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Estimation of wood biomass in the Jubba Valley, southern Somalia, and its application to East African rangelands

IAN DESHMUKH

Associates in Rural Development Inc., PO Box 1397, Burlington, VT 05402, U.S.A.

Summary

A comparative analysis was made of regression equations relating wood biomass (above-ground) of individual trees to their canopy dimensions in semi-arid rangelands of East Africa. 'Best estimates' of wood biomass of bushlands and woodlands in the Jubba Valley of southern Somalia were derived using these relationships. Bushlands carry 1–30 kg ha^{-1} dry weight of wood, woodlands 2–75 kg ha^{-1}. Subdivision of bushland and woodland categories by density of wood canopy gives finer subdivisions of biomass categories. While the statistical precision and accuracy of these estimates cannot be derived, critical comparison with other studies suggests that these wood biomass estimates may be more widely applicable in East Africa. However, a much more site-specific inventory is required to confirm the accuracy of these estimates.

Key words: wood biomass, rangelands, Jubba, East Africa

Résumé

On a fait une analyse comparative des équations de régression reliant la biomasse ligneuse de chaque arbre à la dimension de sa canopée, dans un biotope semi-aride d'Afrique de l'Est. En se servant de ces relations, on a dérivé les 'meilleures estimations' de biomasse de bois en brousse et en forêt dans la Juba Valley, dans le sud de la Somalie. Les milieux buissonneux supportent 1–30 kg/ha de poids sec de bois, les forêts, 2–75 kg/ha. La subdivision des catégories zones buissonneuses et forêts par la densité de canopée boisée donne une analyse plus fine des catégories de biomasse. Puisque la précision statistique et l'exactitude de ces évaluations ne peuvent être dérivées, une comparaison critique avec d'autres études suggère que ces estimations de biomasse ligneuse peuvent être plus largement applicables en Afrique de l'Est. Mais il faut faire un inventaire beaucoup plus spécifique de l'endroit pour confirmer l'exactitude de ces estimations.

Introduction

Biomass of trees and shrubs has rarely been measured accurately in East African rangelands. Yet wood biomass is an essential biotic component of savannas. Wood as fuel, building material and fencing is also a vital part of rural economies throughout Africa. Experience elsewhere suggests that rural planning and development activities require estimates of wood resources if environmental degradation is to be avoided.

Published and unpublished sources were sought of above-ground wood biomass (dry matter) in bushlands and woodlands (*sensu* Pratt & Gwynne, 1977). Estimates for open bushlands (wood canopy cover 20–39%; see Methods) range from 5 t ha^{-1} or less (Lusigi, 1984; Bird, pers. comm.) to more than 30 t ha^{-1} (Western *et al.*, 1981). Because of this wide range of predictions, relationships used to derive them were examined critically. The most appropriate predictions were applied to the vegetation of the Jubba Valley in southern Somalia.

The Jubba River flows due south from the Somalia–Ethiopia border to the Indian Ocean. A detailed description of the area is given by Deshmukh (1989). A 32,000 km^2 study area was defined as the river and its floodplain (approximately 1500 km^2) and surrounding drylands stretching 30 km east and west of the floodplain. The river flows through semi-arid lowlands (elevation is 200 m above m.s.l. at the Ethiopian border). Annual rainfall increases southward from about 300 mm at the border to 600 mm 70 km inland before declining again to 350 mm at the coast. Mean annual temperature is around 30°C.

Vegetation of the floodplain was largely broad-leaved evergreen riverine forest before intensive human occupation. Only 900 ha of this forest remained in 1987 (Deshmukh, 1989). About 50% of the floodplain is cultivated. The remainder is a mixture of deciduous secondary formations classified later in this paper. *Acacia zanzibarica* (S. Moore) Taub. is the most frequent tree in floodplain sites followed by *Thespesia danis* Oliv. and *Terminalia brevipes* Pampan. Outside the floodplain *Acacia–Commiphora* bushlands predominate. *A. horrida* (L.) Willd. is dominant in the north and *A. reficiens* (Vatke) Brenan is dominant to the south.

Objectives of this paper are as follows. First, to determine which relationships predicting above-ground mass of individual trees and shrubs give 'best estimates' appropriate to East African rangelands. Secondly, to present simple methods of field mensuration to which these relationships can be applied. Thirdly, to apply these methods to the Jubba Valley.

Methods

Forest inventory from other studies

Information was sought from other studies in East Africa where destructive sampling of trees and shrubs was carried out to relate dry weight of wood to dimensions of the plants before they were felled. Most studies are of an exploratory nature and none relate specifically to the study area. Details are given in the appropriate Results section.

Field methods for determining vegetation types

A two-stage process was adopted employing ground monitoring sites and sample aerial photographs. Ninety ground monitoring sites were established in the study area. Sites were selected to cover the range of vegetation types identified in a photo-interpretation of the area (AHT, 1984). At each site a 20 × 20 m or 10 × 10 m square was laid out. The smaller plot was used where vegetation was relatively homogeneous or had few larger woody plants. Canopy diameter (mean of two perpendicular horizontal estimates) and height of plants taller than 2 m were measured for all woody plants on each plot. It was assumed that smaller plants (< 2 m tall) contributed negligible wood biomass. Canopy area for each tree and

Table 1. Classification of vegetation types in the Jubba Valley based on structural criteria of wood vegetation

% Woody cover	Canopy <5 m high	Canopy >5 m high
0–2	grassland*	grassland*
2–19	sparse bushland or bushed grassland*	sparse woodland or wooded grassland*
20–39	open bushland	open woodland
40–59	medium bushland	medium woodland
60–79	dense bushland	dense woodland
80+	thicket bushland	forest

*Nature of herb layer determines whether grassland term used; for example, if <2% woody cover, site may be barren land, grassland, forbland or dwarf shrubland depending upon dominant ground cover.

shrub was calculated assuming a circular crown. Total canopy area was related to ground area to give percentage canopy cover at each site. Sites were classified using an enhanced version of the Pratt & Gwynne (1977) rangeland vegetation structure types (Table 1). Cover and height classification is similar to that of Grunblatt, Ottichilo and Sinange (1989), but terms such as 'bushland' and 'woodland' are retained. Such terminology is more familiar for East African rangelands.

To estimate proportions of the study area under each vegetation type, a stratified random sample of 560 vertical aerial photographic monitoring sites was established. These photographs exclude areas of human habitations and farms. Vertical 9 inch (23 cm) square aerial photographs were taken at a scale of 1:1000. Two hundred and ninety-one prints of the floodplains were stratified into eight river stretches north to south and relative to floodplain physiography (see Deshmukh, 1989, for details). Two hundred and sixty-nine prints outside the floodplain were also stratified by river stretch and by east–west co-ordinates. These photographs were analysed to determine woody vegetation cover classes of Table 1 using a dot grid. A 19 cm square grid with one hundred dots in a stratified random pattern was overlain on the centre of each photograph. The number of 'hits' on woody plants was recorded. Woodlands were distinguished from bushlands if crowns of predominate plants were greater than 5 mm (equivalent to 5 m on the ground) in diameter. Data from ground plots indicate that a crown greater than 5 m across normally belongs to a tree 5 m or more tall.

Results

Comparison and evaluation of wood biomass predictions

Twenty regression equations from East Africa relating dimensions of woody plants to dry weight were examined. The eight most pertinent to this study are characterized in Table 2 and Fig. 1. Most relationships refer to total wood mass, two to the smaller amount of wood suitable for charcoal production. Relationships not included fall within those shown in Fig. 1 (additional data of Herlocker, pers. comm., and Epp, Herlocker & Peden, 1982).

To plot equation 7 (Table 2b) in Fig. 1, crown area was converted to crown diameter assuming a circular canopy. Equation 8 (Table 2b) includes height and saw-timber volume in addition to crown diameter. To plot a version of this

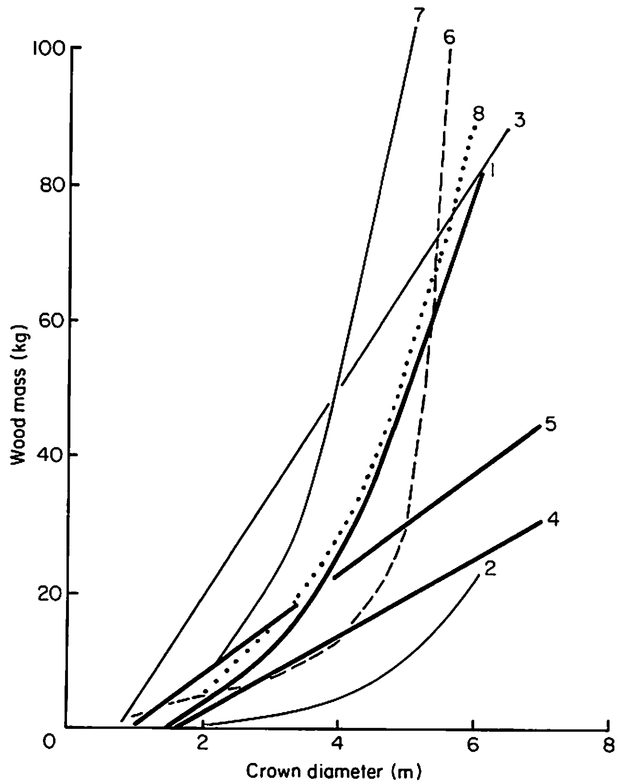

Fig. 1. Relationships between crown diameter and wood mass of trees and shrubs in East Africa. Numbers refer to equations given in Table 2b.

equation, sample trees were taken from Jubba Valley data and their dimensions used in the equation to predict saw-wood volume. Additional categories of wood suitable for charcoal were added according to formulae of Watson & Nimmo (1985). The appropriate line in Fig. 1 relates crown diameter of the Jubba sample trees to dry weight assuming a specific gravity of 0·6 (Synnott, Oxford Forestry Institute, pers. comm.).

Extrapolation of regression predictions to monitoring sites

The selected predictions of wood mass relative to crown diameter for individual plants are heavier lines in Fig. 1. These give 'high', 'medium' and 'low' predictions of wood mass (equations 1, 5 and 4, respectively). Reasons for selection are given in the Discussion. These regression predictions were applied to trees and shrubs in Jubba ground monitoring sites. Summation of individual plants gives biomass per unit area in each vegetation type (Table 3).

To extrapolate results to the Jubba Valley as a whole, the sample aerial photographs were used. The proportion of photographs falling into each vegetation type was assumed to equal the relative frequency of each vegetation type in the study area as shown in Fig. 2a. Proportion of wood biomass in each vegetation type is given in Fig. 2b. These wood biomass data are calculated as median 'best estimates' (Table 4) described in the Discussion. Also shown in Fig. 2 is a comparison of the Jubba floodplain with adjacent non-floodplain lands.

Table 2. Summary of selected regression relationships between tree and shrub dimensions in East Africa and their dry weight of wood above-ground. (a) Descriptors and comments

(a)

Species	Location	Units	Source
(1) *Acacia bussei*	Bay Region, S. Somalia	crown diameter (m) mass (kg); all wood	Bird, 1988
(2) *A. bussei*	Bay Region, S. Somalia	crown diameter (m) mass (kg); charcoal	Bird, 1988
(3) *Balanites* sp.	Marsabit Dist., Kenya	crown diameter (m) mass (kg); all wood	Herlocker, pers. comm.
(4) *Acacia* spp.	Marsabit Dist., Kenya	crown diameter (m) mass (kg); all wood	Herlocker, pers. comm.
(5) *Acacia* & *Commiphora* spp.	Marsabit and Kajiado Dist., Kenya	crown diameter (m) mass (kg); all wood	Epp *et al.* (1982)
(6) *Acacia reficiens*	Marsabit Dist., Kenya	crown diameter (m) mass (kg); all wood	Lamprey, (1986)
(7) 22 spp.	Amboseli NP, Kenya	crown area (m^2) mass (t); all wood	Western *et al.* (1981)
(8) *Isoberlinia doka*	Southern Sudan	crown diameter ($m^{1\cdot68}$) tree height (m) timber volume (m^3); saw wood	Watson & Nimo (1985)

(b) Regression statistics (dia. = crown diameter; na = not available)

Number (from a)	Equation	*n*	r^2
(1)	ln mass = 3·0225 (ln dia.) − 1·0055	49	na
(2)	ln mass = 4·0527 (ln dia.) − 4·1640	49	0·889
(3)	mass = 16·08 (dia.) − 13·85	10	0·55
(4)	mass = 5·54 (dia.) − 8·75	30	0·61
(5)	mass = 7·49 (dia.) − 7·76	83	0·49
(6)	na	21	0·69
(7)	log mass = 1·53 (log area) − 0·04	22	0·93
(8)	volume = height × 0·004 × $\text{dia.}^{1\cdot68}$	38	0·88

Discussion

Selection of 'best estimate' predictions

The work of Bird (1988) and his colleagues is the most accurate published forest inventory carried out in semi-arid bushlands of eastern Africa. Great care was taken over sample selection and treatment, statistical procedures and validation of regression predictions. Their conclusion, that seventy-five trees per species should be felled to establish and validate sound regression relationships, indicates that other relationships reviewed in this paper must be viewed with caution. The largest number of plants of any species in other studies in twenty-eight *A. drepanolobium* measured by Epp *et al.* (1982).

Table 3. Biomass (t ha^{-1}) estimates of vegetation types derived from application of high, medium and low regression equations (see text and Fig. 1) to ground monitoring sites. N = number of sites*; SEM = standard error of mean, those in parentheses are dubious since $N < 5$

Vegetation type	N	High Mean	High SEM	Medium Mean	Medium SEM	Low Mean	Low SEM
Forest	10	225·9	67·7	34·5	4·2	22·4	2·6
Dense woodland	2	74·8	(20·6)	12·1	(1·6)	8·3	(1·1)
Open woodland	2	12·7	(2·8)	3·0	(0·6)	2·0	(0·4)
Wooded grassland	2	2·6	(1·1)	2·0	(0·6)	1·0	(0·6)
Thicket bushland	14	55·9	7·5	33·2	4·6	18·8	2·2
Dense bushland	6	16·1	1·7	11·5	0·5	6·9	0·3
Medium bushland	11	13·5	1·5	6·7	0·3	4·1	0·2
Open bushland	15	7·7	0·8	4·6	0·4	2·6	0·2
Sparse bushland	4	3·7	(0·5)	2·6	(0·2)	1·6	(0·1)
Bushed grassland	10	2·7	0·8	2·2	0·4	1·3	0·3

*14 of the 90 sites had negligible woody vegetation.

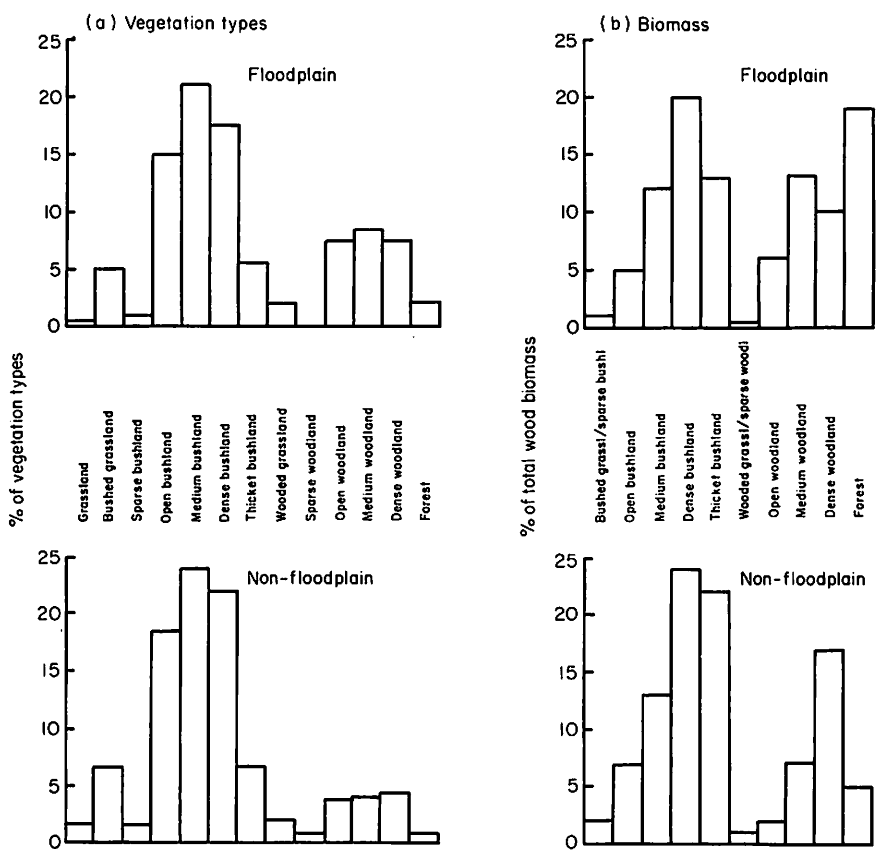

Fig. 2. Proportional distribution of vegetation types (a), and wood biomass (b) in the Jubba Valley floodplain and surrounding rangelands.

Table 4. Suggested 'best estimates' of wood biomass ($t\ ha^{-1}$) in East African rangeland vegetation types

Vegetation type	Median estimate	Range of best estimates
Forest	130	35–225
Dense woodland	45	12–75
Medium woodland	20*	
Open woodland	8	3–13
Sparse woodland & wooded grassland	3	2–3
Ticket bushland	26	19–33
Dense bushland	10	7–12
Medium bushland	6	4–7
Open bushland	4	3–5
Sparse bushland & bushed grassland	2	1–2

*No ground monitoring site; median estimate is interpolated.

Two features of Bird's (1988) work are especially relevant to this paper. First, *A. bussei* has a substantially higher specific gravity (*c.* 1·0) than other *Acacia* species and other common rangeland species (Bird, pers. comm.). Thus, an *A. bussei* tree of a particular crown diameter probably weighs more than other species of similar crown diameter.

Second, although it is well established that relationships between linear dimensions and mass of trees are allometric (as in equations 1, 2, 6, 7, and 8, Table 2), arithmetic plots are suitable for smaller trees and shrubs typical of most bushlands. This point is illustrated by the data of Herlocker (unpubl.) and Epp *et al.* (1982) which refer to trees with canopies up to 5 m in diameter. Smaller trees and shrubs in Bird's (1988) sample have similar characteristics. Up to about 10 m in diameter, arithmetic plots are as valid as logarithmic ones. Thus for bushlands, arithmetic relationships are suitable. For woodlands and forests, allometric relationships are preferable when large trees are common.

In view of the preceding discussion, it is likely that equations 7 and 8 (Table 2) predict wood mass too high for common rangeland types. Equation 8 gives especially high estimates since it refers to wood suitable for charcoal (compare with equation 2 for *A. bussei* charcoal). Equation 6 produces similar predictions to equations 1–5 for smaller trees and shrubs, but high predictions for large trees. Biomass estimates for larger trees may be inaccurate since only two trees greater than 5 m canopy were included in this sample (Lamprey, 1986).

Assessment of methods and statistical procedures adopted suggests that the 'high', 'medium' and 'low' estimates chosen in the Results section provide better estimates of wood mass than the other equations. Equation 1 is likely to overestimate since it refers to the denser wood of *A. bussei*; however, its allometric nature is appropriate for larger plants. Equation 5 predicts suitable 'medium' estimates since it is derived from a mixture of *Acacia* and *Commiphora* species common in many semi-arid regions of East Africa. Equation 4, is the lowest relationships predicting total wood mass, but is similar to some of the *Acacia* spp. relationships of Epp *et al.* (1982). This equation was chosen since acacias dominate many Jubba Valley and East Africa rangelands.

Extrapolatian to the field

To obtain a single 'best estimate' of wood biomass above-ground for each vegetation type, median values in Table 4 were used. For plants taller than 5 m, the median is that between the mean 'high' and 'medium' estimates of Table 3. As stated above, allometric relationship ('high'; equation 1, Fig. 1) are more important for larger plants. However, equation 1 will overestimate for most tree species because of the high specific gravity of *A. bussei*. Thus, use of equation 5 moderates this overestimate and reflects the adequacy of arithmetic relationships for trees up to 10 m in the *A. bussei* data. Mass of smaller trees and shrubs (<5 m tall) is predicted as the median of 'medium' and 'low' estimates in Table 3 since these relationships reflect the importance of *Acacia–Commiphora* (equation 5) bushlands with a predominance of *Acacia* spp. (equation 4) in rangelands of East Africa.

Biomass estimates in Table 4 are regarded as adequate generalizations for different vegetation types where no site-specific inventory has been performed. However, their mode of computation means that no estimates of accuracy or precision are available. Thus caution must be used in applying this data more widely.

Comparison with other studies reinforces the reasonable nature of estimates in Table 4. For Marsabit District, Kenya, Lusigi (1984) quotes 3·5–6·5 t ha^{-1} wood biomass for open bushlands and 6·5 t ha^{-1} for an open woodland with 6% canopy cover. In southern Zaire, physionomic equivalents of forests carried wood biomass of 150–320 t ha^{-1} and open woodland 10 t ha^{-1} (Unesco, 1978). A review of all relevant data and its projection to ecosystems throughout southern Africa ranks woody biomass as follows (t ha^{-1}): coastal forest, 89; rainforest/woodland transition/moist miombo, 71; drier woodlands, 9–75; grasslands and bushlands, 0–23 (Millington & Townsend, 1989).

Western *et al.* (1981) and Watson & Nimmo (1985) provide biomass estimates for rangelands of Kenya and southern Somalia, respectively. Their estimates are much higher than those in Table 4, because they used their own equations (7 and 8, respectively; Table 2, Fig. 1). However, Bird (1988 and pers. comm.) questions their methods and results from the perspective of his more detailed study. His biomass estimate of 5 t ha^{-1} for open bushland is compatible with the results in Table 4.

Relevance to the Jubba Valley

Figure 2a shows remarkably similar overall vegetation structure within and outside the Jubba floodplain despite large differences in original vegetation. Predominance of floodplain bushlands is a recent anthropogenic effect. In contrast, bushlands outside the floodplain results from millenia of interactions between climate, soils, vegetation, herbivorous mammals and low density human occupation.

Figure 2b illustrates the proportional distribution of wood biomass relative to vegetation types. Forest remnants still contribute significantly in the floodplain, but secondary bushlands constitute 50% of total biomass. Outside the floodplain bushlands comprise almost 70% of wood biomass. Thicket biomass is particularly important compared to the area it covers (Fig. 2). Overall, mean wood biomass (excluding current cultivation) is $10{\cdot}4\,t\,ha^{-1}$ in the floodplain and $9{\cdot}8\,t\,ha^{-1}$ outside (Deshmukh, 1989).

Wider applications

Table 4 presents generalized estimates of above-ground wood biomass in rangelands of East Africa. Such information is of interest to savanna ecology in general and to forestry inventory and management in particular. For reasons discussed, these estimates are thought to be reasonable approximations. At present it is not possible to assess accuracy or precision of these estimates. Caution is needed in using these predictions until site-specific data similar to that of Bird (1988) are more widely available. However, until equivalent data exist for many species at many sites, broadly applicable biomass estimates are of great potential value.

Estimates from this study are internally consistent (Tables 3 and 4) and are in agreement with other more comprehensive studies. Vegetation categories in Table 1 are easy to determine approximately by an experienced eye, or more objectively from ground measurements or aerial photographs. The author has erred on the side of conservatism in deriving best estimates. Given the precarious state of forest resources over much of Africa, it is prudent to underestimate rather than overestimate wood availability.

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