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SIZE-PHYTOMASS ALLOMETRY IN SOME HALOPHYTIC OR SALT TOLERANT SPECIES OF KARACHI COAST, PAKISTAN

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ABSTRACT

Allometric equations were developed to estimate aboveground dry phytomass (AGDP) in some coastal herbaceous halophytic species of Karachi viz. *Atriplex griffithii* Moq. *Cressa cretica* L., *Phragmites karka (*Retz.*)* Trin ex Steud., *Limonium stocksii (Boiss.) O. Ktze,* and *Urochondra setulosa* (Trin.) C.E. Hubb. Best fit least square regression models were developed using height and crown diameter to estimate AGDP of individual plants. In case of *P. karka*, culm height, culm basal diameter or culm volume were employed to estimate phytomass of an individual culm.

The crown diameter was generally better predictor of phytomass than height. The inclusion of parameter of height as an independent variable along with crown diameter could not improve the estimation of phytomass significantly except in case of *P. karka* where substantial improvement in estimation of culm mass was recorded (24.3%) when height was included along with culm diameter in a natural log-log model of multiple correlation and regression. Quadratic (curvilinear) relationships between phytomass and crown diameter were significant in all plants. The quadratic equations were more or less as equally statistically efficient as multiple regression models in estimating phytomass in *Atriplex*, *Cressa* and *Limonium*. Culm phytomass in *Phragmites* and AGDP in *Urochondra setulosa* were, however, better estimated by multiple regression models with natural log-log transformed variables.

Key Words: Size-phytomass allometry, herbaceous species, coastal halophytes of Pakistan.

INTRODUCTION

The application of destructive technique for estimating biomass is expensive and not generally appreciated for its negative effects on biota. In non-destructive procedures for estimating standing biomass and its change over time, regression analysis relating biomass to various structural dimensions of plants provide a viable alternative (Martin *et. al*, 1982). Although many regression equations have been worked out by many authors with trees (Roussopoulos and Loomis (1979), Crow (1983), Monk *et. al.* (1970), Pastor *et al.*, (1984), Schreuder and Swank (1971), Swank and Schreuder (1974), Whittaker and Woodwell (1968); Young (1976), Khan *et. al* .(1983), Fownes and Harrington (1991), Mette *et. al.* (2003), Niklas *et. al.*, (2003), Fentu (2005), Pokorný and Tomášková (2007), Litton and Kaufman. (2008), Ghazehei *et. al* (2009), Tanaka *et. al.* (2009), only few published reports are available for herbaceous plants (Elliot and Clinton, 1993). Such studies are useful in predicting carrying capacities of various vegetation types based on browse estimate (Grigel and Moddy, 1980; Ohmann *et. al.*, 1981), in determining maximum level of production of herbs, shrubs and trees (Martin, 1979) in an ecosystem, and in estimating the fuel wood availability (Roussopoulos and Loomis, 1979; Hierro, *et. al*, 2000; Zianis and Mencuccini, 2003; Ghazehei *et. al.*, 2009; Tanaka *et. al.*, 2009). The present investigation was undertaken to develop relevant equations with respect to size-biomass relationship in case of some halophytic or salt tolerant herbaceous species of Pakistan coast viz. *Atriplex griffithii* Moq. *Cressa cretica* L., *Limonium stocksii* (Boiss.) O. Ktze, and *Urochondra setulosa* (Trin.) C.E. Hubb. and a tree grass, *Phragmites karka* (Retz.) Trin ex Steud. as a preliminary to the so imperative but the virgin area of investigations in Pakistan.

MATERIALS AND METHODS

The aim of our studies was to predict the biomass of individual plant from easily measured variables such as plant height and/or canopy diameter. For parameterization, a sizeable number of plants of wide ranges of sizes (Table 1) of selected species from their respective populations around Karachi were randomly harvested at the ground level and prior to their harvest their heights and crown diameters were measured. All the sites were differentially salinity-affected, mostly sandy and basic in reaction. Crown diameters were measured by taking two perpendicular measurements through the centre of each plant. The plant material was dried at $70^{o}C$ for 72 hours and then weighed. *Phragmitis karka* is a perennial reed with long creeping rhizomes and culms. Culms of this species were randomly selected and measured for their height and culm diameter at the base. The volume of the erect culm was determined as conic area: $\pi r^2 h/3$, where r, the radius of the culm at the base and h, the height of the culm including panicle (if any). Several statistical models were tested to predict aboveground biomass of the plant. The selection of the best regression model was based on examining p value and comparison of the coefficients of determination (R^2), values of F and relative standard errors (Elliot and Clinton, 1993).

RESULTS AND DISCUSSION

The plants of wide ranges of sizes of the selected species were included in the sampling for parameterization (Table 1). The least square methods of correlation and regression were applied to the raw data of aboveground phytomass of various species (untransformed) as dependent parameter and their height and crown diameter values as independent parameters (untransformed). Such equations were although statistically significant but suffered from usually low values of adjusted R^2, and high values of Standard errors of regression (Table 2 - 6).

Table 1. Averages and ranges of morphometric parameters of plants harvested and soil characteristics of their sites.

Statistics	*Atriplex griffithii* (N= 40)	*Cressa cretica* (N= 40)	*Phragmites karka** (N = 75)	*Limonium stocksii* (N = 40)	*Urochondra setulosa* (N = 25)
PLANT / CULM HEIGHT (cm)					
Mean	9.53 ± 0.82	7.27 ± 0.68	150.91± 8.60*	12.63 ± 0.99	29.97 ± 2.88
Range	2.0 – 17.0	1.5 – 15.3	16 -320 *	2.5 – 24.0	5.0 – 67.0
CV (%)	42.99	59.20	49.34 *	49.95	47.94
CROWN / CULM DIAMETER (cm)					
Mean	19.953 ± 6.31	8.426 ± 1.45	0.67± .043*	23.21 ± 2.80	21.62 ± 3.35
Range	1.5 - 52.5	0.50-25.0	0.24 – 1.22 *	1.10 - 63.5	1.0 - 63.0
CV (%)	157.23	78.43	55.18 *	76.30	77.52
SHOOT / CULM BIOMASS ($g.plant^{-1}$ OR $g.culm^{-1}$)					
Mean	21.142 ± .86	4.225 ± 0.87	14.75 ± 1.75*	49.44 ± 11.78	142.78 ± 41.31
Range	0.12 – 135.5	0.0232– 21.35	0.30 -62.85 *	0.12-267.2	0.12 – 803.3
CV (%)	66.42	132.79	102.65 *	141.73	144.68
SOIL CHARACTERISTICS					
Texture	Sandy	Loam – Silt loam	Sandy	Sandy loam	Sandy
ECe ($dS.m^{-1}$)	7.35	12.20	35.20	11.20	32.9
pH	7.50	7.40	8.00	7.80	8.15

*, data on culms of *P. karka*. Figures in parenthesis represent the sample size.

Table 2.Correlation and regression analyses between biomass (B, g per plant) and morphometric parameters such as height (H, cm), and crown diameter (CD, cm) of *Atriplex griffithii in* coastal sand bars of Hawkes Bay, Karachi.

Parameters (Y / X)	a	b	r^2	Adj. r^2	F	p	SE
Y = a + bX ± SE (N= 40)							
B / H	- 29.025 t = 3.195 p < 0.003	5.3138 t = 6.05 p < 0.001	0.4909	0.4275	36.63	0.001	22.451
B / CD	- 16.394 t= 4.171 p< 0.001	1.9228 t = 11.882 p < 0.001	0.7881	0.7826	141.352	0.001	14.483
B / loge H	- 56.731 t = 3.289 p< 0.002	36.562 t = 4.67 p < 0.001	0.3643	0.3476	21.776	0.001	25.09
B/loge CD	- 31.620 t = 3.097 p< 0.004	21.457 T = 5.593 p < 0.001	0.4516	0.4371	31.29	0.001	23.301
log B/ H	- 1.935 t = 3.980 p< 0.001	0.3875 t= 8.242 p < 0.001	0.6412	0.6319	67.925	0.001	1.203
Loge B/ CD	- 0.79783 t= 4.149 p < 0.001	0.12930 t= 16.334 p < 0.001	0.8753	0,8720	266.81	0.001	0.7089
Loge B / loge H	-4.827 t = 5.766 p < 0.001	3.0733 t = 8.081 p < 0.001	0.6322	0.6225	65.31	0.001	1.218
Loge B / loge CD	**- 3.1336 t = 14.17 p< 0.001**	**1.880 t = 23.713 p < 0.001**	**0.9367**	**0.9304**	**562.312**	**0.001**	**0.5051**

$Y = a + b_1 X_1 + b_2 X_2 \pm SE$								
Parameters	a	b_1	b_2	r^2	Adj. r^2	F	p	SE
B / H & CD	-17.204 t=2.793 p< 0.001	0.15787 t=0.1722 p < 0.864	1.8876 t=7.2099 p < 0.001	0.7883	0.7769	68.89	0.001	14.671
B /loge H & loge CD	- 46.616 t= 2.848 p< 0.001	13.116 t=1.168 p < 0.250	15.421 t=2.733 p< 0.010	0.4711	0.4425	16.475	0.001	23.191
loge B / loge H & loge CD	**- 3.7236 t = 10.96 p < 0.001**	**0.51604 t= 2.22 p < 0.033**	**1.6819 t= 14.4 p< 0.001**	**0.9441**	**0.9411**	**312.55**	**0.001**	**0.4809**

Note: Given in bold are the best fit equations.

Table 3. Correlation and regression analyses between biomass (B, g per plant) and morphometric parameters such as height (H, cm), and crown diameter (CD, cm) of *Cressa cretica* in coastal sandy saline plain of Korangi, Karachi.

Parameters (Y / X)	a	b	r^2	Adj. r^2	F	P	SE
$Y = a + bX \pm SE$							
B / H	-3.40 t= -3.20 p < 003	1.048 t = 8.31 P <0.001	0.645	0.636	69.04	0.001	3.389
B / CD	-2.506 t = -4.97 p< 0.001	0.786 t = 16.85 P < 0.001	0.882	0.879	283.9	0.001	1.954
B / loge H	-5.598 t = -3.293 p < 0.001	5.558 t = 6.221 p < 0.001	0.505	0.492	38.70	0.001	4.000
B/loge CD	-2.227 t = -1.925 p < 0.001	3.787 t = 6.576 P < 0.001	0.530	0.520	43.42	0.001	3.891
log B/ H	-3.382 t = -11.79 p < 0.001	0.467 t = 13.70 p < 0.001	0.832	0.827	187.66	0.001	0.916
Loge B/ CD	-2.517 t= - 10.04 p < 0.001	0.300 t = 12.75 p < 0.001	0.811	0.806	162.57	.001	0.971
Loge B / loge H	-3.171 t = -18.62 p < 0.001	1.976 t= 24.85 p < 0.001	0.914	0.912	404.1	0.001	0.6542
Loge B / loge CD	**-3.352 t = -20.98 p < 0.001**	**1.976 t = 24.85 p < 0.001**	**0.942**	**0.941**	**617.7**	**0.001**	**0.537**

$Y = a + b_1 X_1 + b_2 X_2 \pm SE$								
Parameters	a	b_1	b_2	r^2	Adj. r^2	F	P	SE
B / H & CD	-1.262 t = 2.17 p< 0.001	-0.565 t = 3.36 p < 0.001	1.137 t= 10.40 p< 0.001	0.910	0.905	186.12	0.001	1.733
B /loge H & loge CD	-2.833 t = -1.14 p < 0.261	0.891 t = 0.287 p < 0.784	3.219 t = 1.51 p < 0.140	.533	0.508	21.13	0.001	3.939
loge B / loge H & loge CD	**-3.977 t=-12.32 p< 0.001**	**0.919 t= 2.20 p < 0.001**	**1.389 t = 5.00 p< 0.001**	**0.949**	**0.946**	**342.34**	**0.001**	**0.512**

Note: Given in bold are the best fit equations.

Table 4.Correlation and regression analyses between biomass (B, g per plant) and morphometric parameters such as height (H, cm), and crown diameter (CD, cm) of *Limonium stocksii* in coastal halo-xeric plains of Hawkes Bay, Karachi.

Parameters (Y / X)	a	b	r^2	Adj. r^2	F	P	SE
Y = a + bX ± SE							
B / H	- 60. 323 t=3.82 p < 0.001	8.689 t = 7.75 p < 0.001	0.6123	0.6021	60.01	0.001	44.20
B / CD	- 34.968 t = 4.76 p < 0.001	3.637 t = 14.39 p< 0.001	0.8450	.8409	207.2	0.001	27.94
B / loge H	-138.63 t= 3.99 P = 0.001	78.791 t = 5.75 P < 0.001	0.4498	0.4354	31.07	0.001	52.64
B/loge CD	-64.251 t = 2.92 p < 006	41.942 t = 5.59 p < 0.001	0.4511	0.4366	31.23	0.001	52.58
loge B/ H	- 1.609 t = 4.43 p < 0.001	0.3219 t = 12.49 p < 0.001	0.8042	0.7999	156.05	0.001	1.1065
Loge B/ CD	- 0.1833 t = 0.652 p < 0.518	0.1137 t = 11.94 p < 0.001	0.7898	0.7842	142.76	0.001	1.0522
Loge B / loge H	- 6.1044 t = 12.272 p < 0.001	3.5874 t = 17.78 p < 0.001	0.8922	0.8893	314.37	0.001	0.7536
Loge B / loge CD	**- 0.2.858 t = 12.53 p< 0.001**	**1.9615 t = 25.18 p < 0.001**	**0.9535**	**0.9420**	**634.05**	**0.001**	**0.5457**

$Y = a + b_1 X_1 + b_2 X_2 \pm SE$								
Parameters	a	b_1	b_2	r^2	Adj. r^2	F	P	SE
B / H & CD	14.602 t = 1.344 P < 0.190	- 4.0214 t = 2.428 P < 0.02	4.948 t= 2.428 p < .001	0.8663	0.6491	119.80	0.001	26.301
B /loge H & loge CD	-105.325 t=2.44 P < 0.035	39.774 t = 0.96 P < 0.34	22.077 t = 1.00 P < 0.32	0.4644	0.4355	16.05	NS	52.64
loge B / loge H & loge CD	**- 3.924 t = 8.45 p< 0.001**	**1.0323 t = 2.580 p < 0.001**	**1.4760 t = 6.80 p< .001**	**0.9520**	**0.9445**	**367.69**	**0.001**	**0.5090**

Note: Given in bold are the best fit equations.

Table 5.Correlation and regression analyses between biomass (B, g per plant) and morphometric parameters such as height (H, cm), crown diameter (CD, cm) and culm volume (Cvol, cm^3) of *Phragmites karka* in a sub-coastal salt marsh of Karachi.

Parameters (Y / X)	a	b	r^2	Adj. r^2	F	P	SE
Y = a + bX ± SE							
B / culm Height (H)	-12.291 t =-6.50 p < 0.001	0.179 t = 15.93 p < 0.001	0.777	0.774	253.8	0.001	7.207
B / Culm diameter (CD)	-9.221 t = -3.16 p < 0.001	35.695 t = 9.02 p< 0.001	0.527	0.520	81.27	0.001	10.488
B / Culm Volume (Cvol)	2.686 t = 2.56 p < 0.001	0.444 t = 17.23 p < 0.001	0.803	0.800	296.84	0.001	6.774
B / loge H	-73.321 t = -7.62 p < 0.001	18.106 t = 9.23 p < 0.001	0.538	0.532	85.17	0.001	10.358
B/ loge CD	25.609 t = 13.93 p < 0.001	21.210 t =8.18 p < 0.001	0.478	0.471	66.91	0.001	11.013
B/ loge Cvol	-5.115 t = -2.29 p < 0.001	7.945 t = 10.28 p < 0.001	0.591	0.586	105.66	0.001	9.746
log B/ H	-0.209 t = -1.56 p < 0.124	0.01519 t = 18.95 p < 0.001	.831	0.829	359.24	0.001	0.5135
Loge B/ CD	3.148 t = 26.88 P < 0.001	2.080 t = 12.59 p < 0.001	0.685	0.680	158.42	0.001	0.7018
Loge B/ Cvol	1.216 t = 10.15 p < 0.001	0.03189 t = 10.85 p < 0.001	0.617	0.612	117.68	0.001	0.7731
Loge B / loge H	-6.964 t = -15.29 p < 0.001	1.860 t = 20.03 p < 0.001	0.846	0.844	401.01	0.001	0.4903
Loge B / loge CD	3.148 t = 26.88 p < 0.001	2.0080 t = 12.59 p < 0.001	0.685	0.680	157.42	0.001	0.7018
Loge B/ loge Cvol	0.0961 t = 0.972 p < .334	0.795 t = 23.24 p< 0.001	0.881	0.879	540.26	0.001	0.4311

Table Continued

Table 5 … Continued.

$Y = a + b_1 X_1 + b_2 X_2 \pm SE$								
Parameters	a	b_1	b_2	r^2	Adj. r^2	F	P	SE
B / H & CD	-14.508 t = -7.23 < 0.001	0.150 t = 9.75 p < 0.001	9.771 t = 2.62 p < 0.001	0.796	0.790	140.49	0.001	6.934
B / H & Cvol	8.362 T = 3.42 p< 0.001	-13.17 T = -2.55 p< 0.001	0.560 T = 10.78 p < 0.001	0.819	0.814	162.89	0.001	6.532
B / CD & Cvol	-5.596 t = -2.97 p< 0.001	0.0876 t = 5.02 p< 0.001	0.262 t=6.16 p< 0.001	0.854	0.850	210.15	0.001	5.871
B /loge H & loge CD	-38.45 t=-2.94 p< 0.001	12.105 t = 4.93 p< 0.001	11.080 t =3.63 p< 0.001	0.610	0.599	56.27	0.001	9.589
B / loge H & loge Cvol	-31.171 t = -2.12 p< 0.038	6.590 t =1.79 P < 0.078	5.546 t = 3.60 P < 0.001	0.609	0.598	56.03	0.001	9.602
B / loge CD & loge C vol	-20.935 t = -2.15 p< 0.035	-12.061 t = -1.67 p < 0.100	11.803 t = 4.85 p < 0.001	0.607	0.596	55.51	0.001	9.629
loge B / loge H & loge CD	**-3.953 t=-8.41 p<0.001**	**1.342 t= 15.23 p< 0.001**	**0.957 t=8.74 p< 0.001**	**0.925**	**.923**	**445.56**	**0.001**	**0.344**
Loge B / loge H & Loge Cvol	**-3.302 t=-6.25 p< 0.001**	**0.859 t=6.51 p< 0.001**	**0.482 t=8.71 p< 0.001**	**0.925**	**0.923**	**444.31**	**0.001**	**0.344**
Loge B / Loge CD & Loge Cvol	**-2.044 t=-6.25 p< 0.001**	**-1.632 t=-6.20 p< 0.001**	**1.317 t=14.86 p< 0.001**	**0.922**	**0.920**	**428.07**	**0.001**	**0.350**

Note: Given in bold are the best fit equations.

In our studies, a natural log-log model multiple regression generally gave the best fit equation between size measurements and total aboveground phytomass of individual plant. The values of adjusted R^2 were generally higher (≥ 0.92) (Table 2 -6). These results are similar to other studies (Brown, 1976; Ohmann *et.al.*, 1976; Murray and Jacobson, 1982; Rittenhouse and Sneva, 1977; Bryant and Kothmann, 1979, Hughes *et.al.*, 1987; Pereira *et.al.*, 1995; Heirro *et.al.*, 2000; Busuki *et.al.*, 2009). The inclusion of parameter of height as an independent variable along with crown diameter could not improve the estimation of phytomass in any substantial magnitude (*Atriplex*: 1.07%; *Cressa*: 0.5%; *Limonium*: 0.25%;l *Urochondra*: 0.2%) except in case of *P. karka* where substantial improvement in estimation of culm mass was recorded (24.3%) when height was included along with culm basal diameter in a natural log-log model of multiple correlation and regression. Fownes and Harrington (1991) have also reported improvement in accounting for variation in biomass due to inclusion of height in addition to stem diameter to be relatively modest.

We found that crown diameter was better predictor of phytomass in natural log-log model of regression and also in the quadratic relationship to the aboveground dry phytomass (AGDP). Amongst various morphological plant parameters in trees, DBH has been found to be better predictor of aboveground organ mass of Norway spruce than height (Pokorný and Tomášková, 2007). DBH is also reported to provide better estimates of aboveground biomass in *Acacia abyssinica*, *A. seyal*, *A. tortilis*, *Eucalyptus globulus*, *E. grandis* and *E. saligna* (Fentu, 2005). Tanaka *et. al*. (2009) also reported better allometric relations for aboveground biomass with DBH in logged-over tropical rainforests in Sarawak, Malaysia. DBH was reported as single successful predictor for range of prediction values of total aboveground biomass closer to lower and upper limits of the observed mean in *Dipterocarpus*, *Hopea*, P*alaquinum* and *Shorea of Dipterocap* forests in east Kalimantan, Indonesia with a log-log model: log e (Total aboveground biomass) = c + a loge (DBH) (Basuki *et. al.* , 2009). The diameter of the longest stem in several species was reported to the best predictor of biomass in Argentine shrubs (Hierro *et. al.*, 2000). Diameter at breast height in *Fagus moesiaca* (a tree in Vermio Mountain of Northern Greece), explained most of the variability in the dependent variables such as total aboveground stem biomass and branch biomass (Zianis and Mencuccini, 2003). Highly significant allometric regression, however, resulted from using basal diameter and crown depth in *Jetropha curcas* L (Ghezehei *et. al*. (2009).

Table 6.Correlation and regression analyses between biomass (B, g per plant) and morphometric parameters such as height (H, cm), and crown diameter (CD, cm) of *Urochondra setulosa* in coastal halo-xeric plain of Hawkes Bay, Karachi.

Parameters (Y / X)	a	b	r^2	Adj. r^2	F	P	SE
Y = a + bX ± SE							
B / H	-195.67 t = 3.19 p < 0.001	11.294 t = 6.09 p < 0.001	0.617	0.600	37.10	0.001	130.59
B / CD	-102.15 t = -3.72 p < 0.001	11.329 t =11.191 p < 0.001	0.845	0.838	125.24	0.001	83.12
B / loge H	-525.098 t = -2.85 P < 0.009	205.198 t = 3.691 p < 0.001	0.372	0.345	13.63	0.001	167.22
B/loge CD	-213.78 T = -2.53 P < 0.001	133.19 T = 8.37 P < 0.001	0.470	0.447	20.41	0.001	153.60
log B/ H	-1.459 t = -2.246 p < 0.001	0.155 T = 7.89 P < 0.001	0.730	0.718	62.18	0.001	1.381
Loge B/ CD	0.266 t = 0.608 p < 0.549	0.135 t = 8.37 p < 0.001	0.753	0.742	70.00	0.001	1.322
Loge B / loge H	-9.237 t = -7.25 p < 0.001	3.814 t = 9.91 p < 0.001	0.900	0.810	98.19	0.001	1.158
Loge B / loge CD	**-3.149 t= - 8.316 P < 0.001**	**2.363 t = 17.93 P < 0.001**	**0.933**	**0.930**	**321.44**	**0.001**	**0.6868**

Y = a +b₁ X₁ + b₂ X₂ ± SE								
Parameters	a	b_1	b_2	r^2	Adj. r^2	F	P	SE
B / H & CD	-91.062 t=- 2.075 p < 0.001	-0.801 t= -0.328 p < 0.001	11.926 t = 5.71 p < 0.001	0.920	0.846	60.25	0.001	84.78
B /loge H & loge CD	33.99 t = 1.12 p< 0.091	-138.584 t = 0.85 p < 0.405	209.132 t = 2.22 p < 0.037	0.487	0.440	10.44	0.001	154.53
loge B / loge H & loge CD	**-1.871 t = -1.39 p < 0.18**	**-0.715 t = - 0.99 p < 0.335**	**2.755 t = 6.58 p < 0.001**	**0.936**	**0.930**	**161.01**	**0.001**	**0.6852**

Note: Given in bold are the best fit equations.

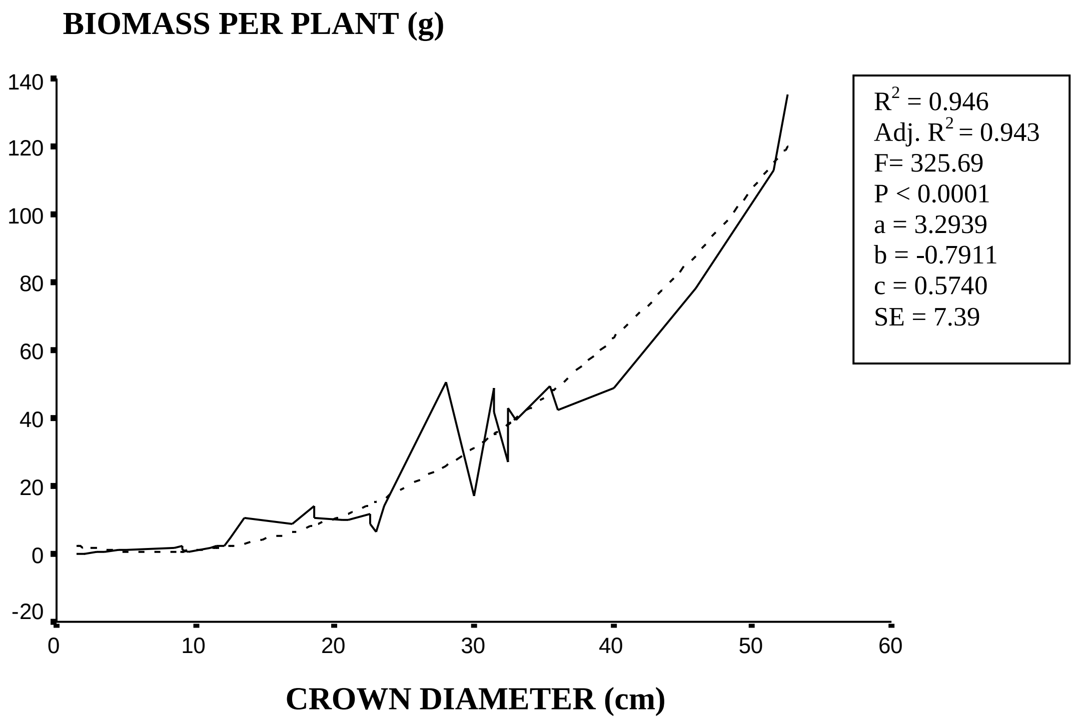

Figure 1. Curve estimation (quadratic relationship) between culm dry mass and crown diameter of *Atriplex griffithii*. Continuous line, observed data; broken line, estimated curve.

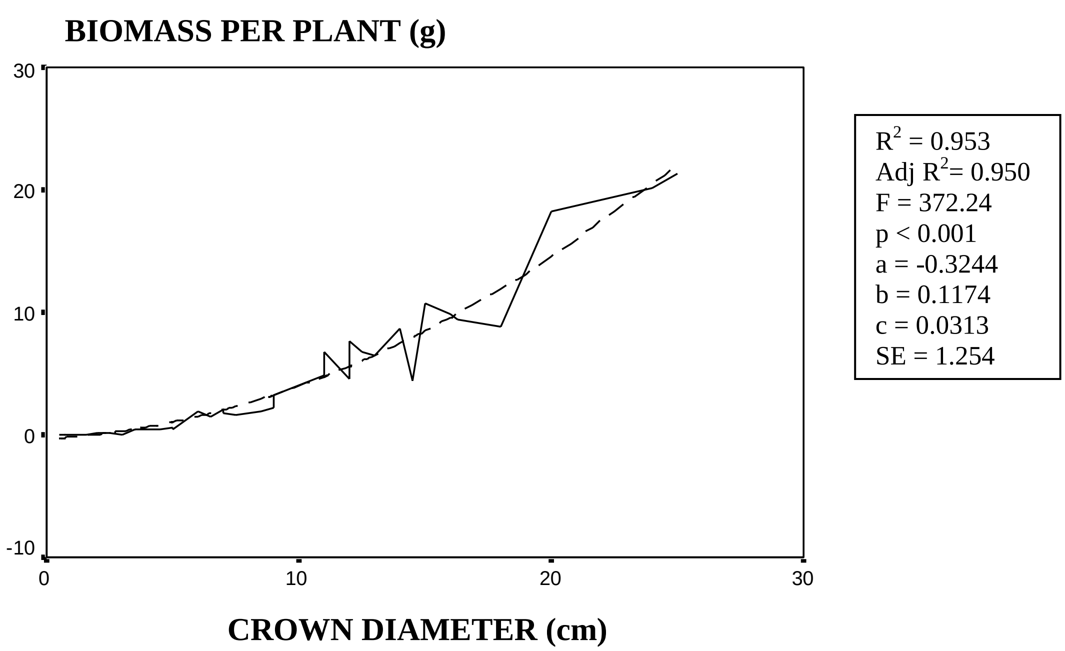

Figure 2. Curve estimation (quadratic relationship) between biomass (g) per plant and crown diameter of *Cressa cretica* (cm). Continuous line, observed data; broken line, estimated curve.

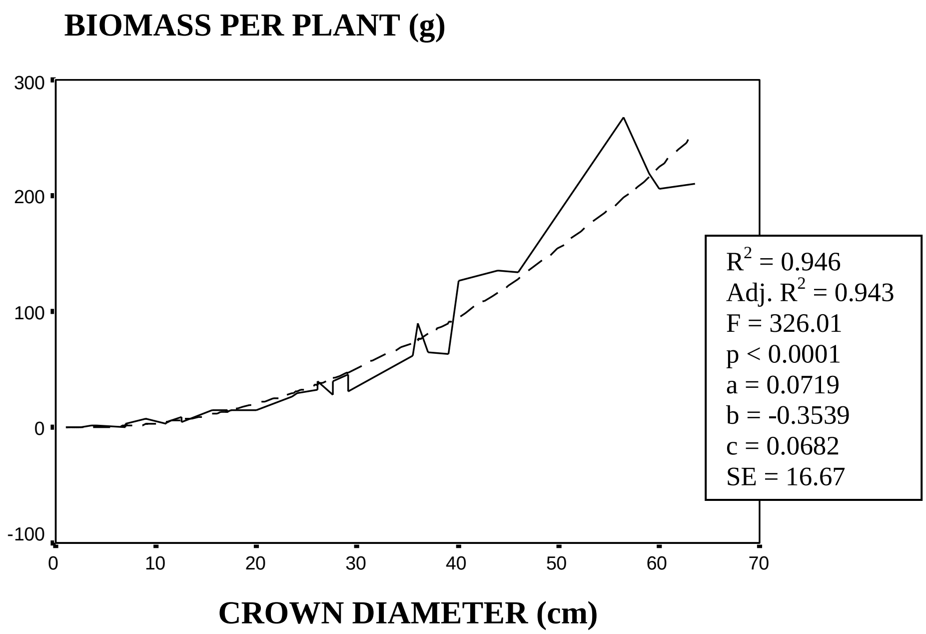

Figure 3. Curve estimation (quadratic relationship) between biomass (g) and crown diameter (cm) of *Limonium stocksii*. Continuous line, observed data; broken line, estimated curve.

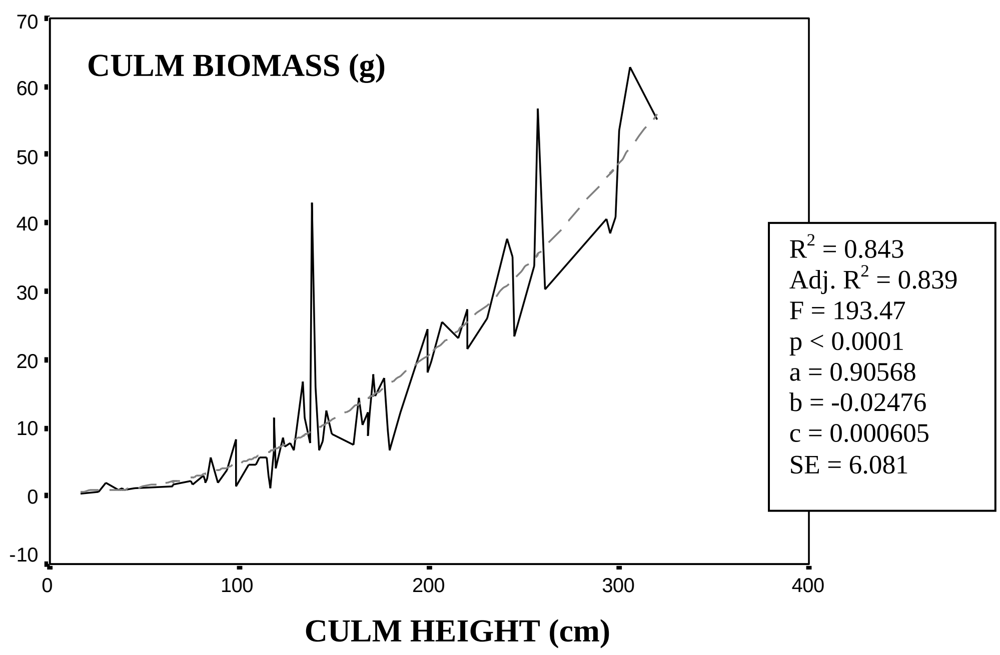

Figure 4. Curve estimation (quadratic relationship) between culm biomass (g) and culm Height (cm) of *P. karka*. Continuous line, observed data; broken line, estimated curve.

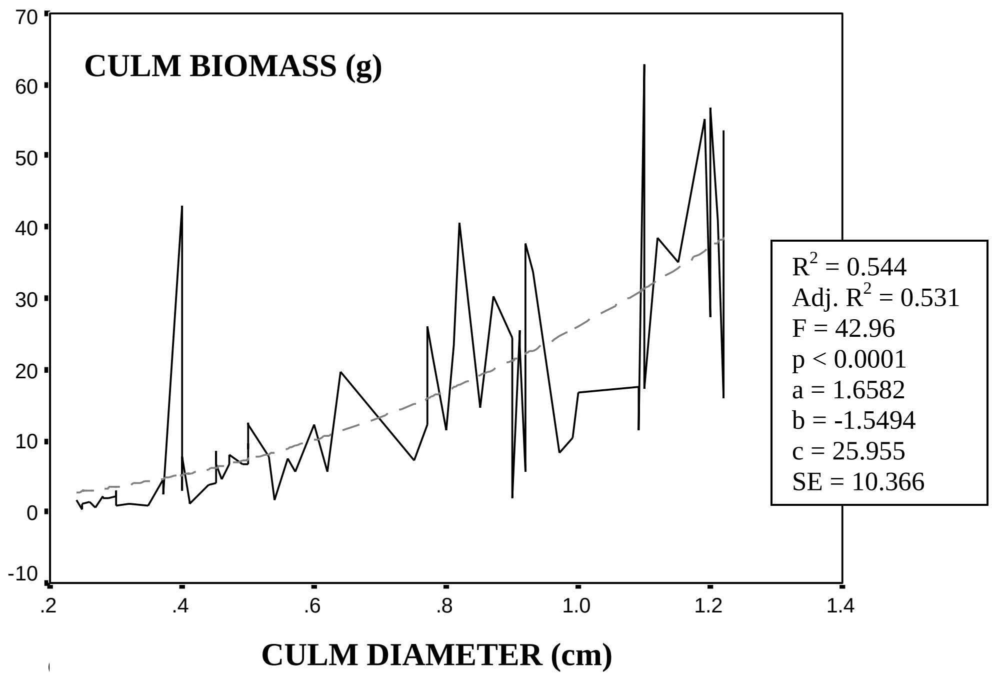

Figure 5. Curve estimation (quadratic relationship) between culm biomass (g) and culm diameter (cm) of *P. karka*. Continuous line, observed data; broken line, estimated curve.

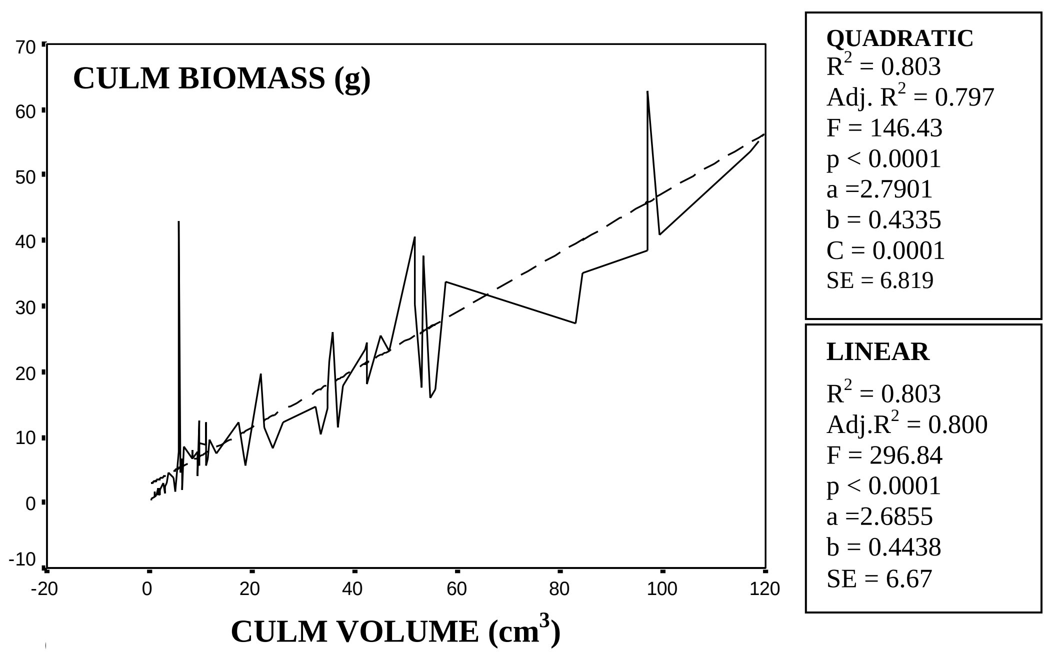

Figure 6. Curve estimation (quadratic relationship) between culm biomass (g) and culm volume (cm^3) of *P. karka*. Continuous line, observed data; broken line, estimated curve.

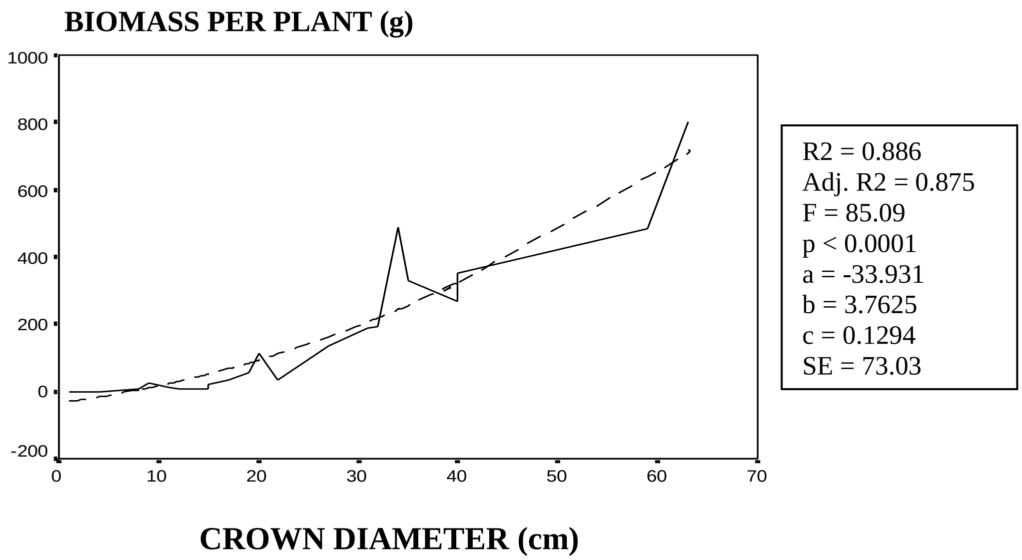

Fig. 7. Curve estimation (quadratic relationship) between plant biomass (g) and crown diameter (cm) in *Urochondra setulosa.* Continuous line, observed data; broken line, estimated curve.

It appears from our study that in herbaceous species in hand crown diameter is more important parameter than plant height so far aboveground phytomass is to be estimated. Logarithmic transformation is commonly employed to linearize data (Niklas, 2006) but such a practice introduces a systematic bias that must be corrected when back-transforming the values. Using logarithmic form of equations produces systematic underestimation of dependent variable (Y) when converting the estimated loge Y back to the original untransformed scale Y. Such a bias was recognized by Fenny (1941). Several authors (Baskerville, 1917; Beauchamp and Olsen, 1973; Yanale and Wiant, 1981; Duan, 1983; Sprugel, 1993; Zianis and Mencuccini, 2003) indicated its potential impact in biomass estimation using logarithmic regressions. The details regarding calculation of correction factor may be seen in Zianis and Mencuccini (2003). We, therefore, examined non-linear models with our data also (Fig. 1 -7) i.e., biomass regressed for curvilinear model ($Y = a + bX + cX^2 \pm SE$) against crown diameter (or culm diameter in case of *P. karka*). The non-linear model as are generally said to be better models than log-transformed linear models based on goodness of fit parameters - p values, R^2 and CV, etc. (Litton and Kauffman, 2008). Quadratic models, in our case, were more or less as equally statistically efficient as natural log-log multiple regression models in estimating phytomass in *Atriplex*, *Cressa* and *Limonium* (R^2 ranging from 0.943 to 0.950). Culm phytomass in *Phragmites* and AGDP in *Urochondra setulosa* were, however, better estimated by multiple regression models with natural log-log transformed variables (around 92%) than quadratic models in these species (Quadratic $R^{2:}$ 0.531 and 0.875, respectively). Culm height and culm volume could, however, defined culm biomass of *P. karaka* curvilinearly only 83.7 and 79.7%.

It has been stated that in *P. karka* in stead of plant mass, culm mass was estimated on the basis of culm diameter, height or culm volume with a view that aboveground biomass in unit area of its populations could be estimated by frequency counting in sampling which is similar to frequency counting of each living shoot or branch (or say the culm) appearing above the ground independently.

Most of the halophytic communities in arid areas are generally open and plants individuality is well explicit. These equations may be useful in estimating phytomass of species in hand during field studies but. But a word of caution is necessary. The proposed equations may only be used for plants falling within the size ranges of sampled plants because exploitation of curves beyond the region of fit is subject to error (Fownes and Harrington, 1991). The testing of these equations in field is, of course, imperative which is underway.

REFERENCES

Baskarville, G.L. (1972). The use of logarithmic regression in the estimation of plant biomass. *Can. J. For. Res*. 2:49-53.

Basuki, T.M., P.E. van Laake, A.K. Skidmore and Y.A. Hussin (2009). Allometric equations for estimating the above-ground biomass in tropical lowland Dipterocarp forests. *For. Ecol. & Manage*. 257 (8): 1684 – 1694.

Beauchamp, J.J. and J.S. Olsen (1973). Correction for bias in regression estimates after logarithmic transformation. *Ecol.* 54: 1402 – 1407.

Bryant, F. and M. Kothmann (1979). Variability in predicting edible browse from crown volume. *J. Range Manage.* 32: 144-146.

Brown, J.K. (1976). Estimating shrub biomass from basal stem diameters. Can. J. For. Res. 6: 153 – 158.

Castelan-Estrada, M., P. Vivin and J.P. Gaudillière (2002). Allometric relationships to estimate seasonal aboveground vegetative and reproductive biomass of *Vitis vinifera* L. Ann. Bot. 89: 401 – 408.

Crow, T.R. (1983). Comparing biomass regression by site and stand age for red maple. Can. J. For. Res. 13: 283-288.

Duan, N. (1983).Smearing estimate: A non-parametric retransformation method. *J. Am. Stat. Assoc*. 78: 605-610.

Elliot, K.J. and B.D. Clinton (1993). Equations for estimating biomass of herbaceous and woody vegetation in early-successional Southern Appalachian Pine-hardwood forests. US dept. Agriculture, Forest service, Southeastern Forest Exp. Station. Research Note NO. SE-365.

Fanny, D.J. (1941). On the distribution of a variable whose logarithm is normally distributed. *J. R. Stat. Soc*. Series B: 155 – 161.

Fantu, W. (2005). Aboveground biomass allometric equations and fuelwood properties of six species grown in Ethiopia. Ph. D. Thesis. Faculty of Forestry, Univesiti Putra Malaysia.

Fownes, J.H. and R.A. Harrington (1991). Allometry of woody biomass and leaf area in five tropical multipurpose trees. *J. Trop. For. Sci*. 4(4): 317 – 330.

Gardner, F.P., R.B. Pearce and R.L. Mitchell (1985). Physiology of crop plants. IOWA State Univ. Press, Ames. P. 187-208.

Ghezehei, S.B., J.G. Annandale and C.S. Everson (2009). Shoot allometry in *Jetropha curcas*. Southern Forests: A *Journal of For. Sci.* 71(4): 279-286.

Grigal, D.F. and N. R. Moody (1980). Estimates of browse by site classes for snowshoe hare. *Wildl. Manage*. 44 (1): 34 – 40.

Hierro, J.L., L.C. Branch, D. Villarreal and K.L. Clark (2000). Predictive equations for biomass and fuel characteristics of Argentine shrubs. *J. Range Manage*. 53: 617-621.

Hughes, G., L. Verner and L. Blankeship (1987). Estimating shrub production from plant dimensions. *J. range manage.* 40: 367-369.

Johnson, P.S. C.L. Johnson and N.E. West (1988). Estimation of phytomass for ungrazed crested wheatgrass plants using allometric equations. J. Range Mange. 41(5): 421- . Utah Agricultural Experimental Station Journal paper No. 3544.

Khan, M.N.I, R. Suwa and A. Hagihara (2005). Allometric relationship for estimating the aboveground phytomass and leaf area of mangrove *Kandelia candel* (L.) Druce trees in the Manko wetland, Okinawa island, Japan. *Trees- Structure & Function* 19 (3): 266 – 272.

Litton, C.M. and J.B. Kaufman (2008). Allometric models for predicting aboveground biomass in two widespread woody plants in Hawaii. *Biotropica* 40(3): 313 - 320.

Matte, T, I. Hajnsek and k. Papathanassiou (2003). Height-biomass allometry in temperate forests. 0-7803-7929-2/03/$17.00(C) 2003 IEEE.
(Web- ieeexplore.leee.org/ie/5/9010/28603/01294300.pdf?arnumber=1294300)

Maghembe, J.A., E.M. Kariuki and R.D. Haller (1983).Biomass and nutrient accumulation in young *Prosopis juliflora* at Mombasa, Kenya. *Agroforestry Systems* (Biomedical & Life sciences and Earth Environmental Science) vol. 1 (1): 313- 321.

Martin, W.L., T.L. Sharik, R.G. Oderwald, and D. Wm. Smith (1982). Phtyomass: Structural relationships for woody plant species in the understory of an Appalachian oak forest. *Can. J. Bot.* 60(10): 1923-1927.

Monk, C.D., G.J. child, S.A. Nicholson (1970). Biomass, litter and leaf surface area estimates of an oak-hickory forest. *Oikos.* 21: 138-141.

Murray, R. and M. Jacobson (1982). An evaluation of dimension analysis for predicting shrub biomass. *J. Range Manage.* 35: 451-454.

Niklas, K.J.(2006). A phyletic perspective on the allometry of plant biomass-partitioning patterns and functionally equivalent organ—categories. *New Phytol.* 171:27-40.

Niklas, K.J., J.J. Midgley and B.J. Enquist (2003). A general model for mass-growth-density relations across tree dominated communities. *Evol. Ecol. Res.* 5: 459-468.

Ohmann, L. F., D.F. Grigel and R. Brandar (1976). Biomass estimation for five shrubs from northeastern Minnesota. *USDA Forestr Serv. Res Note* NC 133.

Ohmann, L.F., D.F. Grigal, and L. L. Rogers (1991).Estimating plant biomass for undergrowth species in northeastern Minnesota forest communities. US Dept. Agriculture Forest Service, North Central Experimental Station, St. Paul, MN.

Pastor, J., J.D. Abor and J.M. Melillo (1984). Biomass prediction using generalized allometric regression for some Northeast tree species. *For. Ecol. & Manage*. 7: 265-274.

Pokorný, R and I. Tomášková (2007). Allometric relationship for surface area and dry mass of young Norway spruce aboveground organs. *J. For. Sci.* 53(12): 548 – 554.

Pereira, J.M.C., N.M.S. Sequeira and M.B. Carreiras (1995). Structural properties and dimensional relations of some Mediterranean shrub fuels. *Int. J. Wildl. Fire* 5: 35-42.

Rittenhouse, L.R. and F.A. Sneva (1977). A technique for estimating big sagebrush production. *J. Range Manage*. 30: 68-70.

Roussopoulos, P.J. and R.M. Loomis (1979). Weights and dimensional properties of shrubs and small trees of the Great Lakes conifer forest. *U.S. Forest Serv. Res.* Pap. NC. 178.

Schreuder, H.T., W.T. Swank (1971). A comparison of several statistical models in forest biomass and surface area estimates. In: Young, H.E (ed.) *Forest Biomass Studies*. IUFRO, section 25: Growth and Yield. Misc. publ. 132.Orono, ME: University of Maine: 125-138.

Sprugel, D.G. (1983). Correcting for bias in log-transformed allometric equations. Ecology 64: 209 – 210.

Swank, W.T. and H.T. schreuder (1974). Comparison of three methods of estimating surface area and biomass for a forest of young eastern white pine. *For. Sci.* 20: 91-100.

Tanaka, K., F. Ryo, H. Daisuke, K.J. Jawa, T. Sota, S. Katsutoshi and N. Ikuo (2009). Allomteric equations for accurate estimation of above-ground biomass in logged-over tropical rainforests in Sarawak, *Malaysia. J. For. Res.* 14 (6): 365 – 372.

Whittaker, R.H. and G.M. Woodwell (1968). Dimensions and production relations of trees and shrubs in the Brookhaven forest. *J. Ecol*. 56: 1-25.

Yanale, D.O. and H.V. Wiant (1981). Estimation of plant biomass based on the allometric equation. *Can. J. For. Res.* 11: 833 – 834.

Young, H.E. (1976). A summary and analysis of weight table studies. In: Young, H.E. (ed.). Oslo Biomass Studies. Orono, ME: University of Maine. 251 – 282.

Zianis, D. and M. Mencuccini (2003). Aboveground biomass relationships for beech (*Fagus moesiaca* Cz.) trees in Vermio Mountain, Northern Greece, and generalized equations for *Fagus* sp. *Ann. For. Sci.* 60: 439 – 448.

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