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Tree Species Diversity and Carbon Stock in Community and Religious Forests of Rupandehi, Nepal

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Abstract

Forest is one of the most important natural resources of the ecosystem which contributes in biodiversity conservation as well as plays a significant role in maintaining the earth's climate by sequestrating atmospheric carbon. Tropical forests are rich in biodiversity and store large amounts of carbon. The studied Bolbum Community Forest (BCF) and Brahmakumari Global Religious Forest (BGRF) lie in tropical region between the altitudes 120 and 300 m asl in Rupandehi District of Nepal. The main objective of this research was to assess and compare tree diversities and carbon stocks in two different management regimes, namely, community forest and religious forest. Stratified random sampling technique was used for data collection. The allometric equation biomass-diameter regression (Model II) was used for estimation of carbon stock of tree species while Simpson and Shannon-Wiener indices were used to measure tree species diversity. The results showed that the carbon stock value was 27.15 t.ha^{-1} in BCF and 40.94 t.ha^{-1} in BGRF. The community forest had lower value of tree carbon stock than that of the religious forest. However, tree diversity was higher in BCF (25) than in BGRF (20). *Shorea robusta* was found to be the single dominant species in BGRF with higher basal area (102.24 m^2.ha^{-1}) and contributed 56% of the carbon stock. The contribution of carbon stock of two co-dominant tree species in BCF were 32% for *Shorea robusta* and 26% for *Terminalia anogeissiana*. There was significant (p=0.05) positive relationship of carbon stock with basal area and DBH in both forest types.

Keywords: Aboveground biomass, Belowground biomass, Regression, Wood density

Introduction

Forests play a significant role in offsetting the emission of carbon dioxide, the primary anthropogenic green-house gas. Forests in the United States alone sequester about 200 million metric tons of carbon each year. Growing trees may be a potential way to help reduce the amount of carbon dioxide in the atmosphere by allowing it to accumulate in the form of biomass (Chavan & Rasal, 2010).

There are six different types of forest management practices in Nepal to conserve the biodiversity (Bhattarai, 2016), *viz.* government managed forest, leasehold forest, religious forest, protection forest, community forest and private forest. There are differences in their forest management practices. Community forestry is a participatory forest management system in Nepal that was started in the late 1970s. Gilmour and Fisher (1991) defined community forestry as the control, protection and management of forest resources by rural communities for whom trees and forests are an integral part of their farming systems. Sacred groves or religious forests are forest patches having traditional and cultural values for local and indigenous people who protect the groves with their strong socio-religious beliefs and taboos (Khumbongmayum et al., 2006). Sacred groves, as a pioneer of community managed natural resource management regime in Nepal, have received considerable attention. Religious forests are not harvested and there is a belief that it is devoted in the name of the god (Acharya, 2003).

Species diversity in an ecological community incorporates both richness and evenness of species abundances. Diversity is measured to determine if an environment is degrading and to compare two or more environments. Diversity indices provide important information about the composition of community. Species diversity can be expressed in a single index number. Ecologists have developed many indices of species diversity among which Simpson index (Simpson, 1949) and Shannon-Wiener index (Shannon & Weaver, 1949) are the most commonly used indices.

Carbon stock refers to the amount of carbon stored, mainly in living biomass and soil, but to a lesser extent, also in dead wood and litter. In the total ecosystem (living plus dead biomass plus soil), the carbon stock is determined by the balance between the fluxes of carbon gain by Net Primary Productivity, and carbon loss by decomposition of dead biomass and heterotrophic respiration. Ecosystem carbon stocks vary because environmental conditions influence the carbon fluxes of photosynthesis, decomposition and autotrophic and heterotrophic respiration differently (Keith et al., 2009; Mukul et al., 2020). Carbon dioxide emission and its control have become a major problem nowadays (Baul et al., 2021; United Nations Framework Convention on Climate Change, 2015). Due to their ability to store one-fourth of the world's terrestrial carbon, tropical forests play a significant part in the removal of atmospheric carbon dioxide (Adame et al., 2013; Mitchard, 2018).

Our study aims to estimate the tree species diversity and their contributions in the carbon stock in two differently-managed tropical forests of the Rupandehi district.

Figure 1: Map of the study area

Materials and Methods

Study area

For the present study, two forests with different management practices i.e. Bolbum Community Forest (BCF) of Sainamaina municipality (ward no. 1, 4, 5 and 7) and Brahmakumari Global Religious Forest (BGRF) or Brahmakumari Global Peace Park of Butwal sub-metropolitan city (ward no. 17) were chosen. Both the study areas lie in the tropical region and are dominated by *Shorea robusta* Gaertn.

BCF covers an area of 623.03 ha. The dominant tree species of this forest include *Shorea robusta, Buchanania cochinchinensis* (Lour.) Almeida, *Wendlandia heynei* (Schult.) Santapau & Merchant, *Semecarpus anacardium* L. fil. and *Terminalia elliptica Willd.*. Silvicultural practice is present in this forest.

BGRF covers an area of 10.32 ha. This forest is managed by Brahma Kumaris. The dominant tree species of this forest include *Shorea robusta, Wendlandia heynei, Semecarpus anacardium, Terminalia elliptica* and *Lagestroemia parviflora* Roxb.

Data collection and analysis

Both primary data (from field visit) and secondary data (from internet, books, reports, journals and forest users groups) were collected. Stratified random sampling was done for the collection of primary data. Fifty plots of 10 m × 10 m were laid in each forest and tree species on the plots were recorded along with their height and diameter at breast height (DBH). Plants species with DBH ≥ 10 cm were considered as tree (Allaby, 1998). The height of the tree was recorded by using clinometer, while the DBH was measured using the DBH tape. Identification of the collected plant species was done following the standard literature (Shrestha, 1998; Siwakoti & Varma, 1999) and local experts.

The vegetation analysis was done following the method proposed by Misra (1968). The density, relative density, frequency, relative frequency, abundance, relative abundance and Important Value Index (IVI) were calculated following the formula stated by Zobel et al. (1987) as seen in (1) to (8).

$$\text{Density (pl/ha)} = \frac{\text{Total no. of plant species}}{\text{Total no. of quadrates studies} \times \text{area of quadrates}} \times 10{,}000 \quad (1)$$

$$\text{Relative density (\%)} = \frac{\text{Density of individual species}}{\text{Total density of all the species}} \times 100 \quad (2)$$

$$\text{Frequency (\%)} = \frac{\text{Number of plots in which species occurred}}{\text{Total number of plots taken}} \times 100 \quad (3)$$

$$\text{Relative Frequency (\%)} = \frac{\text{Frequency of a species}}{\text{Total frequency of all species}} \times 100 \quad (4)$$

$$\text{Abundance} = \frac{\text{Total no. of plant species}}{\text{No. of plots in which species occurred}} \times 100 \quad (5)$$

$$\text{Relative Abundance (\%)} = \frac{\text{Total no. of individual species}}{\text{Total no. of individual of all the species}} \times 100 \quad (6)$$

Importance Value Index (IVI) = RD + RF + RA (7)

Where, RD = Relative Density, RF = Relative Frequency, RA = Relative Abundance

$$\text{Basal Area } (m^2) = \frac{\pi d^2}{4} \quad (8)$$

The diversity indices, i.e. Shannon-Wiener index and Simpson index, were calculated by using (9) and (10) stated by Shannon and Weaver (1949) and Simpson (1949) respectively.

$$H = -\sum_{i=1}^{S} p_i \ln p_i \quad (9)$$

Where H = Shannon's index, p_i = species proportion (based either on species count or species basal area).

$$D = 1/p_i^2 \quad (10)$$

Where pi is the proportion of individuals in species community

The similarity index was calculated by using (11) given by Gerg-Smith (1964).

$$\text{Index of Similarity} = \frac{2C}{A + B} \times 100 \quad (11)$$

Where A = Total Number of Species in one sample, B = Total Number of Species in another sample, C = Total Number of Species in both the sample.

The allometric equation biomass-diameter regression (Model II) (12) developed by Chave et al. (2005) for moist forest stand was used to estimate above ground tree biomass.

$$\text{Above ground tree biomass} = 0.059 \times \rho D^2 H \quad (12)$$

Where, ρ = Wood density, H = Height of tree in meter, D = Diameter at breast height

The biomass of root system of tree was estimated by assuming that it constitutes 15% of the above ground biomass (MacDicken, 1997). Total biomass was obtained by adding aboveground biomass and belowground biomass. Similarly, carbon stock of individual tree species was determined by summing up density values of whole forest for that particular species.

Statistical analysis of the data was done by using the SPSS 16.0 software where one way ANOVA and regression analysis were done based on the need of the data.

Results and Discussion

Plant diversity indexes of the forest

The total number of tree species was comparatively higher on the BCF (25 spp.) than on that of BGRF (20 spp.) (Figure 2). This might be due to management practices and plantation. In BCF, silvicultural practices like cutting, pruning, singling, litter and fodder collection, and timber extraction are common. These activities create open space for the establishment of new species. Pandey et al. (2014) also documented more tree species in community forest than in national park forest as the forest management communities have interests in multiple species. This might be the reason for the presence of more tree species in BCF than in BGRF.

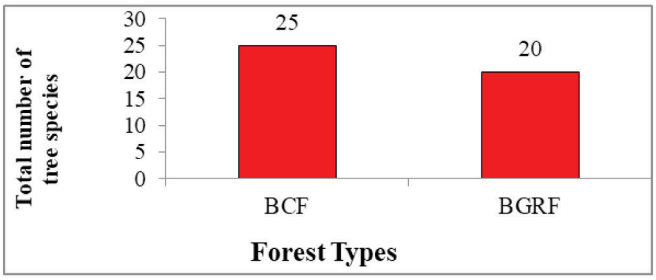

Figure 2: Tree species richness in BCF and BGRF

The dominance and ecological succession of a plant species is shown by the IVI of that species with a

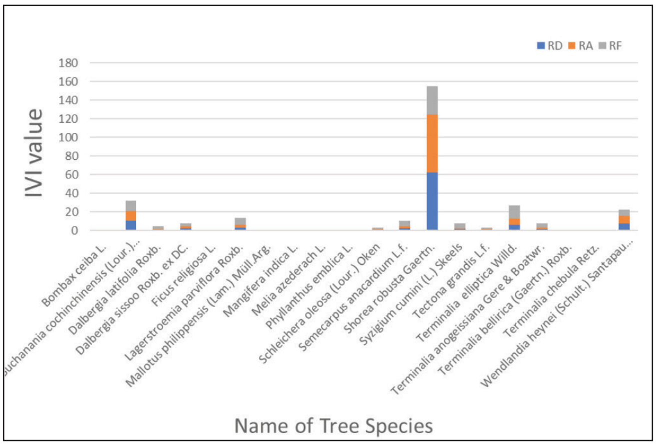

Figure 3: IVI value of tree species showing RD, RF and RA of Brahmakumari Global RF

single value. In BCF, *Terminalia anogeissiana* Gere & Boatwr. had the highest value of IVI followed by *Shorea robusta, Buchanania cochinchinensis* and *Terminalia elliptica* (Figure 4). This showed that, in BCF, *T. anogeissiana* is the dominant species on the basis of IVI value. Similarly, other tree species associated also are suitable on that altitude in that community forest. Similarly, in the BGRF, *S. robusta* was dominant in terms of IVI and was found to be associated with *B. cochinchinensis, T. elliptica* and *Wendlandia heynei* (Figure 3).

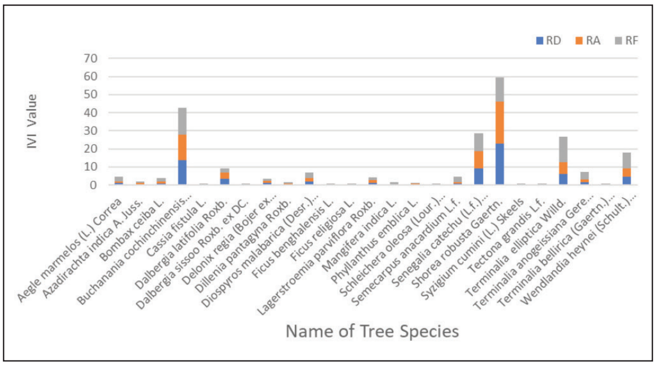

Figure 4: IVI value of tree species showing Relative Density, Relative Frequency and Relative Abundance of Bolbam CF

Diversity index of two forest

Both the diversity indices i.e. Shannon-Wiener index and Simpson's diversity index were higher in the BCF (i.e. 2.16 and 6.19 respectively) than in BGRF (i.e. 1.45 and 2.42 respectively) (Table 1). The result indicated high tree diversity in BCF than in BGRF. One of the most significant and inclusive systems of forest management developed in Nepal is community forestry (Chowdhary & K.C., 2015). It replenishes degraded land with trees, provides habitat for flora and fauna, recharges water sources, and acts as a corridor for wild animals to exchange genetic material to maintain species diversity. The Simpson index obtained was 6.19 for BCF; this indicates that there is even distribution of tree species in BCF. Similarly, the numbers of tree species was 20 in BGRF and Simpson index obtained was 2.418, which indicates uneven distribution of tree species. The tree species in BCF were more evenly distributed (0.6708) than in BGRF (0.4842).

Table 1: Diversity indices of Bolbum Community Forest (BCF) and Brahmakumari Global Religious Forest (BGRF)

Forest Types	Shannon's diversity index	Simpson's diversity index(D)
Bolbum CF	2.16 (0.67)	6.19
Brahmakumari Global RF	1.45 (0.48)	2.42

Table 2: Species wise carbon stock and their contribution percentage in BCF and BGRF

S.N.	Name of species	Bolbum community Forest (BCF)		Brahmakumari Global religious Forest (BGRF)	
		Carbon stock in t ha^{-1}	% Contribution of species	Carbon stock in t ha^{-1}	% Contribution of species
1	*Aegle marmelos* (L.) Correa	0.102	0.375		0
2	*Azadirachta indica* A. Juss.	0.072	0.265		0
3	*Bombax ceiba* L.	0.35	1.286	0.007	0.017
4	*Buchanania cochinchinensis* (Lour.) Almeida	1.547	5.683	1.408	3.439
5	*Cassia fistula* L.	0.011	0.040		0
6	*Dalbergia latifolia* Roxb.	0.26	0.955	0.045	0.109
7	*Dalbergia sissoo* Roxb. ex DC.	0.089	0.326965	0.932	2.2765
8	*Delonix regia* (Bojer ex Hook.) Raf.	0.022	0.080823		0
9	*Dillenia pantagyna* Roxb.	0.037	0.135929		0
10	*Diospyros malabarica* (Desr.) Kostel.	0.471	1.730345		0
11	*Ficus benghalensis* L.	0.492	1.807494		0
12	*Ficus religiosa* L.	0.166	0.609846	0.045	0.10992
13	*Lagerstroemia parviflora* Roxb.	0.154	0.56576	1.245	3.04104
14	*Mallotus philippensis* (Lam.) Müll.Arg.		0	0.007	0.0171
15	*Mangifera indica* L.	0.035	0.128582	0.084	0.20518
16	*Melia azederach* L.		0	0.02	0.04885
17	*Phyllanthus emblica* L.	0.067	0.246143	0.007	0.0171
18	*Schleichera oleosa* (Lour.) Oken	0.006	0.022043	0.654	1.59746
19	*Semecarpus anacardium* L.f.	0.074	0.271859	0.207	0.50562
20	*Senegalia catechu* (L.f.) P.J.H.Hurter & Mabb.	1.633	5.999		0
21	*Shorea robusta* Gaertn.	8.752	32.15283	30.879	75.425
22	*Syzigium cumini* (L.) Skeels	0.014	0.051433	0.245	0.59844
23	*Tectona grandis* L.f.	0.006	0.022043	0.151	0.36883
24	*Terminalia elliptica* Willd.	4.895	17.9831	2.948	7.20078
25	*Terminalia anogeissiana* Gere & Boatwr.	7.088	26.039	1.084	2.648
26	*Terminalia bellirica* (Gaertn.) Roxb.	0.049	0.180015	0.05	0.12213
27	*Terminalia chebula* Retz.		0	0.067	0.16365
28	*Wendlandia heynei* (Schult.) Santapau & Merchant	0.767	2.817781	0.86	2.10064
	Total	27.22	100	40.94	100

Species wise carbon stock in community forest

In the BCF, *Shorea robusta* had the highest carbon stock (8.752 t ha ^{1}) contributing 32.15% in the study result. It was followed by *Terminalia anogeissiana* (26.04%), *T. elliptica* (17.98%), *Senegalia catechu* (L.f.) P.J.H.Hurter & Mabb. (5.99%) and *Buchanania cochinchinensis* (5.68%) respectively (Table 2). The tree species *Tectona grandis* L.f. had the lowest carbon stock contributing only 0.022%. Similarly, in the BGRF, *Shorea robusta* had the highest carbon stock contribution 75.425% in the present study. It was followed by *Terminalia elliptica* (7.20%), *Buchanania cochinchinensis* (3.44%), *Lagerstroemia parviflora* Roxb. (3.04%) *and Terminalia anogeissiana* (2.65%). The tree species *Mallotus philippensis* (Lam.) Müll.Arg. had the lowest carbon stock contributing only 0.017% (Table 2).

Shorea robusta contributed 32.22% of carbon stock in BCF and 71.42% of carbon stock in BGRF (Table 2). These values are less than the values obtained for *S. robusta* in above ground carbon stock of Laxmi Mahila CF (95%) and Jalbire Mahila CF (86%) of Gorkha, district reported by Neupane and Sharma (2014), but are higher than the carbon stock contributed by *S. robusta* in Fulbari CF (65%) and Taldanda CF (44.7%) of Tanahun district reported by Gaire (2015).

The dominant species shows a major role in term of carbon storage in the forest (Genath et al., 2019; McNicol et al., 2018; Padmakumar et al., 2018; Winfree et al., 2015). However, in BCF, the IVI of *Terminalia anogeissiana* is comparatively higher than that of the *Shorea robusta*, but in the context of the carbon content contribution, the *S. robusta* was found to be the highest contributing tree species in both the site although the wood density of *T. anogeissiana* was higher (0.790 g cm^{-3}) (Hong et al., 1999) than that of *S. robusta* (0.730 g cm^{-3}) (Limaye & Sen, 1953). This may be due the higher DBH and larger height of the *S. robusta* in the study site as Ogawa et al. (1965) reported that combining DBH and height was a suitable predictor for above ground biomass.

Carbon stock, Basal area and DBH relation

The regression graph showed significant correlation of the carbon stock of the two different forest types with the DBH of the tree species of the respective forest (Figure 5 and 6).

The regression graph showed significant correlation of the carbon stock of the two different forest types with the basal area of the tree species of the respective forest (Figure 7 and 8).

The relation of the carbon stock of the tree species with the DBH and basal area showed that the increasing stand structure would enhance the productivity of the forest.

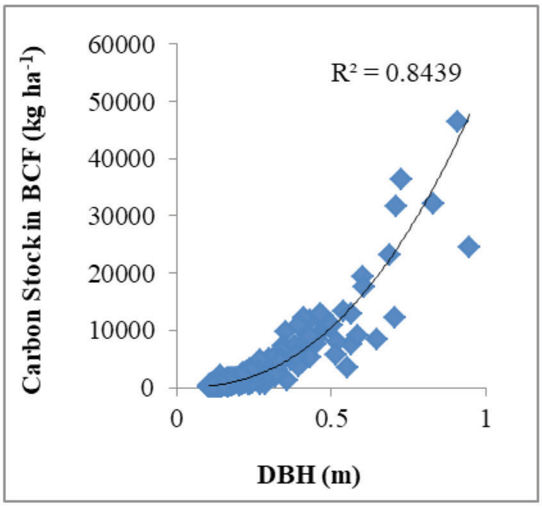

Figure 5: DBH and Carbon-stock relation in BCF

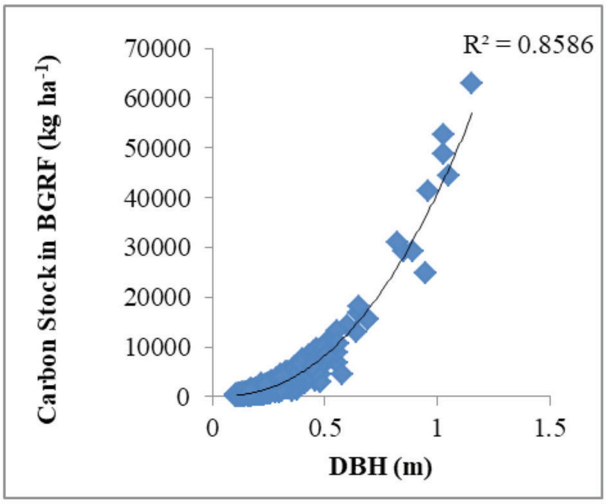

Figure 6: DBH and Carbon-stock relation in BGRF

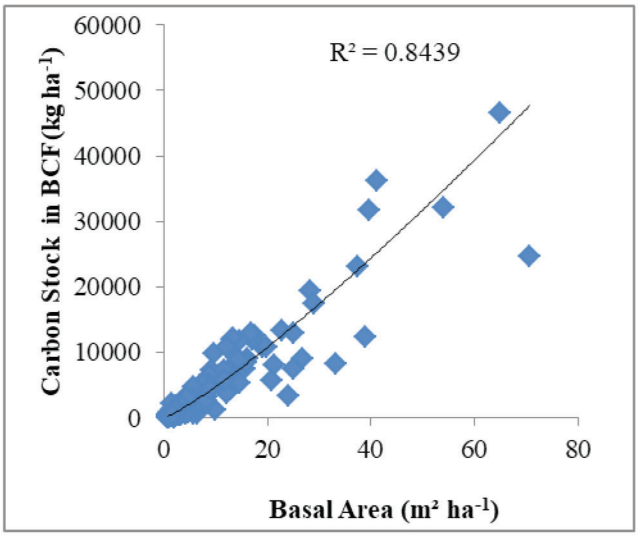

Figure 7: Basal area and Carbon stock relation in BCF

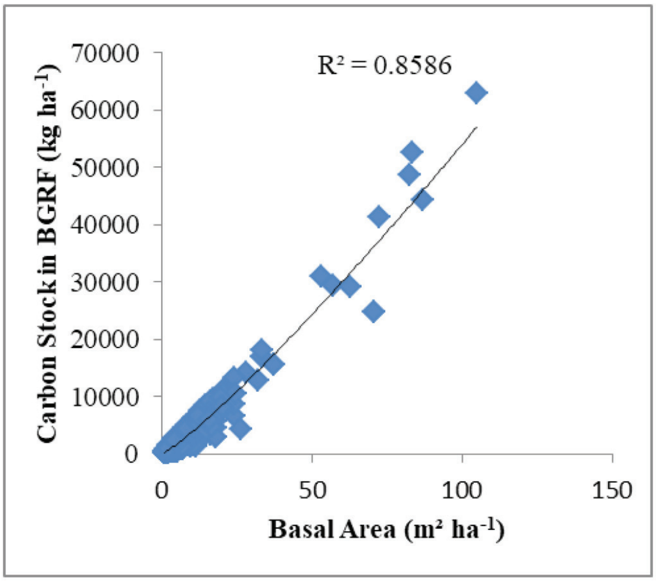

Figure 8: Basal area and Carbon stock relation in BGRF

Conclusion

The highest IVI value of *Shorea robusta* was recorded at BGRF and associated tree species were *Buchanania cochinchinensis*, *Terminalia elliptica*, and *Wendlandia heynei*. However, *Terminalia anogeissina* was found to have highest IVI value in BCF and other associated species were *Shorea robusta, Terminalia elliptica, Senegalia catechu* and *Buchanania cochinchinensis.* Dominance of *Shorea robusta* was observed in BGRF but co-dominance of *Terminalia anogeissina* and *Shorea robusta* was observed at BCF. Carbon stock was recorded higher in BGRF (40.94 t ha^{-1}) than in BCF (27.15 t ha^{-1}). Lower value of carbon stock in BCF than in BGRF indicates that the management practices in BCF like thinning, singling, pruning, pole stage thinning, litter collection, firewood collection, timber extraction etc. might have influenced carbon stock in forests. Tree diversity was higher in BCF than in BGRF, plantation of trees with non-timber forest product values in BCF might have contributed in it. The contribution of *Shorea robusta* was found to be highest in both forests under different management practices. About 32.22% of carbon stock in BCF and 71.42% of carbon stock in BGRF are contributed by *Shorea robusta* alone.

Author Contributions

All the authors were involved in concept development, research designing, defining of intellectual content and literature research. Poudyal, A., Subedi, B. and Khanal, R.P. collected and analyzed data, and prepared manuscript. Chettri, M. K. edited and reviewed the manuscript, and is the guide for each and every work from research design to preparation of this article. All the authors read and approved the final version of the manuscript.

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