Assessment of carbon stocks in Sal forests (*Shorea robusta*) under core and buffer zones of Shuklaphanta National Park, Nepal

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Abstract: Forests play a significant role in sequestrating carbon and regulating the global carbon and energy cycles. Estimation of total biomass and soil carbon sequestered in any forest is very important as it gives ecological and economic benefits to the local people. The study was carried out to quantify and compare the carbon stocks in the Sal (S. robusta) forest in the core and buffer zones of Shuklaphanta National Park in Kanchanpur district of Nepal. A total of 50 sample plots with 25 in each core and buffer zone were laid in the field. Circular nested plots with an area of 500 m2, 100m2, and 25m2 were established in the field to measure trees, poles, and saplings respectively. The soil samples were collected from 0-10 cm, 10-20 cm, and 20-30 cm depth. The above ground and below ground biomass of forests was estimated using Chave et al. and soil carbon was analysed using Walkley and Black method. The total carbon stock in the core zone was estimated to be 258.56 t/ha with 75.64% in biomass and 24.36% in the soil. In the buffer zone, the total carbon stock was almost 25% lower than that at the core zone but a slightly higher composition of biomass (i.e, 80.41% of 193.3 t/ha). These differences are likely due to the effect of the differences in management practice in the core and buffer zones. These estimates suggest that national parks have the great potentiality to sequester more carbon than the buffer zones. Findings from this study provide useful information on how different management practices could alter forest carbon stocks in Nepal.

Keywords: *Biomass, carbon stock, buffer zone, core area, Shorea robusta, soil organic carbon*

Introduction

Carbon sequestration is the capture and secure storage of carbon that would otherwise be emitted to or remain in the atmosphere (FAO, 2000). Forests play an important role in the local, regional, and global carbon cycle by storing large quantities of carbon in vegetation and soil and exchanging carbon with the atmosphere through photosynthesis and respiration (Brown and Pearce 1994). Forest vegetation and soil share almost 60% of the world's terrestrial carbon (Winjum et al., 1992). The sink of carbon sequestration in forests and wood products helps offset the release of carbon dioxide to the atmosphere from human-induced processes, such as urbanization, deforestation, forest degradation, forest fires, and fossil fuel consumption. Carbon emissions from deforestation account for an estimated 20% of global carbon emissions (IPCC, 2006), which is second only to emissions from fossil fuel combustion (Campbell et al., 2008). To successfully reduce greenhouse gas emissions from land cover change, effective strategies for protecting natural habitats are needed.

The establishment of protected areas (PAs) is one of the most effective strategies for the reduction of deforestation and biodiversity loss (Coetzee et al., 2014; Collins and Mitchard 2017; Pradhan et al., 2019). PAs are also a climate change mitigation strategy that can help reduce the atmospheric load of carbon dioxide (Ricketts et al., 2010). PAs play a significant role in mitigating the impacts of climate change on biodiversity and providing safer habitats for species to provide opportunities for the management of plants that can yield positive effects(Lehikoinen et al., 2018). Among these opportunities is sustainable management of stand structure to increase biomasses and sequester more carbon. The extent to which PAs are effective at conserving their carbon stores is not well explored. This depends on many factors, such as whether areas are actively managed or not, the level of enforcement, the level of resource use permitted land-use change pressures, and governance. The majority of the study focused on forest protected areas suggests that protected areas are an effective tool for reducing deforestation within their boundaries (Clark et al., 2008). Estimation of total biomass and soil carbon sequestered in any forest is very important as it gives ecological and economic benefits to the local people. So, above-ground biomass and below-ground root biomass both need to be measured to enable better calculations of forest carbon (Hamburg, 2000). Reducing Emissions from Deforestation and degradation (REDD+) which includes the roles of conservation, sustainable management of forest, and enhancement of carbon stocks, is an initiative to protect the existing forest and enhance forest cover. Under the REDD+ framework, developing countries are encouraged to enhance their forest cover in return for carbon credits to prevent people from cutting trees and instead earn their livelihood from preserving the forests. REDD+ mechanism has a brighter prospect for a country like Nepal, where 23.39 % area of Nepal is covered by protected areas and is designated with the objectives of not only conserving biodiversity but also fulfilling an important role of maintaining the terrestrial carbon stocks. It is also useful to make of good mitigation strategy for climate change effects, as Nepal is a member of the Forest Carbon Partnership Facility (FCPF), an innovative approach for financing efforts to combat climate change.

Sal (*S. robusta*) is the most dominant species of the tropical and subtropical broadleaved forest of Nepal (Jackson, 1994). It has the highest stem volume (31.76 m3/ha or 19.28%) in forest at the national level (DFRS, 2015). Sal forests not only have higher economic value but also serve as an important ecological benefit in the form of slackening global warming and climate change through sequestering atmospheric carbon dioxide (Shrestha, 2008). The quantification of sequestered carbon in both forests profiles with different management regimes could be important for better management of natural resources in Nepal.

Species composition, stand age, and management practices as well as site characteristics such as soil properties and climate can influence local carbon stocks and fluxes (Mund and Schulze , 2006). The amount of carbon in different pools such as deadwood, soil, and aboveground biomass may also depend on environmental factors and management practices. Numerous studies have been carried out in Nepal to assess the carbon stock in different land-use types, forest management regimes and species (e.g. Shrestha et al., 2019; Aryal et al., 2017; KC et al., 2018; Kafle et al., 2019). However, there is an information gap on the differential amount of carbon stocking in protected areas and community-managed forests in the current scenario of the Terai forest in Nepal. Knowledge of carbon stocks is important in developing the strategies for the different management operations. Therefore, the present study aims to quantify and compare the above and below-ground biomass carbon stocks and soil organic carbon stocks within the Sal forest in the core and the buffer zones of Shuklaphanta national park, along with the similar climate and altitudinal range, located at Terai region of Kanchanpur District, Nepal.

Materials and Methods

Study area

The present study was undertaken in the core area and buffer zone community forest (BZCF), Baijnath of Shuklaphanta National Park with similar climate and altitudinal ranges, located at the far south-western Terai of Kanchanpur district in Nepal (Figure 1). The climate of the region is tropical with an altitude ranging from 174 m to 1386 m from the mean sea level. The average temperature ranges from 7°C in winter to 42°C in autumn with an average annual precipitation of 1579 mm. The total area of Shuklaphanta National Park is 305 km^2, with a buffer zone of 243 km^2. The vegetation types primarily include Sal (*S. robusta*) forest, Sal savanna, which is part of the continuum between climax forest and grassland that is maintained by fire and floods (DNWC, 2021). Sal forest is the most dominant vegetation type in the study area. The core zone is managed by DNPWC, whereas the buffer zone community forest is managed by the local community. The buffer zone community forest is located in Bedkot Municipality, which covers an area of 605 ha. This buffer zone community forest has sufficient growing stock to fulfilll the basic forest needs of local people. The forest management practices, such as thinning, pruning, clearance of leaf litter, cutting and logging of trees, and others have been followed as per their operational plan approved by the warden of the national park.

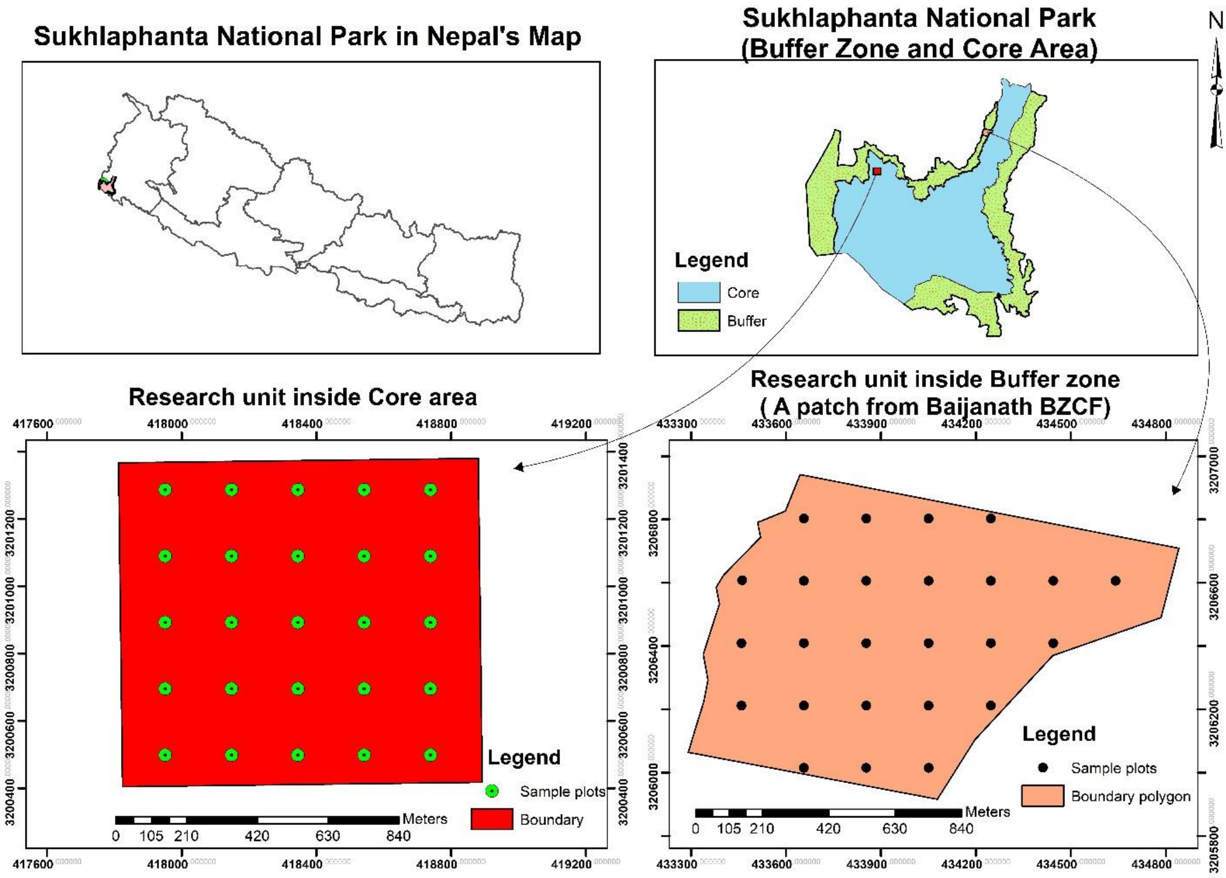

Figure 1: Location of the study area

Data collection

This study employed a systematic random sampling method to collect data with a sampling intensity of 1.25% (MFSC, 2004). From each forest zone (i.e., PA and buffer area), a 100 ha forested area was selected randomly and was divided into 25plots. Circular nested plots of different radius were laid covering 500 m², 100 m², and 25 m² within a plot to measure trees, poles, and saplings, respectively. Diameter at breast height (DBH) was measured using diameter tape and the height of each tree was measured using a Sunto-clinometer. The soil samples at depths 0-10 cm, 10-20 cm, and 20-30 cm were collected from ten sample plots each plot in four cardinal directions using soil corer and placed in the labeled plastic bag. The collected samples were brought to the laboratory to determine the soil organic carbon.

Data analysis

(i) Tree and Pole aboveground biomass

The Above-ground tree biomass (AGTB) was calculated using equation (I) for tropical moist hardwood forests suggested by Chave et al. (2005).

AGTB = 0.0509 * ρ D2 H (I)

where, AGTB is the aboveground tree biomass (kg); ρ is the wood-specific gravity (gm/cm3); D is Diameter at Breast Height (DBH) (cm), and H is the tree height (m).

(ii) Sapling aboveground biomass

The above-ground sampling biomass (AGSB) was calculated by using the formula (II) suggested by Tamrakar (2000).

Log (AGSB) = a +b log (D) (II)

where, AGSB is the aboveground sampling biomass (kg); Log is natural log; 'a' and 'b' are regression coefficients; D is the diameter at breast height (cm).

(iii) Belowground biomass

Below ground biomass was calculated using the root to shoot ratio method in which root to shoot value was taken as 1:5 (i.e. the below-ground biomass is 20% of the above-ground biomass) following MacDicken (1997).

(iv) Carbon stock

All the biomasses were converted to carbon stock using the IPCC (2006) default fraction of 0.47. C = 0.47 × total dry biomass (III)

(v) Soil Organic Carbon

Total carbon stock in forest soil was calculated using equation (IV) following Pearson et al. (2005).

SOC = ρ * d* %C (IV)

where, SOC is the soil organic carbon stock per unit area (t/ ha), p is the soil bulk density (g /cm3), d is the total depth at which the sample was taken (cm), and % C is carbon concentration (%). Soil organic carbon was analyzed using Walkley and Black (1934) in the Soil Testing Laboratory of Sundarpur, Kanchanpur District, Nepal.

(vi) Total carbon stock

The total carbon stock (TCS) density was calculated using equation (V) by summing up C stock in the TAGC, TBGC, and SOC.

TC = TAGC+TBGC+SOC (V)

where, TC is Total Carbon Stock (t/ha); TAGC is Total above ground Carbon Stock (t/ha); TBGC is Total below ground Carbon Stock (t/ha). The total carbon stock was converted to tons of carbon dioxide equivalent by multiplying it by 3.67 (Pearson et al., 2005).

Data were analyzed using descriptive and inferential statistical tools in R software. The graphs and tables were constructed using MS-Excel 2010. To compare the carbon stock densities between the two areas,t-test was used at a 5% level of significance with R statistical software.

Results and Discussion

Carbon Stocks

The above-ground carbon stock was found to be 162.98 t/ha in the core area with 128.43 t/ha, 30.18 t/ha, and 4.36 t/ha, in trees, poles, and saplings respectively (Table 1). This amount was higher than the above-ground carbon stock in the buffer zone community forest, where the estimated carbon stock was found to be 129.53 t/ha (64.62 t/ha, 62.86 t/ha, and 2.05 t/ha in the trees, poles, and saplings, respectively). Similarly, the below-ground carbon stock was found to be higher in the core zone forests (32.59 t/ha vs 25.91 t/ha in the buffer zone forests) though the below-ground carbon stock in the poles of buffer zone forests was found to be slightly higher than that of core zone forests (Table 1). The core zone showed a total carbon stock of 195.58 t/ha, which was 25.82% higher than in the buffer zone (155.44 t/ha) (Table 1). Carbon stocks of trees, poles, and saplings were significantly different for both sites ($p<0.05$; Table 2).

Table 1: Distribution of above ground and below ground carbon stock

Sites	Above Ground Carbon Stock(t/ha)			Below Ground Carbon Stock(t/ha)			Total Carbon Stock(t/ha)
	Trees	Poles	Saplings	Trees	Poles	Saplings	
Core area	128.43	30.18	4.36	25.68	6.03	0.87	195.58
Buffer Zone	64.62	62.85	2.05	12.93	12.57	0.41	155.44

Overall, the carbon stock was found to be higher in the trees, followed by the poles, and saplings. The carbon stock in the poles in the core area was less than the buffer zone. The above-ground carbon stock in the core area was found to be higher than in the buffer zone. Likewise, the core area had the greater belowground carbon stock compared to the buffer zone. More restrictions on forest products harvesting from forests, as enforced in the core area of the national park, could have attributed to the larger the stock of carbon in the biomass carbon pool in the core area.

Table 2: Biomass carbon stock, SOC, total carbon stock (t/ha), and result of the t-test.

Carbon pool	df	Core Area	Buffer Zone	Mean	P-value	Remarks
Tree carbon stock (t/ha)	46	154.12	77.55	115.83	0.0056	*
Pole carbon stock (t/ha)	46	36.22	75.43	55.82	0.0051	*
Sapling carbon stock (t/ha)	39	5.24	2.47	3.85	0.0015	*
Total of biomass carbon stock		195.58	155.44	175.51		
Soil organic carbon (t/ha)	18	62.98	37.88	50.43	0.0009	*
Total carbon stock		258.56	193.33	225.94		

Remarks: * = significant at $P<0.05$

Soil Organic Carbon (SOC)

The soil organic carbon in the core area (62.98t/ha) was significantly ($p<0.05$; Table 2) higher than in the buffer zone (37.88 t/ha) of the national park. The average soil organic carbon in the core area was found to be highest in the uppermost layer (0-10cm) with 33.42 t/ha and lowest in the lowermost layer (20-30cm) with 13.22 t/ha (Figure 2). Likewise, the average soil organic in buffer zone community forest was found to be highest in the uppermost layer (0-10cm) with 17.57 t/ha and lowest in the lowermost layer with 9.52 t/ha (20-30) (figure 3). These findings and carbon stock values from this study correspond with Khadka et al. (2019), who found that the soil organic carbon inside Banke National park (68.42 t/ha) was higher than outside Banke National park (59.59 t/ha). SOC was higher at the upper layers that gradually decreased with the soil depth. A higher amount of soil organic carbon may be also due to the higher density of trees, poles, and saplings and their organic residues. The presence of higher organic carbon in the top layer may be due to the decomposition of forest leaf litter and deadwood in the uppermost layer under suitable environmental conditions.

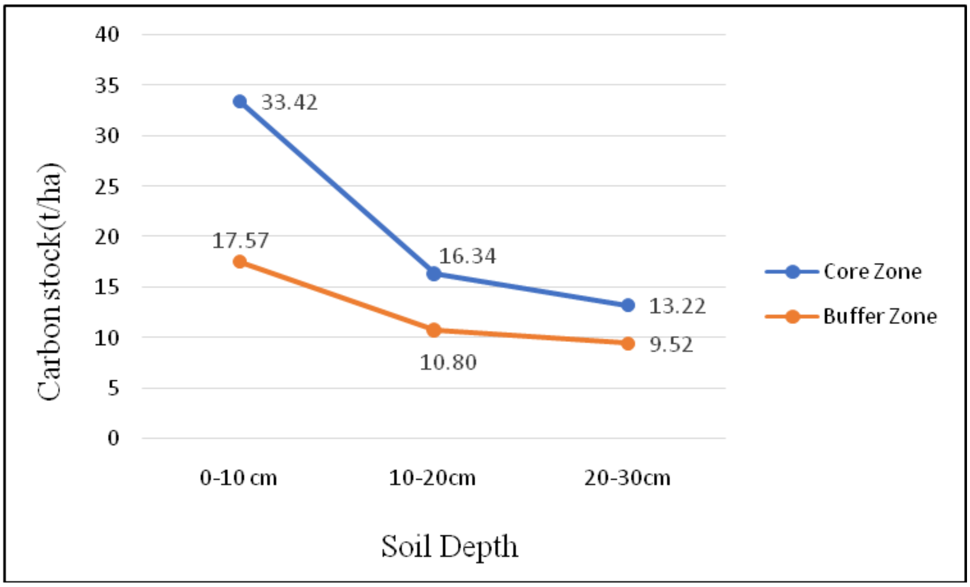

Figure 2: Soil organic carbon in different soil depths

Total carbon stock

Above ground and below-ground biomass carbon stocks when pooled together registered carbon stock (195.58 t/ha) in the core zone, and carbon stock (155.44 t/ha) in the buffer zone. The soil organic carbon registered carbon stock (62.98 t/ha) in the core area, and carbon stock (37.88 t/ha) in the buffer zone respectively. In both zones, the contribution of above-ground biomass carbon was maximum to the total carbon stock, followed by soil organic carbon and below-ground biomass. The core area forest stored total carbon stock (258.56 t/ha) was considerably higher than those in the buffer zone (193.32 t/ha) (Figure 3). This difference is expected to be from the effect of management practices and land-use patterns, as the environmental conditions across both sites are similar. The thinning, pruning, clearance of leaf litter, cutting and logging of the tress for livelihood sustainability of local people and the disturbance from cattle grazing, mining activities in the river beds inside the forest, might have led to lower carbon stock in the buffer zone.

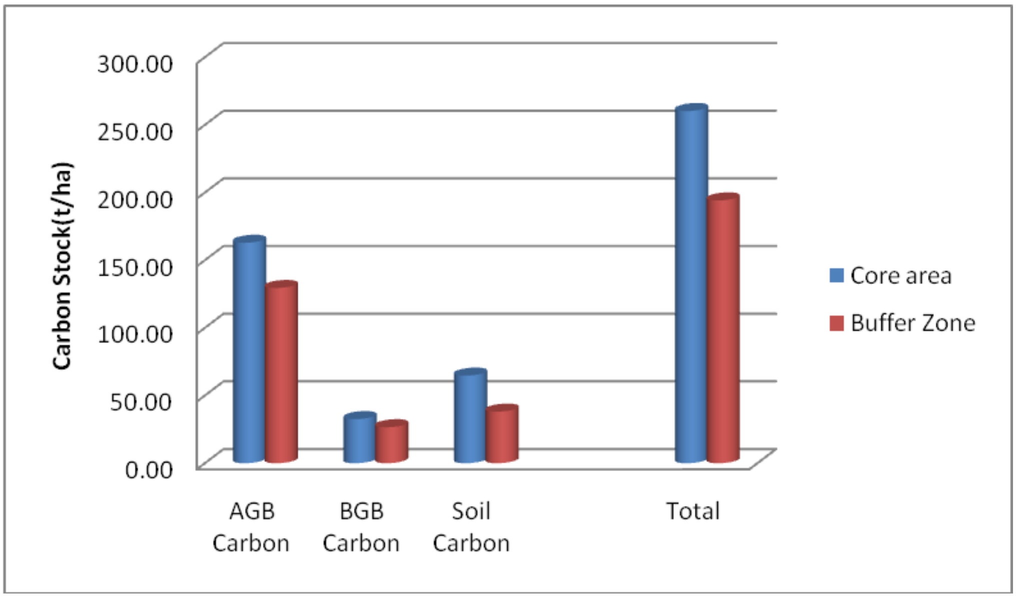

Figure 3: Carbon stock in the core area and buffer zone

In a study by DFRS, soil organic carbon and tree component carbon stock in the forest of the Terai region in 2015 were found to be 33.66 t/ha, and 104.47 t/ha, respectively (DFRS, 2015), which are lower than those found in this study. This is expected given that the tree samples are more mature than the ones surveyed by DFRS. The study done by Pandey et al. (2016) showed that the estimated biomass carbon stock and soil organic carbon stock were 384.20 t/ha, and 95.09 t/h respectively in Terai S. robusta-dominated community forest, which is higher than the present study. Similarly, the study done by Mbaabu et al. (2014) found that the value of the average carbon stock in the community forest of Chitwan in the Terai was found to be 244 t/ha, which is slightly higher than the present study. The main reason for the highest carbon stock of *S. robusta* was the dominancy of this species in the community forests than that of the current study area. The study conducted by Gurung et al. (2015), which showed the carbon stocks in the protected areas and community forests were 291.55 t/ha, and 237.15 t/ha respectively in the Terai Arc Landscape, Nepal. These results are comparable and slightly higher than the present estimates of carbon stock values of 258.56 t/ha in the core zone and 193.33 t/ha in the buffer zone. Khadka et al. (2019) reported that carbon stock in Banke National Park and outside Banke National Park was found to be 218.92 t/ha and 195.86 t/ha, which is nearly similar to the present finding. Soil organic carbon stock was consistently lower at all soil depths after disturbance compared to undisturbed conditions. The carbon stock values are closer and variation in carbon stock values may be due to other factors such as stand density. The carbon stock values would vary according to the geographical location, plant species, age of the stand, aboveground input received from leaf litter, decomposition of fine roots below ground, management practices, and other operating ecological factors (Singh et al., 1987).

Conclusion and Recommendations

This study was carried out to assess and compare the carbon stock of the core and surrounding areas (buffer zone) of Sal forests in the Shuklaphanta national park. Results suggest that sal forests in the core zone store more carbon per unit area than those in the buffer zone within similar climate and altitudinal ranges, largely due to minimal human interventions in the core zone. For example, current restrictions in the harvesting of forest products allow forests to be in their natural conditions in the core area, while open forests in the buffer zone are heavily intervened with several forest management activities that include the extraction of forest products. The soil organic carbon appears to decline with depth across forests in both zones and was also found to be higher in core zone forests as indicated by its relatively high below-ground carbon stocks. Results suggest that protected areas play a significant role in the sequestration of atmospheric carbon and reducing greenhouse gas emissions by storing more carbon in different vegetation and soil than managed forests. However, it is required to assess the trend of carbon sequestration in PAs to confirm the effectiveness of PAs in REDD+ like financial incentives. Future studies should explore the spatiotemporal distribution of carbon stock across the core PAs and its surrounding buffer zone area in Nepal. In addition, how different management practices alter carbon stocks in Sal forests should be explored to help identify the best management practice that can minimize CO2 emissions, as all forests cannot be managed as PAs. Overall, this study provides useful background for future research to assess the trend of carbon sequestration in PAs (core areas) to bring PAs to the carbon incentives including REDD+ and also to understand how different management practices alter carbon stock across different forest systems in Nepal.

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