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Carbon sink potential in fragmented forests of different patch sizes along with disturbance gradients in Uttara Kannada district of central Western Ghats, Karnataka

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Abstract
Carbon sequestration is the permanent or longer time storage of atmospheric carbon dioxide in a terrestrial system. Forests are considered to be a potential sink in the terrestrial system for carbon sequestration. The continuous stretch of forests has become fragmented due to severe biotic pressure. Those fragmented forests are traditionally conserved in the name of sylvan deity and are called as Kaan forests. These are virgin patches of the natural forest communities. Therefore, estimation of above ground biomass and carbon pool of these remnants of sacred Kaans could be of great help to understand the natural rate of carbon sequestration potential. In the present study, estimation of the biomass and carbon stock by non-destructive method through measurements of DBH and tree height in each of the belt transects in the Kaan forests of Sirsi taluk. The maximum biomass and carbon stock was found in less disturbed Kaans. Among the different disturbance level, significantly higher AGB was obtained in less disturbed level (688.34 Mg ha^{-1}) and was least in high disturbed level (247.40 Mg ha^{-1}). The similar trend was noticed in below ground biomass with 178.98 Mg ha^{-1} and 64.32 Mg ha^{-1} in less and high disturbance level respectively. The total biomass was found to be significantly higher in less disturbed Kaans (867.32 Mg ha^{-1}) compared to highly disturbed Kaans (311.72 Mg ha^{-1}). Higher carbon stock and carbon equivalent was recorded in less disturbed Kaan (407.64 Mg ha^{-1} and 1496.04 Mg ha^{-1}) compared to highly disturbed Kaan (146.50 Mg ha^{-1} and 537.68 Mg ha^{-1}) respectively. It is evident from the results that the less disturbed large Kaans showed higher values of biomass and carbon stock compared to Medium and Small Kaans. Sacred Kaans not only harbour`s biodiversity but also mitigates carbon and plays a major role in carbon cycling.

Keywords: Kaan forest, fragments**,** above ground biomass, carbon stock

Introduction
Habitat fragmentation is the major causes of biodiversity loss; tropical trees increasingly survive only in remnant fragments. Habitat fragmentation by definition is the “breaking apart” of continuous habitat such as tropical forest into distinct patches. The process of land clearing and habitat fragmentation is continuing rapidly all around the globe, but especially in areas of tropical rainforest. The Western Ghats are one of the 36 global biodiversity hotspots and a well-known biodiversity hub in India, home to more than 30% of the country's plant, fish, fauna, bird, and mammal species. However, this diverse biodiversity is under threat from a variety of human pressures, and only one-third of the total area of the Western Ghats is covered by natural vegetation (Anon, 2017) [4]. Nature worship is an important aspect of sacred customs and practices in India, with small patches of indigenous vegetation traditionally protected and managed by local communities. As part of their religious and cultural values, local communities protect and preserve a specific region as a "sacred grove." Sacred groves are landscape segments containing vegetation, other forms of life, and geographical features that are delimited and protected by human societies in order to keep them relatively undisturbed as an expression of humans' important relationship with the divine (Hughes and Chandran, 1998) [7]. These patches of vegetation, which can be found all over India, are dedicated to Gods or other deities, ancestral spirits, and are revered by locals as the deity's sacred territory. All forms of vegetation including shrubs, trees and climbers are believed to be protected by the reigning deity of that grove. Even the removal of dead parts of trees may be a taboo in some cases (Prabhu, 2021) [10].
These islets or groves may be considered as the relics of the past extent of the evergreen forests. Despite the fact that many parts of the Western Ghats are subjected to severe

anthropogenic pressures, these types of relic formations have retained their identity to this day. In the central Western Ghats of Uttara Kannada and Shimoga, these relic forests are known as Kaans. The context of ecological history demonstrates that people have preserved these forest patches as abodes of local deities since time immemorial. Kaans are one of the rare, ecologically sensitive and endangered ecosystems in Western Ghats. This ecosystem is regarded as halfway between forests and agro-ecosystem in view of their species composition which is primarily determined by climatic conditions and human settlements (Chapman and Reiss, 1997) [5]. Kaans ranging in area from part of a hectare to few hundred hectares and protected from time immemorial, may be considered as the best samples of climax forest of the region.
Terrestrial carbon sequestration is the net removal of CO_2 from the atmosphere, carbon dioxide emissions from terrestrial ecosystems into the atmosphere. The process of removal includes CO_2 uptake from the atmosphere by chlorophyllous plants through photosynthesis. The carbon is stored in the form of plant biomass (in the trunks, branches, leaves and roots of the plants) and as soil organic carbon (SOC) in the soil (IPCC, 2000). Carbon sequestration is an important aspect from the environmental point of view because all living and non-living organic matter contains approximately 50% carbon. Carbon exists in various forms and is cycled between several biotic and abiotic pools including oceans, terrestrial biota and atmosphere (Skole *et al*., 1995) [11]. Forest ecosystems are the major biological filters of atmospheric CO_2, and the most extensively forested areas with traditional associations have the highest carbon sink potential (He *et al*., 2015) [6]. Therefore, such sacred forests should be conserved for better management of carbon stock. This could help in better understanding the feasibility of their use in a carbon credit mechanism and will be a good basis to the incentive provisioned for Reducing Emission from Deforestation and Forest Degradation (REDD) mechanism. Since the sacred Kaans have been maintained traditionally for such a long time, it is essential to document the biomass and carbon stock of such land uses. Unfortunately, these effects have not been documented. In this context we have studied the above ground biomass and carbon stock potentiality of the Kaan forests of Sirsi taluk as influenced by the level of disturbance as well as by the size categories.

Material and Methods

The present study was carried out in the Kaan forests of Sirsi Forest Division in Canara Circle, Uttara Kannada District. It consists of 3 sub divisions namely Sirsi subdivision, Janmane sub division and Siddapura sub division and Six range Forest office. The present study area mainly falls under Sirsi and Janmane sub divisions which has Sirsi and Banavsi ranges as well as Janmane and Hulekal ranges respectively. The Sirsi taluk selected for the present investigation falls within the latitude of 14.61°N and 75.84°E (Figure. 1). The altitude of the site is varying from 510 to 630 m M.S.L. The total geographic area of Sirsi taluk is 3695 sq km and total population of 62,882 as per the 2011 census.
The information on the area of the Kaan forests were gathered from the revenue and forest department as well as consulting with local village heads. Based on the information on Kaans size, and level of disturbance, the Kaan forests were grouped into 2 main categories. Kaan sizes into large (>50 ha), medium (15-50 ha) and small Kaan (0-15 ha). Depending on the level of disturbance, each size class of Kaan forests were categorized into two broad categories such as less disturbed, where the range of disturbance level was less than 40 percent and highly disturbed, if the disturbance level was more than 40 percent respectively.
To estimate biomass of different trees, a non-destructive method was used through measurement of DBH and tree height in each of the belt transects in the Kaan forests. The main purpose of taking measurement was to assess the carbon stocks of aboveground biomass using standard equations for each tree species and was estimated as weight or volume per tree, further which was extrapolated to per hectare basis. In the present study, the sampling localities are very variable in size as the Kaans are a fragmented patchy ecosystem. In order to overcome the problem of variable size, emphasis was given on sampling random. For sampling the vegetation of Kaan forests belt transect method (Methodology: Department of Biotechnology, New Delhi) was employed. The transect length of 500 m × 10 m breadth (0.5 ha) was laid in each Kaan forest of large, medium and small categories from highly disturbed and less disturbed Kaans respectively.
The plant form related parameters were recorded like tree, size, shrub and name of each individual species. Diameter or girth was determined by measuring tree Girth at Breast Height (GBH), at 1.37 meter from the ground. The GBH of trees having diameter greater than 30 cm were measured directly by measuring tape and expressed in meters. The tree height was measured and tree height is also one of the important parameters for estimation of volume of tree. The dominant trees with greater height with overlapping canopies were measured using Ravi Multimeter and expressed in meters (m).
Above ground biomass (AGB) of trees
The above ground biomass of tree includes the whole shoot, branches, leaves, flowers, and fruits. It is calculated using the following formula;
AGB (kg) = volume of tree (m^3) x wood density Kg/m^3x BEF
$V = \pi r^2 H \times FF$
V = Volume of the cylindrical shaped tree in m^3
r = Radius of the tree in meter
H = Height of the tree in meter
FF = Form factor (0.5) (Adekunle *et al*., 2013) [1]
BEF = Biomass Expansion Factor (3.4) (Anon, 2003) [3]
Belowground biomass (BGB) of tree

The belowground biomass (BGB) includes all biomass of live roots excluding fine roots having < 2 mm diameter. The belowground biomass was calculated by multiplying the above ground biomass (AGB) by 0.26 factors as the root: shoot ratio.
Belowground biomass (BGB) (kg/tree or ton/tree) = Aboveground biomass (AGB) x 0.26.
Carbon stock of tree
The carbon stock of tree is the sum of both above and below ground biomass. It was calculated using the following formula. The carbon stock of tree was expressed in Mg (Mega grams or tons per hectare).
Carbon stock (CS) = Total biomass (AGB + BGB) x C – organic (47%)
Carbon equivalent (Carbon dioxide equivalent)
The CO_2 in the atmosphere is assimilated by trees in the process of photosynthesis. In order to derive the amount of CO_2 converted into carbon and retained in the biomass, the

molecular weight relation between carbon and oxygen is used as follows.

CO_2 Eq (kg) = (12 + (16×2))/12 C = 44/12 C = 3.67 C.

Thus, one molecule of carbon = 3.67 molecules of CO_2 or 1 ton of carbon = 3.67 tons of CO_2.
The data obtained for all the parameters for each of the objectives was statistically analyzed by Analysis of Variance (ANOVA) using Factorial Randomized Block Design (RBD) where ever necessary. The level of significance used in F test was P= 0.05. Critical difference values were calculated, wherever F test was found significant.

Results and Discussion

The effect of disturbance gradient and size class on biomass parameters of Kaan forest in Sirsi taluk was depicted in Table 1. The overall results indicated that all biomass parameters such as above ground, below ground and total biomass were found to be statistically significant difference for only disturbance gradient. On the other hand, the latter biomass parameters failed to show significant difference for both Kaan size categories as well as the interaction between Kaan size and disturbance gradient.
Under the different disturbance level, significantly higher AGB was obtained in less disturbed Kaans (688.34 Mg ha^{-1}) compared to high disturbed Kaans (247.40 Mg ha^{-1}). As like above ground biomass, the below ground biomass showed similar trend. Where the below ground biomass of less disturbed category was found to be maximum (178.98 Mg ha^{-1}) than highly disturbed Kaans (64.32 Mg ha^{-1}) respectively. The total biomass once again showed significantly superior in less disturbed Kaans (867.32 Mg ha^{-1}) and least in high disturbance category (311.72 Mg ha^{-1}) (Figure 2).
Among three different Kaan size categories, all the biomass parameters showed descending pattern from large to small size Kaan in less disturbed category. Whereas in case highly disturbed category, maximum biomass was found in small Kaans followed by large and minimum was recorded in medium size fragments (Table 1). The overall data pooled over different Kaan size category irrespective of disturbance level showed maximum total biomass for large size Kaan (616.87 Mg ha^{-1}) followed by medium size (591.39 Mg ha^{-1}) and minimum total biomass was recorded in small size Kaans (560.29 Mg ha^{-1}) (Figure 3).
In the present investigation the attempt was made to quantify the total carbon stock potentiality of the Kaan forests as influenced by level of disturbance and Kaans size categories. Where, the total biomass was considered to obtain the total carbon stock of the Kaan forests by following standard formulae. The total carbon stock was calculated for each the sampling units and finally extrapolated for hectare which was expressed in Mega grams. The present experiment on assessing the total carbon stock considering different disturbance gradients in Kaans of Sirsi taluk and the results are presented in Table 2. It is apparent from the results that, the pattern of significance was similar as like biomass component, where Carbon stock (Mg ha^{-1}) and Carbon equivalent (Mg ha^{-1}) showed significant difference only for disturbance gradient and whereas different Kaan size categories as well as interactions did not vary significantly.
Among two different disturbance gradient, highest carbon stock was recorded in less disturbed Kaans (407.64 Mg ha^{-1}) and lowest was recorded in high disturbed Kaans (146.50 Mg ha^{-1}) (Figure 4). The similar trend was also noticed in carbon equivalent, wherein less disturbed Kaans recorded significantly higher carbon equivalent (1496.04 Mg ha^{-1}) compared to highly disturbed Kaans (537.68 Mg ha^{-1}) (Table 2). As for as Kaan size category is considered, the pattern of total carbon stock as well as carbon equivalent exhibited similar pattern as like biomass parameters. Among three different Kaan size categories, both carbon stock and carbon equivalent showed descending pattern from large to small size Kaan in less disturbed category. Whereas in case highly disturbed category, maximum carbon stock and carbon equivalent was found in small Kaans followed by large and minimum was recorded in medium size fragments (Table 2). The overall data pooled over different Kaan size category irrespective of disturbance level showed maximum total carbon stock for large size Kaan (289.93 Mg ha^{-1}) followed by medium size (277.95 Mg ha^{-1}) and minimum total carbon stock was recorded in small size Kaans (263.34 Mg ha^{-1}) (Figure 5).
Prabhu (2021) worked on Kaan forests of Soraba taluk. The results revealed that maximum biomass and carbon stock was found in Kaans presented in high rainfall areas (170.78 Mg and 80.26 Mg, respectively) compared to low rainfall zones (163.55 Mg and 76.87 Mg, respectively). In the two rainfall zones, the total biomass and carbon stock was significantly higher in less disturbed Kaans (227.99 Mg and 226.38 Mg and 107.16 and 106.40 Mg respectively) compared to highly disturbed Kaans (113.56 Mg and 100.73 Mg and 53.37 and 47.34 Mg, respectively). The total biomass and carbon stock showed direct relation with extent of Kaan size. The study reveals that the sacred groves of Soraba taluk in Central Western Ghats are species rich, have higher carbon sequestration potential and calls for an immediate attention for conservation.
A study on assessment of carbon stock of scared groves in Garhwal Himalaya, Uttarakhand by Vikrant and Nazir, (2019) [12]. The results depicted tree density of 688 trees ha^{-1}, whereas total carbon stock and biomass were 587.19 Mg ha^{-1} and 1159.90 Mg ha^{-1}. Highest biomass and carbon density was observed for Cedrus deodara. Waikhom *et al*. (2018) depicted similar result of above ground biomass and carbon stock of scared groves in Manipur, Northeast India. The results showed that the aboveground biomass and carbon stock ranged from 962.94 to 1130.79 Mg ha^{-1}, 481.47 to 565.40 Mg ha^{-1} respectively. Trees in largest groves with diameter class of 80–100 cm contributed the highest proportion of aboveground biomass and carbon stock. The total biomass and carbon stock in sacred groves of Central India, Madhya Pradesh as revealed by Javid *et al*. (2019) was ranged from 34.9-409.8 Mg ha^{-1} with a mean value of 194.01 Mg ha^{-1}, while, tree carbon stock ranged between 17.5 to 204.9 Mg C ha^{-1} with a mean value of 97.0 Mg C ha^{-1}. The contribution from larger groves with a tree density of 500 to 675 no. of stems ha^{-1} was found to be maximum. In another similar study by Konkane *et al*. (2018) [9], the carbon sequestration potential of sacred groves was conducted in Ambegaon taluka of Pune district. The study revealed that the carbon sequestration potential is directly proportional to number of individual trees present in the grove.

Table 1: Effect of disturbance gradient and size class on biomass parameters (Mg/ha) of Kaan forests in Sirsi taluk

Disturbance level	Kaan size	AGB	BGB	TB
Highly Disturbed	Large	244.96	63.70	308.66
	Medium	241.12	62.68	303.80
	Small	256.10	66.60	322.70
Mean of Disturbance gradient		247.40	64.32	311.72
Less Disturbed	Large	734.18	190.90	925.08
	Medium	697.60	181.38	878.98
	Small	633.24	164.64	797.90
Mean of Disturbance gradient		688.34	178.98	867.32
SEm ±	Disturbance gradient (D)	41.06	10.68	51.74
	Kaan size (S)	50.28	13.08	63.36
	D × S	71.12	18.50	89.60
CD @ 5%	Disturbance gradient (D)	121.98	31.72	153.70
	Kaan size (S)	NS	NS	NS
	D × S	NS	NS	NS

Note: AGB – Above Ground Biomass
BGB – Below Ground Biomass
TB – Total Biomass

Table 2: Effect of disturbance gradient and size class on carbon stock and carbon equivalent (Mg/ha) of Kaan forests in Sirsi taluk

Disturbance level	*Kaan* size	Carbon stock	Carbon equivalent
Highly Disturbed	Large	145.08	532.40
	Medium	142.78	524.02
	Small	151.66	556.62
Mean of Disturbance gradient		146.50	537.68
Less Disturbed	Large	434.80	1595.68
	Medium	413.12	1516.14
	Small	375.02	1376.28
Mean of Disturbance gradient		407.64	1496.04
SEm ±	Disturbance gradient (D)	24.32	89.24
	Kaan size (S)	29.78	109.30
	D × S	42.12	154.56
CD @ 5%	Disturbance gradient (D)	72.24	265.10
	Kaan size (S)	NS	NS
	D × S	NS	NS

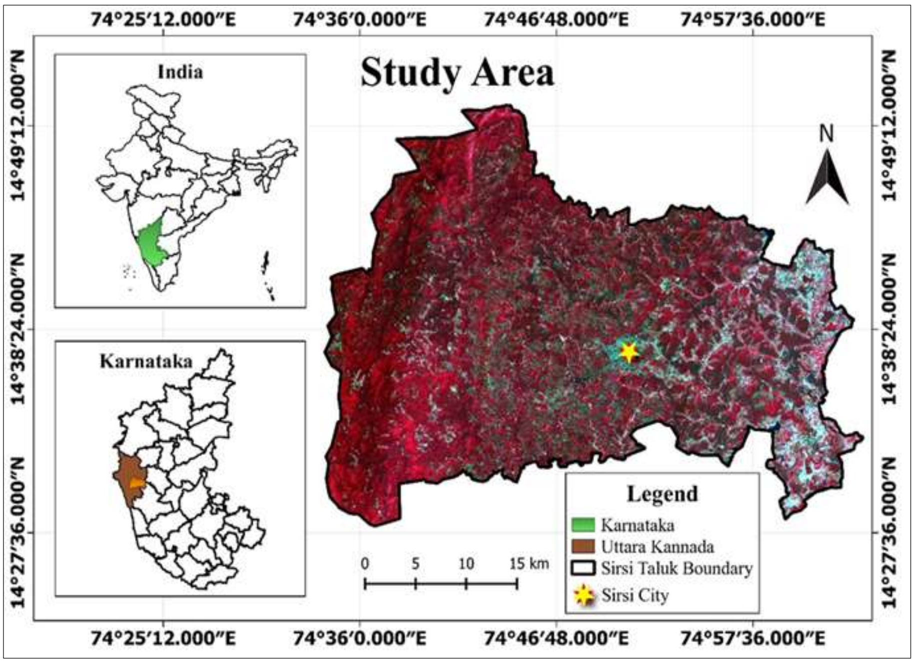

Fig 1: Study area map of Kaan forests, Sirsi taluk

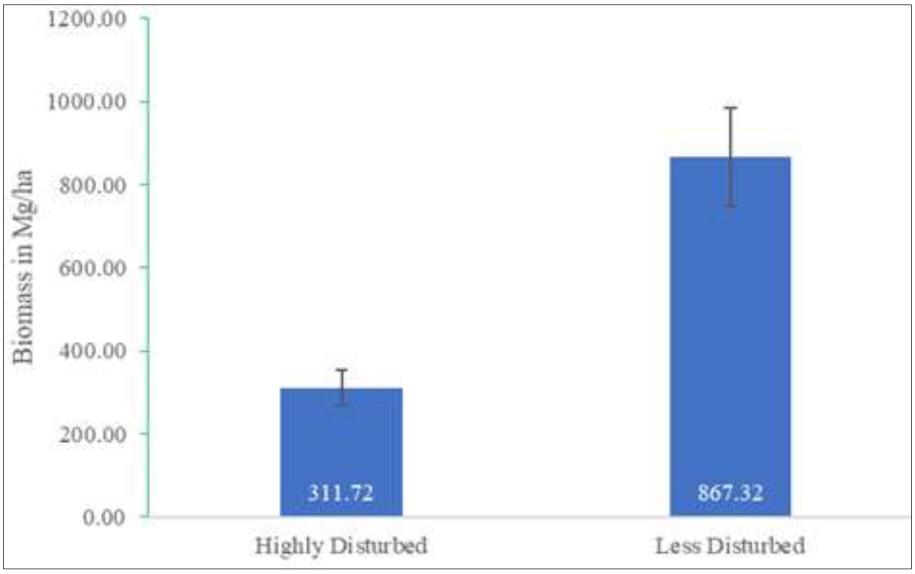

Fig 2: Total biomass (both above and below ground) (Mg/ha) in two different disturbance level of Kaan forest

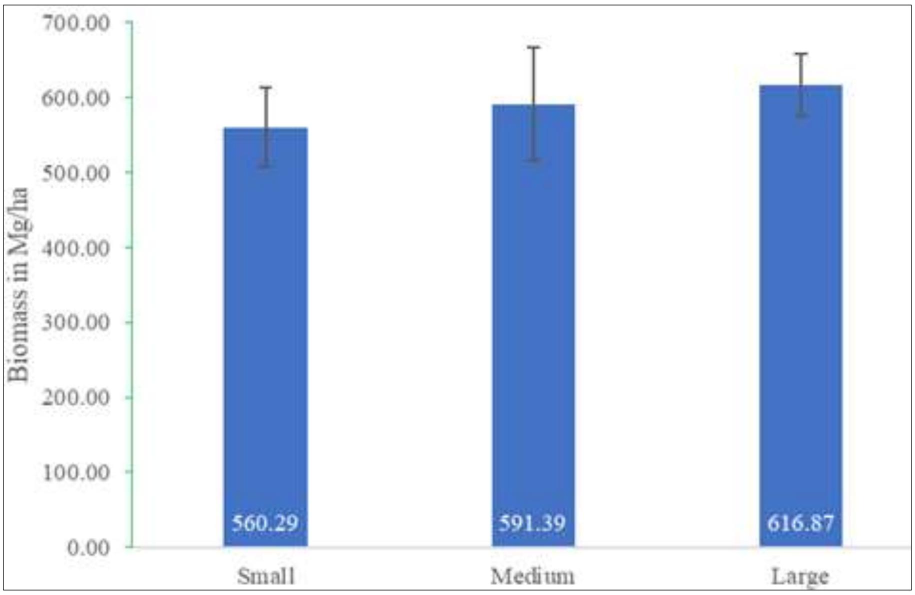

Fig 3: Total biomass (both above and below ground) (Mg/ha) in different size class of Kaan forest

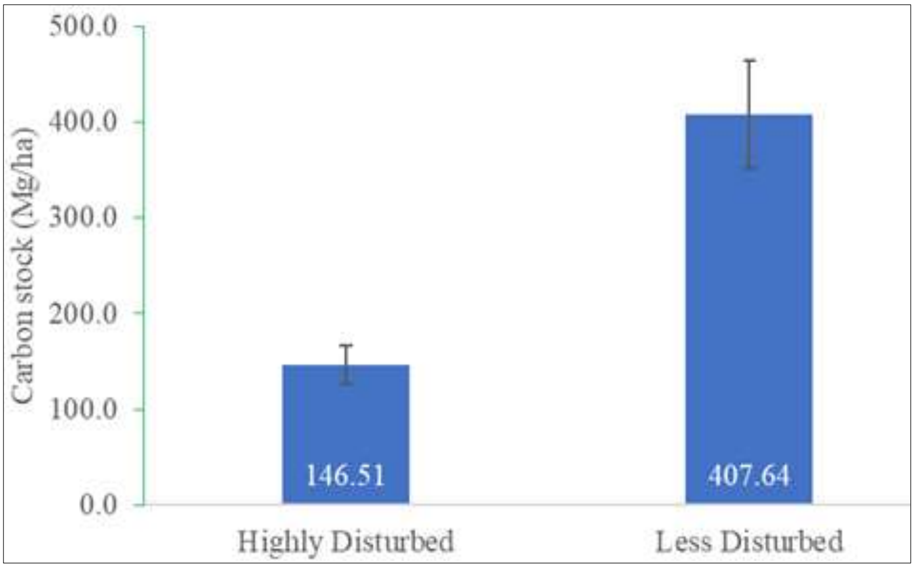

Fig 4: Total carbon stock (Mg/ha) in two different disturbance level of Kaan forest

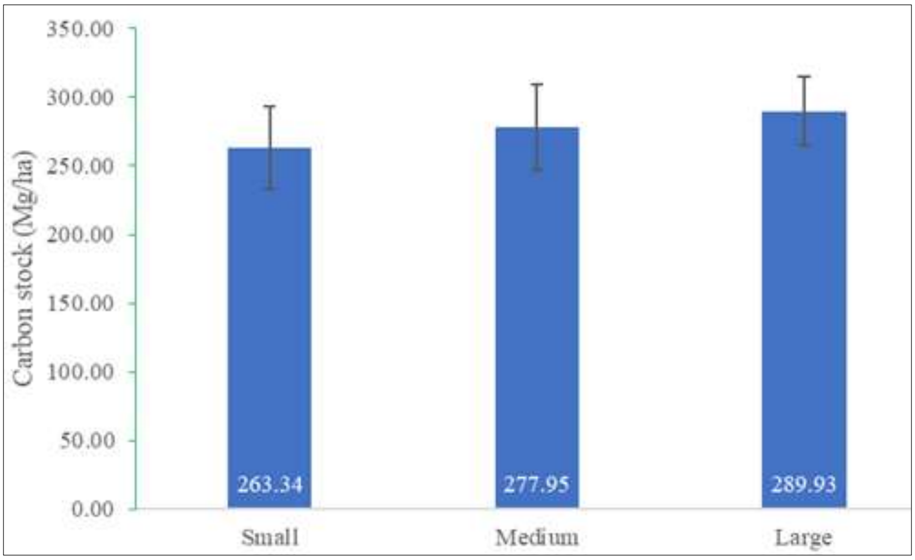

Fig 5: Total carbon stock (Mg/ha) in different size class of Kaan forest

Conclusion

The reduction in total areas of forests, isolation of small mosaic patches, loss of habitat with increased disturbance are all due to forest fragmentation. All these were responsible for decrease in total biomass and carbon stock in the Kaan forests. The maximum biomass and carbon stock was found in less disturbed Kaans. Among the different disturbance level, significantly higher AGB was obtained in less disturbed level (688.34 Mg ha^{-1}) and was least in high disturbed level (247.40 Mg ha^{-1}). The similar trend was noticed in below ground biomass with 178.98 Mg ha^{-1} and 64.32 Mg ha^{-1} in less and high disturbance level respectively. Once again, the total biomass was found to be significantly higher in less disturbed Kaans (867.32 Mg ha^{-1}) compared to highly disturbed Kaans (311.72 Mg ha^{-1}). Significantly higher carbon stock was recorded in less disturbed Kaan (407.64 Mg ha^{-1}) compared to highly disturbed Kaan (146.50 Mg ha^{-1}). It is evident from the results that the less disturbed large Kaans showed higher values of biomass and carbon stock compared to Medium and Small Kaans. In this context, study on impact of forest fragmentation especially in Kaan forests Sirsi taluk on above ground biomass and carbon stock will provide significant support to develop effective conservation strategies in protecting these pristine habitats.

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