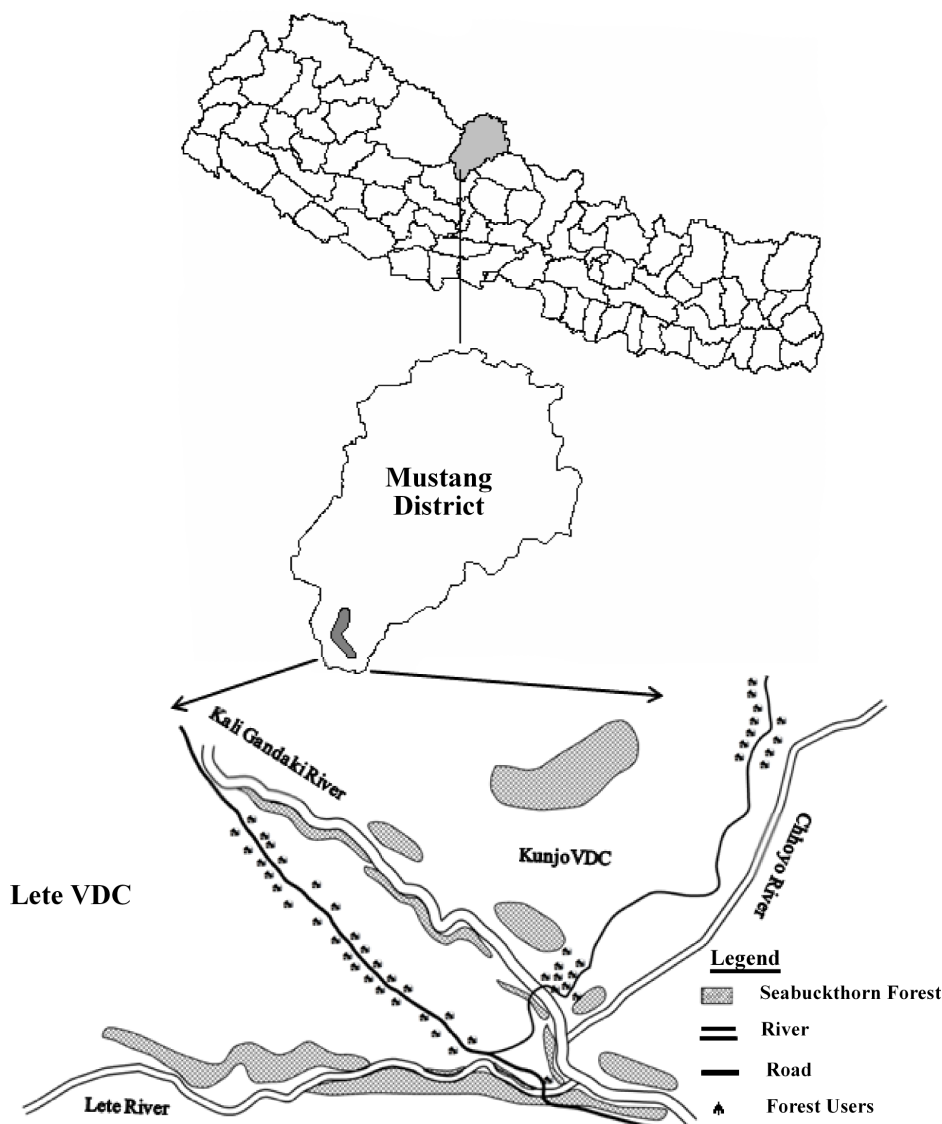
Fig. 1: Map of the study area and the locations of Seabuckthorn (*Hippophae salicifolia*) forests

and the leaves as well as fruits were weighed *in situ* to the nearest gram using a battery-powered balance.

Sample collection for oven-dry weight

Wood discs of stems (approximately 1 inch thick) from different parts of the trees were sawn off in the field, and the fresh weight was determined to the nearest gram using a battery-powered Balance. Representative samples of leaves were collected, and weighed to the nearest gram. Wood and leaf samples were kept in a dry and shady place prior to final oven-drying.

Oven-dry weight determination

The wood samples were oven dried at a constant temperature of 105°C for 48 hours (FRI, 1986) to obtain constant weight (weighing to the nearest

0.01 gram). The leaf samples were oven dried at 70°C (Rayachhetry *et al.*, 2001) for 12 hours, until no further weight loss was observed. For each sample, the dry matter content (DMC, in per cent of fresh weight) and the moisture content (MC, in per cent of dry weight) were calculated as:

$$DMC = \frac{W_{dry}}{W_{fresh}} \times 100\% \text{ , and } MC = \frac{W_{fresh} - W_{dry}}{W_{dry}} \times 100\%$$

where, W_{fresh} is fresh weight and W_{dry} is oven-dry weight.

Based on these values, average *DMC* and average moisture content (*MC*) were estimated for wood and leaves. Using these estimates and the fresh weight measurements made for trunk and branch segments and piles of leaves, oven-dry weights were calculated for each tree for application in

regression models. For fruit, the fresh weight measured in the field was used directly in regression models.

Biomass models

A range of different biomass models including some of the models commonly encountered in the literature were tested. The tested models are as follows:

Model 1: $\ln B = a + b \ln D$

Model 2: $\ln B = a + \ln D^2 H$

Model 3: $\ln B = a + b \ln D + c \ln H$

Model 4: $B = a + b D$

Model 5: $B = a + b H$

Model 6: $B = a + b D + c H$

Model 7: $B = a + b D^2 H$

Model 8: $B = a + b D + c D^2$

Model 9: $B = a + b C_d$

where, D is diameter at 30 cm, H is total height of the tree, C_d is the crown diameter, B is biomass of oven-dry wood, oven-dry leaves, or fresh fruit of Seabuckthorn, and a, b, and c are parameters to be estimated.

Comparison of different models was based on: (i) adjusted coefficient of determination (adj. R^2) which makes it possible to compare models with different numbers of parameters (Montgomery *et al.*, 2001); (ii) significance of parameter estimates when tested at the 5% level; (iii) homogeneity of residual variance and distribution of the residuals; (iv) Standard Error of the Estimates or Standard Deviation of the Residuals (SEE); and (v) simplicity and low requirements with respect to number of variables that need to be measured in the field.

Many biomass studies apply data splitting procedures when validating biomass models (e.g. Poudel *et al.*, 2011). However, due to the low number of observations, it would be too wasteful to split the data into separate calibration and validation datasets. Instead, repeated cross-validation was carried out where, in each of N validation runs, a single observation was omitted and the model parameters estimated on the remaining N-1 observations. Each of the N resulting models was subsequently used to predict

biomass for the tree that was omitted in each of the cases. The errors obtained through this leave-one-out cross-validation were summarised as per centage bias (PBIAS) and root mean squared error per centage (RMSE%) as follows:

$$PBIAS = 100\% \times \frac{\sum_{i=1}^{n}\left(B_{obs,i} - B_{pred,i}\right)}{n\,\overline{B}_{obs}}$$

and

$$RMSE\% = \frac{100\%}{\overline{B}_{obs}}\sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(B_{obs,i} - B_{pred,i}\right)^2}$$

where $B_{obs,i}$ is observed and $B_{pred,i}$ is predicted biomass and i = 1…n.

Limitations of the study

H. salicifolia is a dioecious and biennial plant species and, therefore, only female trees bear fruit and only every second year. Fruit ripening starts in autumn and remain on the branches until the following spring. In this study, only fruiting trees were considered as female, and were, thus, included in the estimation of the biomass model for fruit. Fruits were collected in November during the peak ripening time of the autumn season, and the fruit biomass models, therefore, express the maximum amount of fruit in 2006. *H. salicifolia* is also a deciduous plant species, and the amount of leaves varies from season to season every year. The plant starts producing leaves in late spring; the leaf biomass reaches maximum during the summer. The leaves begin to fall in the autumn, and completely fall off the branches in the winter. Since sample trees were felled in November, the biomass function for leaves expresses the amount of foliage after the annual peak, but before the minimum was reached.

Results and discussion

Results

Basic data

As described above, average moisture and dry matter contents of wood and leaves were estimated for samples of wood discs and leaves. The estimated average moisture contents of wood and leaves were 137.4% (SE 1.5%, n=10) and 186.2 % (SE 0.5%, n=5) of dry weight, respectively. The corresponding average dry matter contents of wood and leaves were 42.1% and 34.9% of the fresh weight respectively. Based

on these values and the fresh weights measured in the field, oven-dry weights of wood and leaves were estimated for each sample tree. The entire set of measurements of different variables is presented in table 1.

Development of models

As expected, the biomass increased with increasing diameter and height. A preliminary examination of scatter plots showing the biomass of wood, fruit, and leaves against diameter and

Table 1. Measurements of biomass components and other variables for 30 individual trees of Seabuckthorn (*H. salicifolia* D. Don.) sampled in Lete VDC, Mustang District, Nepal in November 2006.

SN	Diameter at 30 cm (cm)	Total height (m)	Oven-dry biomass (kg)		Fresh fruit biomass (kg)	Crown diameter (m)	Bark thickness (mm)	No. of growth rings†	Sex‡
			Wood	Leaves					
1	1.4	1.8	0.18	0.03	0	0.9	2	2	U
2	2.5	2.2	0.67	0.06	0	1	2.5	3	U
3	3.4	2.6	0.46	0.12	0	2.5	3	4	U
4	3.5	2.6	0.55	0.14	0.16	2.7	3.2	5	F
5	4.1	3.3	1.27	0.13	0.2	1.4	3.8	5	F
6	4.7	2.7	0.58	0.22	0.31	2.7	4	5	F
7	4.9	3.7	1.73	0.07	0	1.9	4	6	M
8	5.2	3.5	3.58	0.23	0.96	2.1	3.8	5	F
9	6.8	3.5	6.89	0.41	1.24	2.3	3.89	5	F
10	10.0	3.88	10.70	0.63	1.352	1.8	4.5	9	F
11	10.0	4.9	9.14	0.24	0.668	3.55	4	8	F
12	10.8	5.3	14.61	0.33	0.095	4.15	3.5	7	F
13	12.1	8.6	22.32	0.79	0.5	3.85	6	9	F
14	12.5	5.8	21.41	0.58	0	3.8	4.37	10	M
15	16.0	9.3	46.92	1.12	0.46	4.7	7.13	14	F
16	18.8	8.7	58.60	0.13	1.08	5.6	11.5	16	F
17	19.0	6.8	62.92	0.75	3.875	5.1	10	22	F
18	20.8	8.2	71.64	0.75	2.16	5.8	13.75	30	F
19	21.1	7.4	60.98	1.24	0.97	5	7	23	F
20	26.0	9.5	113.38	0.75	3.7	4.4	8	26	F
21	26.3	9.7	141.64	1.36	3.9	5.6	9	30	F
22	26.8	9.8	164.76	1.59	3.412	8.5	14.3	33	F
23	27.5	13.4	170.64	2.50	2.08	6.8	11.5	16	F
24	28.9	8.0	143.93	1.22	10.26	6.75	11	64	F
25	29.0	11.5	148.18	4.06	0	6.55	13.3	60	M
26	34.1	10.5	259.69	3.00	0	7.1	13.5	44	M
27	35.9	11.4	280.77	2.40	5.82	8.85	15.8	51	F
28	36.5	13.4	307.45	4.64	0	8.75	12	41	M
29	40.1	14.0	409.72	5.10	8.51	9.05	13.5	42	F
30	43.2	15.2	528.71	5.49	6.76	9.6	14	38	F

† Number of growth rings was counted 30 cm above ground

‡ Sex: U: Unknown (n=3), M: Male (n=5), F: Female (n=22)

height indicated that relationships between biomass and independent variables were non-linear and characterised by heterogeneous variance. This is illustrated in figure 2.

Crown and Schlaegel, 1988; Kadeba, 1991; Ter-Mikaelian and Korzukhin, 1997; Ingerslev and Hallbacken, 1999 and Claesson *et al.*, 2001). Consequently, for the biomass of wood, fruit, and
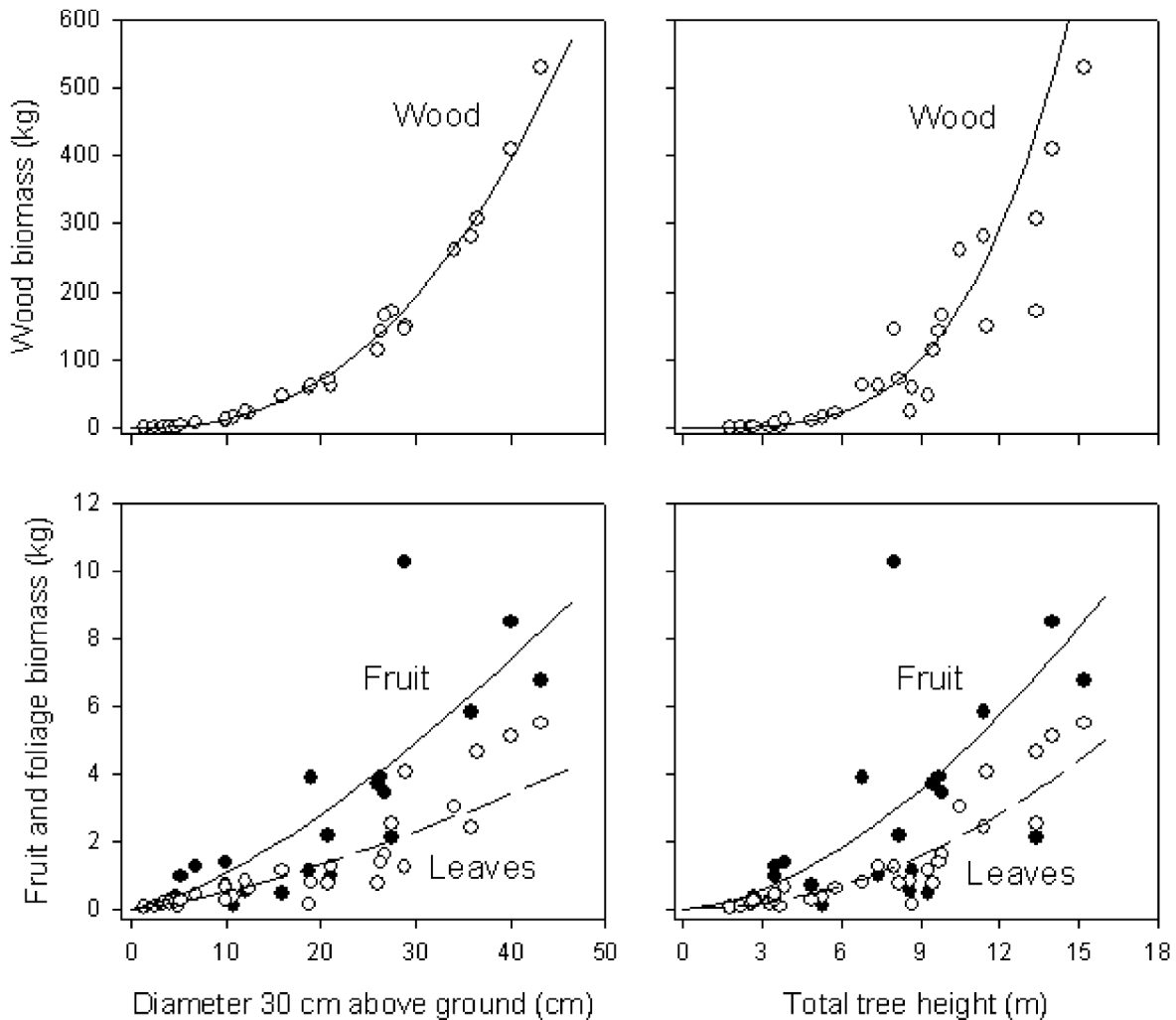

Fig. 2: Biomass of wood, fruit and leaves vs. stem diameter (30 cm above ground) and total tree height

Models were developed using stem diameter 30 cm above ground and total tree height as independent variables. A range of regression models were compared to identify the best possible model for which no deviations from the general assumptions of linear regression were observed and which provided the best possible statistical fit. Among such models, the most attractive relationships between biomass and diameter and/or height was obtained when the logarithm of biomass, ln B, was regressed against the logarithm of diameter, ln D or the product of height and squared diameter, ln D^2H. Such double-logarithmic allometric models are widely used in tree biomass studies as they generally provide reliable results for many types of biomass measures (Whitesell *et al.*, 1988;

leaves, the selected models were:

Model 1:   ln B = a + b ln D, and

Model 2:   ln B = a + b ln D^2H

where ln is the natural logarithm, B is the biomass, D is the diameter at 30 cm above ground, and H is the total height of the tree.

These models are log-transformed power functions, i.e. $Y = aX^b$, but unfortunately, the transformation introduces bias to the estimated biomass (Finney, 1941; Beauchamp and Olson, 1973; Lee, 1982). Sprugel (1983), therefore, proposed a correction factor (CF) which adjusts for the logarithmic bias:

$$CF = \exp\left(\frac{SEE^2}{2}\right)$$

For the final selection between the two models, comparisons were made with respect to the significance of the parameters of the regressions, adj. R^2, SEE, residual distributions (using scatter plots and histograms), cumulative probability plots and practical applicability of the models. For each of the three biomass components, one major outlier was detected and removed (#6 for wood, #12 for fruit and #16 for leaves, see Table 1) before preparing the final models. Parameter estimates of the models are presented in table 2. Residual plots are shown in figure 3.

All models were highly significant (Pr>F < 0.001), and except for the fruit biomass models, all adjusted R^2 values exceeded 0.8. In Model 1, the estimated slope parameter (b) was generally greater than 1, indicating that the biomass of wood, fruit, and leaves all increase progressively with increasing diameter. Furthermore, in agreement with the fact that leaves and fruit are attached to the same structures of the tree, the estimated slopes of the fruit and leaves biomass functions were similar. For wood and leaves, model 2 yielded a slightly better fit (lower SEE, higher adjusted R^2) than model 1, but for fruit, the model fit was not improved by including tree height.

Cross-validation

The cross-validation showed that both models 1 and 2 for wood and fruit produced small percentage bias values (between -2% and +2%), whereas numerically they were slightly larger (about -6%) for leaves (Table 2). In agreement with the patterns observed for SEE and adjusted R^2, the root mean squared error percentages for wood and leaves were slightly lower for model 2 than for model 1, whereas the opposite pattern was observed for fruit. Moreover, in agreement with the wide scatter (relative to biomass) observed for fruit and leaves in figure 2, the root mean squared error percentage was much greater (51–68%) for fruit and leaves than for wood (14–18%).

Table 2: Regression models describing above ground biomass components of *H. salicifolia*. Units of measurement: diameter 30 cm above ground (D): cm, height (H): m, biomass (B): kg.

SN	Variable (biomass) B	Param. estimates (and standard errors)		Adj. R^2	SEE	CF	F Value	Pr>F	Leave-one-out cross-validation errors	
		a	b						PBIAS† %	RMSE‡ %
Model 1: Models with D as independent variable (ln B = a + b ln D)										
1	Wood (dry)	-3.083 (0.149)	2.436 (0.054)	0.986	0.269	1.037	2031.12	<0.001	-1.61	18.17
2	Fruit fresh)	-3.237 (0.512)	1.346 (0.181)	0.730	0.633	1.222	55.19	<0.001	0.18	62.09
3	Leaves (dry)	-4.013 (0.226)	1.403 (0.083)	0.910	0.423	1.093	282.72	<0.001	-6.03	56.70
Model 2: Models with D²H as independent variable (ln B = a + b ln D²H)										
1	Wood (dry)	-3.277 (0.150)	0.924 (0.020)	0.987	0.264	1.036	2104.87	<0.001	0.89	13.68
2	Fruit (fresh)	-3.146 (0.563)	0.485 (0.074)	0.679	0.690	1.269	43.36	<0.001	1.99	68.27
3	Leaves (dry)	-4.121 (0.224)	0.532 (0.031)	0.915	0.409	1.087	303.56	<0.001	-5.57	50.95

Note: Number of observations: n=29 for wood and leaves and n=21 for fruit (one outlier omitted in each case)

† Bias: mean error in per cent of mean biomass
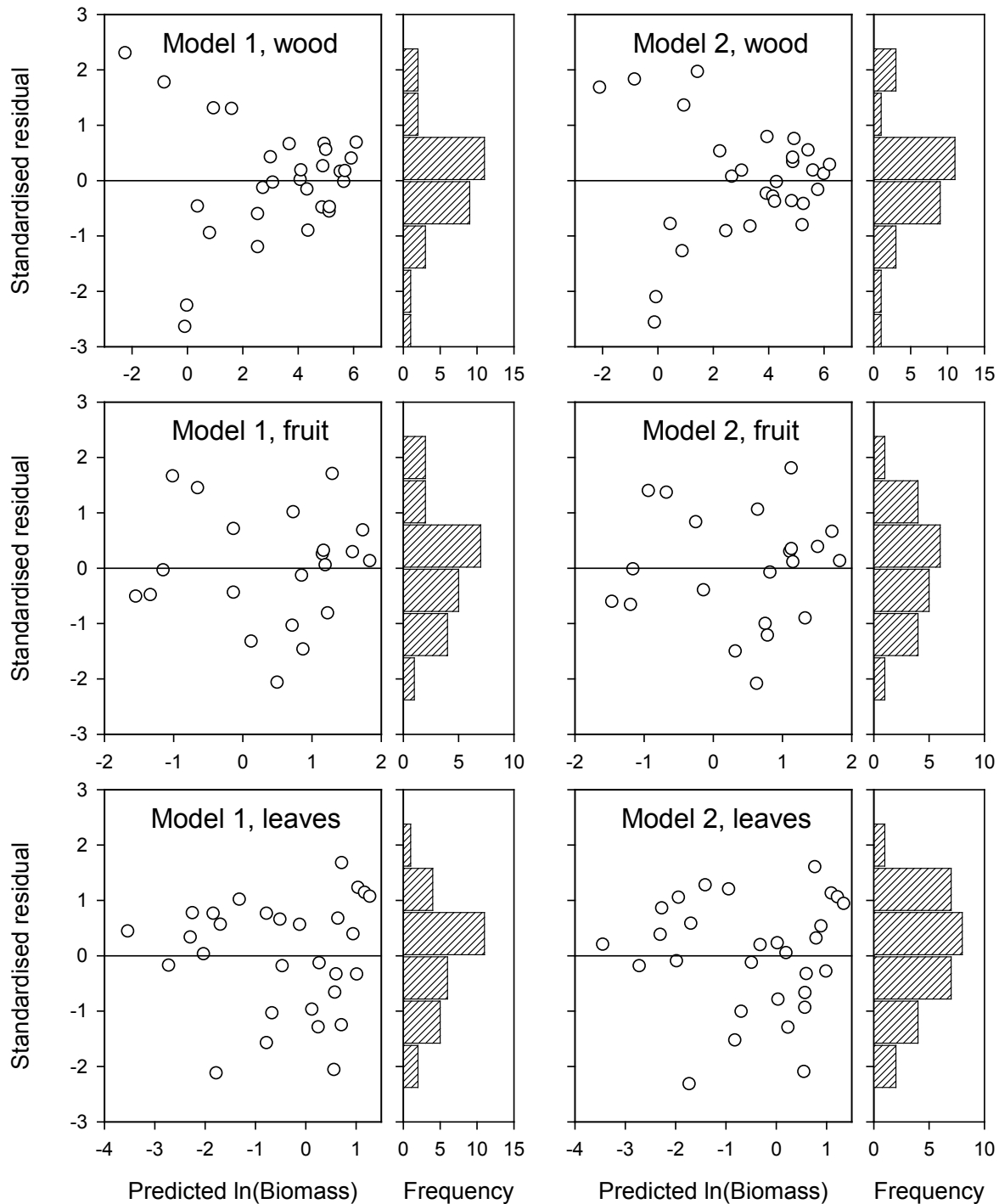
‡ Root mean squared error in per cent of mean biomass

Fig. 3: Standardized residuals for model 1 (left): ln Biomass = a + b ln Diameter; and model 2 (right): ln Biomass = a + b ln Diameter^2 × Height for oven-dry wood (top) and leaves (bottom), and fresh fruit (middle).

Discussion

Suitability of the models

Based on the results in table 2, the allometric model 2, ln B = a + b ln D^{2}H, seems to be better suited for wood and leaves because the adj. R^2 and SEE values are better (higher and lower, respectively) for this model than for the alternative,

ln B = a + b ln D. Conversely, for fruit, the most attractive model is ln B = a + b ln D.

Based on the graphs in figure 3, it appears that for all biomass components, i.e. wood, fruit, and leaves, the standardized residuals of the two alternative models were found to be approximately normally distributed with mean zero. Most standardized

residuals are small, exhibit no clear pattern and only few values exceed ±2. A visual examination and comparison of the residual plots of the two model types did not reveal any major advantages of one over the other. Line fit plots also showed that the predicted biomass do not deviate much from observed values for any of the biomass components (not shown).

Some Seabuckthorn trees in the study area had lost a major proportion of their branches to firewood, berry and fodder collectors. Others were damaged in other ways. When selecting the 30 sample trees, severely damaged or malformed trees were deliberately avoided, and the models presented here, therefore, describe the expected biomass of trees that are intact or almost intact. When applying the models to populations of trees that have lost part of their crowns, a biomass loss (in terms of percentage) assessment should also be done.

Fruiting presumably varies between years and given the fact that the models presented here are based on data gathered within a single year, observations made in other years may deviate markedly from model predictions. Similarly, it should be noted that the amount of leaves in a given tree varies over the season and from year to year, and leaf biomass models based on data collected in a single year; therefore, the models may not produce central estimates of leaf biomass in other years, or at other times or locations.

Validation of the models

Due to the low number of observations, creation of separate calibration and validation datasets was considered inappropriate. Instead, leave-one-out cross-validation was carried out, essentially simulating a situation where the final model was applied to a new observation from the same study site. Since no data were available from outside Lete and Kunjo VDCs or from other years than 2006, it is impossible to state exactly how the models would perform outside this area and year, particularly for fruit and leaves. In agreement with the visual impression (Fig. 2), the cross-validation showed that the validation errors (in per cent) obtained for fruit and leaves varied considerably more than for wood. However, average per centage bias was low for both wood and fruit, but slightly greater for leaves (approx. -6%). Flowering, fruiting, and foliation are sensitive to time of year, and the current physiological

state of the individual fruit is produced only to the extent that resources are available. By contrast, wood biomass is cumulative by nature. Therefore, while the effect of fluctuating growth conditions are smoothened for biomass of wood, the biomass of foliage and particularly fruit vary considerably between individuals of the same size in a given year, as well as between years for a given individual. The relatively poor performance of models for fruit, both in terms of Adj. R^2 and RMSE%, is, therefore, not unexpected.

Applicability of the models

Both models, $\ln B = a + b \ln D$ and $\ln B = a + b \ln D^2H$, are capable of describing the local variation of the biomass of wood, fruit, and leaves. The regression parameters, residual plots and line fit diagrams did not provide any strong arguments for choosing one model over the other. Hence, the following conclusions can be drawn.

For local model application, considering diameter only is a practical solution because including height did not lead to a much better explanation of the variation in biomass. The advantage of a model with diameter as the only independent variable is that it is simple, practical and easy to use (Wang *et al*., 2000; Ter-Mikaelian and Korzukhin, 1997). The biomass table in annex 1 is, therefore, based on models only including diameter. Several researchers have concluded that tree biomass is primarily a function of diameter (Onyekwelu, 2004; Verwijst and Telenius, 1999; Rapp *et al*., 1999; Wang *et al*., 2000; Naidu *et al*., 1998; Ter-Mikaelian and Korzukhin, 1997; Kadeba, 1991). Furthermore, considering the time that would need to be invested in obtaining height measurements in the field, the associated measurement errors, and the fact that the inclusion of height did not significantly improve the performance of the model, the application of diameter alone is easy to justify.

Growth conditions vary from site to site, and at sites that are poorer or drier than those where the trees were sampled, tree height for a given diameter is likely to be lower than in the dataset used for calibration of the biomass models. Forouhbakhch *et al*. (2006) showed that the diameter and height are not only good indicators of the site conditions but are also dependent on other factors such as interspecies competition. Feldpausch *et al*. (2011) stated that the relation between diameter and height varies significantly

depending on geographical region, climate, forest type and structure. Hence, although the available data did not allow us to validate the models in other areas or for other years, it seems likely that among the two model types presented here, the model type that would be least sensitive to site conditions, and may, therefore, be somewhat safer to use at other sites, is Model 2 with the independent variable D^2H. However, before applying the model, local validation should always be carried out.

Conclusion

Based on a sample of 30 *H. salicifolia* trees, a range of allometric biomass models were tested, and two models for each biomass component (wood, fruit, and leaves) were proposed, one for local use and another that, after successful validation, may be suitable within a broader range of conditions (Table 2). The entire dataset presented in table 1 should allow future studies to use the dataset for validation of models based on datasets from other stands with *H. salicifolia*. Moreover, future studies may combine the dataset with their own data to prepare models including variation between sites.

Acknowledgments

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Annex 1. Biomass table for wood (above-ground, dry weight), fruit (fresh weight) and leaves (dry weight) for Seabuckthorn (*H. salicifolia* D. Don.). model 1, cf. Table 2.

	Biomass†				Biomass†		
Diam30 (cm)	Wood dry (kg)	Fruit fresh (kg)	Leaves dry (kg)	Diam30 (cm)	Wood dry (kg)	Fruit fresh (kg)	Leaves dry (kg)
1	*0.048*	*0.048*	*0.020*	26	132.9	3.853	1.911
2	0.257	0.122	0.052	27	145.7	4.053	2.015
3	0.690	0.211	0.092	28	159.2	4.257	2.120
4	1.391	0.310	0.138	29	173.5	4.463	2.227
5	2.396	0.419	0.189	30	188.4	4.671	2.336
6	3.736	0.535	0.244	31	204.1	4.882	2.446
7	5.438	0.659	0.303	32	220.5	5.095	2.557
8	7.529	0.788	0.366	33	237.6	5.310	2.670
9	10.03	0.924	0.431	34	255.5	5.528	2.784
10	12.97	1.065	0.500	35	274.2	5.748	2.900
11	16.35	1.210	0.572	36	293.7	5.970	3.017
12	20.21	1.361	0.646	37	314.0	6.194	3.135
13	24.57	1.516	0.723	38	335.1	6.421	3.254
14	29.43	1.675	0.802	39	357.0	6.649	3.375
15	34.81	1.837	0.883	40	379.7	6.880	3.497
16	40.74	2.004	0.967	41	403.2	7.112	3.620
17	47.22	2.175	1.053	42	427.6	7.347	3.745
18	54.28	2.349	1.141	43	452.8	7.583	3.871
19	61.92	2.526	1.231	44	*478.9*	*7.821*	*3.998*
20	70.16	2.706	1.322	45	*505.8*	*8.062*	*4.126*
21	79.01	2.890	1.416	46	*533.7*	*8.304*	*4.255*
22	88.50	3.077	1.512	47	*562.4*	*8.548*	*4.385*
23	98.62	3.267	1.609	48	*592.0*	*8.793*	*4.517*
24	109.4	3.459	1.708	49	*622.4*	*9.041*	*4.649*
25	120.8	3.654	1.809	50	*653.8*	*9.290*	*4.783*

† Numbers in italics are outside diameter range of the calibration data

Models:
Wood: ln Biomass = -3.083+2.436 ln Diam30, SEE=0.269, Adj. R^2 = 0.986, n=29
Fruit: ln Biomass = -3.237+1.346 ln Diam30, SEE=0.633, Adj. R^2 = 0.730, n=21
Leaves: ln Biomass = -4.013+1.403 ln Diam30, SEE=0.423, Adj. R^2 = 0.910, n=29

Calibration data:
Data collected at Kali Ghandaki and Lete Rivers, Lete and Kunjo VDCs (cf. Fig. 1), November 2006.
Range of diameter 30 cm above ground (Diam30): 1.4 – 43.2 cm
Range of total tree height: 1.8 – 15.2 m
Range of wood biomass (dry weight): 0.179 – 528.7 kg
Range of fruit biomass (fresh weight): 0.095 – 10.26 kg
Range of leaf biomass (dry weight): 0.0342 – 5.4929 kg