Taiwania, 59(4): 353– 359 , 2014
DOI: 10.6165/tai.2014.59.4.353

RESEARCH ARTICLE

Above Ground Biomass and Carbon Stocking in Tropical Deciduous Forests of State of Madhya Pradesh, India

Onkar Salunkhe[1]*, P.K. Khare[1], T.R. Sahu[2] and Sarnam Singh[3]

1. *Laboratory of Ecology,Department of Botany, Dr. Hari Singh Gour (A Central) University, Sagar, Madhya Pradesh, India. 470 003.*
2. *Laboratory of Plant Taxonomy, Department of Botany, Dr. Hari Singh Gour (A Central) University, Sagar, Madhya Pradesh, India470 003.*
3. *Indian Institute of Remote Sensing, 4-Kalidas Road, Dehradun, 248 001, Uttrakhand, India*
** Corresponding author. Email: onkarsalunkhe@yahoo.com*

(Manuscript received 29 April 2014; accepted 9 November 2014)

ABSTRACT: The present study deals with the estimation of tree density, basal area, biomass and carbon status with the help of nondestructive allometric equations method in tropical deciduous forest in 0.1 ha permanent plots, established in twenty sites in four districts of state of Madhya Pradesh in central India. The volume of tree was calculated using site specific local or regional volume equation. The biomass of each species was estimated taking tree volume and species specific gravity. The relationship between basal area and above ground biomass showed positive correlation for all sites and forest types. Field measurements for density ranged from 147 trees ha^{-1} to 777.5 trees ha^{-1} while basal area were 0.6 $m^2 \cdot ha^{-1}$ to 10.72 $m^2 \cdot ha^{-1}$. The biomass ranged from 3.99 $t \cdot ha^{-1}$ to 53.90 $t \cdot ha^{-1}$ and carbon stock from 1.89 $t \cdot ha^{-1}$ to 25.6 $t \cdot ha^{-1}$ across the all different study sites. This study concludes that tropical deciduous forests of the studied area in Madhya Pradesh are having strong potential for carbon sequestration. Estimation of above ground tree biomass in the present study provides data for tropical deciduous forests covering a large part (24.66%) of state for further use.

KEY WORDS: Allometric equation, basal area, biomass, deciduous forest, Nondestructive, specific gravity.

INTRODUCTION

Forests merit attention due to their important role in the global carbon (C) flux. They store large quantities of carbon in vegetation ecosystem and exchange carbon with the atmosphere through photosynthesis and respiration, and act as sources of atmospheric carbon if they are disturbed by some human activities (*e.g.* harvesting, clear cutting for conversion to non-forest purposes, poor harvesting procedures) or natural causes (*e.g.* wildfires) (Haripriya, 2003). More than 40% of global gross primary production in forest ecosystem accounted by tropical and subtropical forest (Beer, 2010). Tropical forest ecosystem is one of the richest biodiversity rich terrestrial ecosystems, which stores approximately half of the world living terrestrial carbon and a very significant proportion are fixed in the form of above ground biomass, thus they play an important role in global carbon cycle and regulating the biospheric climate. Besides, these forest ecosystems also support variety of life forms and maintain huge global biodiversity (Shi *et al.*, 2002). Through carefully planned forest carbon and biomass estimation projects we check the ability of forests to function as net carbon sinks, planning that will require accurate data on the carbon contained within tree species. At a given spatial and temporal scale forest carbon sequestration occurs when the amount of carbon taken in and stored by mainly trees and other components of forest vegetation which is greater than the total amount of CO_2 emitted due to respiration, decay, disturbances, and due to wood processing (Neilson *et al.*, 2006). Unrestricted utilization of natural resources, rapid population growth and faster industrial development cause harmful changes in vital ecological processes of the Earth. Today the greatest crisis ever faced by mankind is global warming because of anthropogenic activities of human being (Backéus *et al.*, 2005). The United Nations Framework Convention on Climate Change (UNFCCC, 1992) requires reporting from signatory countries for to develop their national inventories of forest carbon (C) source and sinks (Brown, 2002). In this context, terrestrial ecosystem carbon sequestration can reduce the rate of buildup of greenhouse gases in the atmosphere and therefore can contribute to slow down the current and future environmental changes.

In India, presently various agencies have already started assessing the vegetation carbon pool through satellite data to estimate the amount of carbon in terms of biomass. As per the records of Forest Survey of India (FSI 2003), in India, the area under forest was 102.68 m ha in 1880, which has reduced to 67.83 m ha in 2003.

Since 2003, carbon stocks in Indian forests are continuously decreasing (Sheikh *et al.*, 2011). The data envisaged that forests are under excessive anthropogenic pressures (Rai, 2001).

Madhya Pradesh (M.P.) is a centrally located and second largest state of India. The area of forest cover is 94,689 km^2 which is 30.72% of the total geographical area of state (FSI 2011). In terms of forest canopy density classes, the state has 6640 km^2 area under very dense forest; 34,986 km^2 under moderately dense forest; and 36074 km^2 under open forest. A total of 18 forest types have been identified in M.P. (Champion *et al.*, 1968). Broadly, these forest types belong to three groups namely, Type Group 5: tropical dry deciduous forests (88.65%), followed by Type Group 3: tropical moist deciduous forest (8.97%) and Type Group 6: tropical thorn forest (0.26%). Tropical dry deciduous forests are the major forest type in this state. In M.P., loss of biodiversity and low productivity are increasing rapidly which leads to degradation poor and regeneration of important tree species in forest area and also 50% villages surrounded the forest area and population relying on forest for their livelihood security (Manhas *et al.*, 2006 Pande, 2005, Bahuguna, 2000). In the present study we focus on estimation of biomass stored in tropical dry deciduous forests of M.P. For estimation of above ground forest biomass and carbon, various methods are being employed which include destructive, non- destructive and remote sensing techniques. Non-destructive field measurement method is considered to yield good estimates of biomass (Devgiri *et al.*, 2013). In the present study, the non-destructive method (field measurement) for estimation of biomass and carbon was considered, where the basal area, tree height, species specific gravity and volume equations were used as inputs.

TAXONOMIC TREATMENT

Study area

Madhya Pradesh lies between 21° 17’ and 26° 52’ north latitude 78° 08’ and 82° 49’ east longitude. According to forest survey of India, The average annual rain fall varies from 800mm to about 1,800mm with the annual temperature ranging from 22.5° C to 25° C. Population of the state is 60.4 M which constitutes 5.9% of the country’s population. Out of this, rural population is 73.5% and urban 26.5%. The variation in physiography, geology and wide climatic range, forest vegetation of Madhya Pradesh show diversity in forest types (FSI 2011)

Present study was carried out in the year 2010 at total of twenty selected sites in four different districts of tropical dry deciduous forests of MP, namely Damoh, Katni, Raisen and Sagar. The selections of representative sites for field observations in different districts were based on mainly magnitude of anthropogenic activities, disturbance, location of villages among forest area and crown density in the forests. The classification of density was based upon the tree crown cover such as D1 or very dense forest (more than 70% crown cover); D2 or dense forest (40-70% crown cover) and D3 or open forest (10-40% crown cover). The area under forest cover and different density classes of study sites were described in Table 1.

Sampling design

One super plot of 250 × 250 m size was laid down at each site (*i.e.* 20 sites). Four sample plots, each of 31.6 m × 31.6 m (≅ 0.1 ha) size in all the four directions i.e. NE, NW, SW and SE, respectively were laid in each super plot. Thus, the total sample size consisted of 20 super

Table 1. Area under forest cover and different density classes of study sites

District	**Geographic area (km^2)**	**Forest cover (km^2)**			**Total area (km^2)**	**Per cent of geographic area**
Name of Districts	Geographical Area	Very dense	Moderately dense	Open	Total	% of Geographical Area
Damoh	7,306	2	862	1,742	2606	35.67
Katni	4,950	102	607	573	1282	25.90
Raisen	8,466	22	1,331	1,382	2,735	32.31
Sagar	10,252	2	1,178	1,726	2,906	28.35

plots and 80 sample plots within super plots. Details of sampling design are given in Fig. 1. During the field visits, topo sheets of survey of India and GPS device (Garmin 72) were used to approach the sites. A detail of sampling design at plot level study is presented in Fig. 1.

Observations

The strata considered for the estimation of above ground biomass and carbon were only restricted to trees species as they greatly influence the magnitude and pattern of energy that is stored in trunks, branches, leaves and roots (Supriya *et al.*, 2009). Plants having more than 10 cm diameter at breast height (DBH; 1.37 m above ground) were considered as trees. In each sample plot (0.1 ha quadrat), stratification in the forest was observed and data was classified into top, first and second order canopies. The categorization of top, first and second order canopy species was done using stand height of each tree species. Height and diameter at breast height (DBH) of all trees in four sample plots within each super plot were measured using Blume Leiss Hypsometer (which is based on the trigonometric method) and digital tree caliper (Haglof, Sweden), respectively. All the trees were marked with unique number. The identification of species recorded was done with the help of herbarium section at Department of Botany, Dr HS Gour University, Sagar, India and Flora of M.P. (BSI, 1993).

Estimation of biomass/carbon

A non-destructive allometric equation approach was adopted for assessing biomass/carbon, which requires the parameters like tree measurements (height and DBH), application of standard volume equations and species specific gravity for each tree species. Tree volume was estimated by using the site or region specific (phytogeographic/ physiographic) volume,general and biomass equations, procured from State Forest Departments, Forest Research Institute and Forest Survey of India (Dadhwal *et al.*, 2009). Species specific gravity data were obtained from Forest Research Institute (FRI 1996). Species volume equation and species specific gravity of recorded tree species are summarized in Table 2. The DBH and height for each tree species were used for regression analysis to get an estimate of biomass (Roy *et al.*, 1996). The formula used for calculating biomass was as follows: Biomass ($t \cdot ha^{-1}$) = Volume of tree × Species specific gravity. The tree volume of each individual species was calculated by using the volume equations as suggested by FSI (1996).

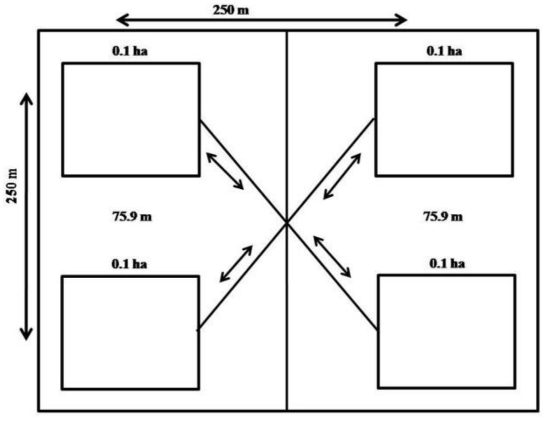

Fig. 1. Diagram showing sampling design.

Carbon concentration

Phytomass (Plant Biomass) has direct relationship with amount of carbon present in that Plant Biomass. Based on the results of different studies related to estimation of carbon in wood, it was observed that carbon varies between 45% to 50% for different ecosystems and it was assume that all biomass pool contained 47.5% carbon (Kotto-Same et al., 1997)

Statistical analysis

All the data were analyzed statistically by using SYSTAT version 12. Sites for different attributes were compared using ANOVA.

RESULTS

Observations of tree density, basal area, biomass and carbon of twenty sites by using ANOVA test are presented in Fig. 2. At (F-ratio 8.56, *p*- 0.05, 60 df) maximum tree density was found at site Katni 5 (777.5 trees$\cdot$ ha^{-1}) and it was minimum at Sagar 5 (147.5 trees$\cdot ha^{-1}$). Density wise Katni 5 site also showed significant differences with more than 50% of the site selected. Even within the same district (Katni), a few sites were found to have lower densities. Interestingly, basal area distribution showed an inverse relation with that of density. In general, site with low tree densities were found to have more basal area (10.72 $m^2 \cdot ha^{-1}$) at Damoh 2. However, the differences were not significant. The poorest site in this context was Sagar 5 where both density and basal area were minimum.

Tree biomass at (F- ratio 8.40, *p*- 0.05, 60 df) was maximum at Damoh 2 (53.90 ± 11.30 $t \cdot ha^{-1}$) and Raisen 1 (53.80 ± 4.76 $t \cdot ha^{-1}$) which were comparable to each other, followed by Raisen 2 (49.25 ± 6.86 $t \cdot ha^{-1}$) and Sagar 1 (45.90 ± 14.07 $t \cdot ha^{-1}$). However, minimum biomass was recorded at Sagar 5 (3.99 ± 2.89 $t \cdot ha^{-1}$), followed by Sagar 3 (6.53 ± 1.94 $t \cdot ha^{-1}$), Katni 3 (7.74 ±

1.76 t·ha^{-1}), Katni 2 (7.55 ± 1.80 t·ha^{-1}), and Katni 5 (8.68±0.85 t·ha^{-1}). These were comparable with each other. While the carbon was maximum at Damoh 2 (25.60 ± 5.36 t·ha^{-1}) and Raisen 2 (25.55 ± 2.26 t·ha^{-1}) which were comparable to each other. Minimum carbon contain was recorded at Sagar 5 (1.89 ± 1.37 t·ha^{-1}), followed by Sagar 3 (3.10 ± 0.92 t·ha^{-1}), Katni 4 (3.45 ± 0.54 t·ha^{-1}) which were comparable to each other.

DISCUSSION

A direct relationship exists among basal area, biomass and carbon stock. At any given location it is now established that biomass is a function of tree density, height and basal area. The parameters such as tree density and basal area were contributed to estimate above ground biomass or carbon. The density and above ground biomass varied from site to site in present study because of different types of plant community structure, variation in plant species, composition of forest or succession stage of forests due to some anthropogenic practices in different sites of forest ecosystems. Some sites having a high density of young plants with small girth size usually have a high biomass. On the other hand, some mature sites with large-diameter trees harbor higher biomass as compared to sites having a high tree density. In addition, wood collection by surrounding villagers and stone mining have lead to destruction of forests and thus the reduction of biomass in some of the sites. All of the above factors are responsible for site to site variation of biomass and such type of external as well as internal factors found in this research are supported by a number of workers (Whitmore, 1984; Brunig, 1983; Pande, 2005; Terakunpisut *et al.*, 2007). Field measurements for density ranged from 147 trees·ha^{-1} to 777.5 trees·ha^{-1} while basal area were 0.6 m^{2}·ha^{-1} to 10.72 m^{2}·ha^{-1}. The biomass ranged from 3.99 t·ha^{-1} to 53.90 t·ha^{-1} and carbon stock from 1.89 t·ha^{-1} to 25.6 t·ha^{-1} across the all different study sites.

Table 2. List of volume equations and species specific gravity used in the present study

Sr. No.	Types of Species	Volume equations[1]	Type of Equation	Species Specific gravity[2]
1	*Acacia catechu*	(0.02471+0.16897*D+1.12083*D*D+2.9328)*(D*D*D)	L	0.875
2	*Acacia nilotica*	(-0.00142+2.61911*D-0.54703*SQRT(D))^2	L	0.670
3	*Aegle marmelos*	(0.0697/(D*D)+(-1.4597/D)+11.79933-2.35397*D)*(D*D)	G	0.754
4	*Albizia procera*	(0.0697/(D*D)+(-1.4597/D)+11.79933-2.35397*D)*(D*D)	G	0.579
5	*Annona squamosa*	(0.0697/(D*D)+(-1.4597/D)+11.79933-2.35397*D)*(D*D)	G	0.788
6	*Anogeissus pendula*	(0.00085/(D*D)+(-0.35165/D)+4.77386-0.90585*D)*(D*D)	L	0.619
7	*Bauhinia racemosa*	(-0.04262+6.09491*D*D)	L	0.619
8	*Boswellia serrata*	(-0.1503+2.79425*D)^2	G	0.498
9	*Butea monosperma*	(0.0697/(D*D)+(-1.4597/D)+11.79933-2.35397*D)*(D*D)	G	0.465
10	*Cassia fistula*	(0.0697/(D*D)+(-1.4597/D)+11.79933-2.35397*D)*(D*D)	G	0.746
11	*Chloroxylon swietenia*	(0.0697/(D*D)+(-1.4597/D)+11.79933-2.35397*D)*(D*D)	G	0.458
12	*Dalbergia latifolia*	(0.0697/(D*D)+(-1.4597/D)+11.79933-2.35397*D)*(D*D)	G	0.754
13	*Dalbergia sissoo*	(0.04422+2.328465 *(D*D)+0.309150 *(D*D)*H)	L	0.669
14	*Diospyros melanoxylon*	(0.15581-2.2075*D+9.17559*D*D)	L	0.678
15	*Elaeodendron glaucum*	(0.0697/(D*D)+(-1.4597/D)+11.79933-2.35397*D)*(D*D)	G	0.619
16	*Ficus racemosa*	(0.0697/(D*D)+(-1.4597/D)+11.79933-2.35397*D)*(D*D)	G	0.619
17	*Ficus religiosa*	(0.0697/(D*D)+(-1.4597/D)+11.79933-2.35397*D)*(D*D)	G	0.385
18	*Flacourtia ramontchi*	(0.0697/(D*D)+(-1.4597/D)+11.79933-2.35397*D)*(D*D)	G	0.619
19	*Gardenia latifolia*	(0.0697/(D*D)+(-1.4597/D)+11.79933-2.35397*D)*(D*D)	G	0.635
20	*Holarrhena antidysenterica*	(0.0697/(D*D)+(-1.4597/D)+11.79933-2.35397*D)*(D*D)	G	0.592
21	*Holoptelea integrifolia*	(0.0697/(D*D)+(-1.4597/D)+11.79933-2.35397*D)*(D*D)	G	0.37
22	*Kydia calycina*	(0.0697/(D*D)+(-1.4597/D)+11.79933-2.35397*D)*(D*D)	G	0.648
23	*Lagerstroemia parviflora*	(0.01617-0.66446 *D+9.71038*D*D)	L	0.513
24	*Lannea coromandelica*	(0.14004/(D*D)+(-2.35990/D)+11.90726)*(D*D)	L	0.619
25	*Madhuca latifolia*	(-0.051-0.034*D+4.542*D*D)	L	0.619
26	*Melia azadirach*	(0.0697/(D*D)+(-1.4597/D)+11.79933-2.35397*D)*(D*D)	G	0.619
27	*Ougeinia oojeinensis*	(0.0697/(D*D)+(-1.4597/D)+11.79933-2.35397*D)*(D*D)	G	0.704
28	*Phyllanthus emblica*	(0.0697/(D*D)+(-1.4597/D)+11.79933-2.35397*D)*(D*D)	G	0.619
29	*Saccopetalum tomentosum*	(0.0697/(D*D)+(-1.4597/D)+11.79933-2.35397*D)*(D*D)	G	0.619
30	*Stephegyna parvifolia*	(0.0697/(D*D)+(-1.4597/D)+11.79933-2.35397*D)*(D*D)	G	0.619
31	*Syzygium cumini*	(0.08481-1.81774 *D+12.63047 *D*D-6.6955*(D*D*D))	L	0.647
32	*Tectona grandis*	(0.04346-0.26352*SQRT(D)+8.79334)*(D*D)	L	0.577
33	*Terminalia alata*	(0.33695-1.23004*SQRT(D)+11.86676)*(D*D)	L	0.694
34	*Terminalia bellerica*	(-0.14017+3.364233*D)^2	L	0.628
35	*Terminalia cuneata*	(0.0697/(D*D)+(-1.4597/D)+11.79933-2.35397*D)*(D*D)	G	0.686
36	*Zizyphus jujuba*	(0.0697/(D*D)+(-1.4597/D)+11.79933-2.35397*D)*(D*D)	G	0.597
37	*Zizyphus xylopyra*	(0.0697/(D*D)+(-1.4597/D)+11.79933-2.35397*D)*(D*D)	G	0.597

D= DBH (m), H= height (m), SQRT= square root, L= Local volume equations, G- General volume equation.

[1]FSI (1996), FRI[2] (1999)

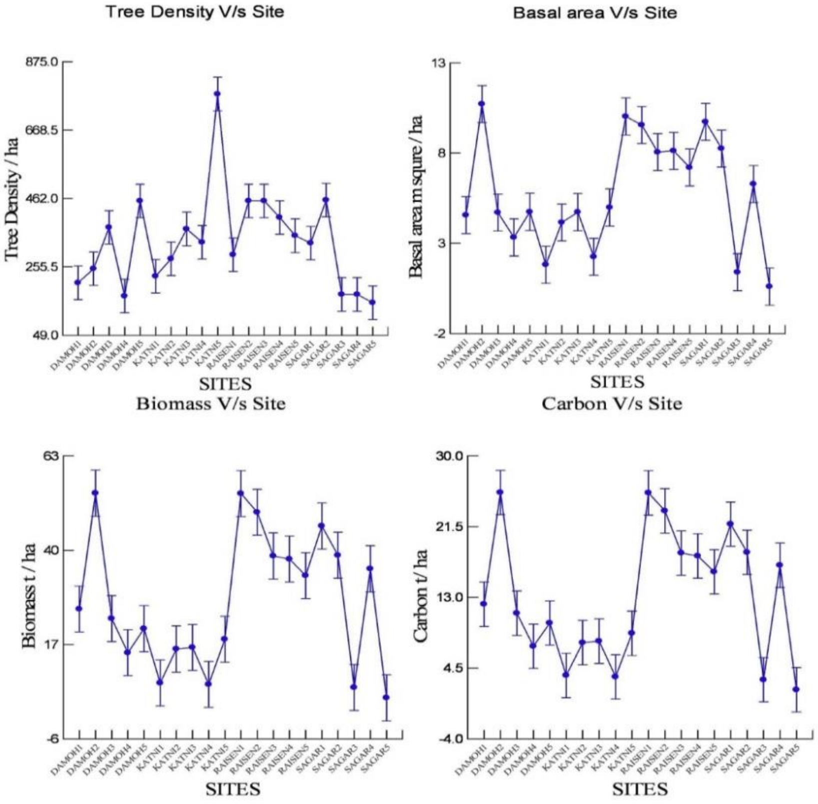

Fig. 2. Observations of tree density, basal area, biomass and carbon of twenty study sites.

The lower biomass in sites such as Sagar 5, Sagar 3 could be attributed to relatively young forests with a high tree density of <10 DBH. At Katni 4 and Katni 5 sites the tree density was more but estimated biomass was very low due to small bole size as compared to other sites. Other forest sites such as Damoh 4, Katni 2 and Katni 3 forests sites also had lower biomass in terms of the number of trees due to dry condition and excessive ground water utilization by a number of cement factories and mining industries and other disturbances such as daily removal of biomass from local people, over grazing, cutting of tree branches etc. According to Pande (2005) poor soil depth and soil structure of any site can be responsible for low above ground biomass. All the remaining sites were stabilized having average number of trees and basal area as well as biomass. Although the biomass of medium size boles varied considerably among different forest sites and such types of forests exhibited greater potential for sequestration of carbon as compared to the forests having large bole size trees (Acker *et al.*, 1998). Results of the present study envisage that tree density does not have a bearing on biomass. In fact it is the basal area of tree that determines it. AGB at particular site depends upon tree basal area because basal area and AGB are strongly associated with tree architecture but not the density (Chiba, 1998).

The estimated range of biomass in present study is 3.99 t·ha^{-1} to 53.90 t·ha^{-1} while the average values of above ground biomass (27.40 t·ha^{-1}) and carbon (13.01 t·ha^{-1}) in this state lie in between values of some earlier reports such as 27.6 t ha^{-1} by George et al. (1990), 19 t ha^{-1} and 24 t ha^{-1} by Devagiri *et al.* (2013), 28.68 t C ha^{-1} by Singh *et al.* (1991), 28.1-85.3 t ha^{-1} by Pande (2005)**.** Also these results could be compared with the other available biomass and carbon estimation of different forest types in India. Chaturvedi *et al.* (2011) estimated that carbon stock ranged from 15.6 t·ha^{-1} to 151 t·ha^{-1} in tropical dry forest of India. Bhat *et al.* (2003) reported that the accumulation of biomass in tropical rain forest of Western Ghat ranging from 92 t·ha^{-1} to 268.49 t·ha^{-1} while FAO (2007) estimated the average carbon density at 35 t·ha^{-1} in India. Our results also showed the similarity with above cited national level estimation of biomass. The comparison of estimated biomass of studied cites with other worker within similar state or region were difficult because of variation in the method employed for estimation of biomass in different studies and no previous estimation was done in this state or region.

ACKNOWLEDGEMENT

Authors thanks to Indian Institute of Remote Sensing, (IIRS), Dehradun, India for funding the project Vegetation Carbon Pool Assessment under ISRO Geosphere Biosphere Program. Onkar Salunkhe acknowledges award of Junior Research Fellowship to him under this project. Thanks are also due to the Principal Chief Conservator of the forests of Madhya Pradesh, India for permission and support during field work in forest areas.

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