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Sacred groves: a model of Zagros forests for carbon sequestration and climate change mitigation

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Summary

Forests are the most important carbon pools among terrestrial ecosystems, and ensuring less disturbance of sacred groves might constitute a form of forest management for carbon sequestration and climate change reduction. The carbon contents in Zagros oak sacred groves and silvopastoral lands were compared to determine the carbon sequestration potential of these forests. Using a nested sampling design, we measured total carbon content (tC ha^{-1}; aboveground tree biomass, aboveground sapling biomass, belowground biomass, soil organic carbon, leaf litter, herbs and grasses and dead wood and fallen stumps) in both forest groves and silvopastoral lands. The mean total biomass and mean total carbon content varied between sacred groves (453.8 t ha^{-1} and 338.79 tC ha^{-1}, respectively) and silvopastoral lands (89.4 t ha^{-1} and 113.46 tC ha^{-1}, respectively). Mean soil organic carbon was significantly lower (71.44 tC ha^{-1}) in silvopastoral lands than in sacred groves (125.49 tC ha^{-1}). The mean total sequestered carbon dioxide (CO_2) was 1243.36 tCO_2 ha^{-1} in the sacred groves and 416.40 tCO_2 ha^{-1} in silvopastoral lands. We conclude that human activities have reduced the CO_2 absorption capacity of the forests. The substantial disparities between the landscapes emphasize the need to restore damaged forests, and sacred groves might be a useful model for increasing carbon storage in these forests.

Introduction

Increased concerns about global warming have resulted in special attention being paid to forests, soils and their ability to sustain carbon sequestration (Johnsen et al. 2001, Pahlavan Yali et al. 2016). Forest ecosystems are the most important carbon pools among terrestrial ecosystems and can mitigate climate change (Labrecque et al. 2006, Pan et al. 2011, Lin & Ge, 2019, Santini et al. 2019, Zhang et al. 2019). The high capacity of these ecosystems to reduce greenhouse gas emissions makes carbon management a key component of future natural climate solutions (Griscom et al. 2017, Fargione et al. 2018, Ontl et al. 2020). The Zagros forests span more than 5 million ha and are considered to represent the natural forest ecosystems of Iran, and their economic value in terms of carbon sequestration is substantial (Jazirehi & Ebrahimi Rostaghi 2013). Despite severe and continuous exploitation of these forests, some parts have been less disturbed, notably sacred groves, which are sacred religious areas and cemeteries (Pungetti et al. 2012, Plieninger et al. 2020). In these, a more natural state of the Zagros forests can be found (Shakeri 2007, Jazirehi & Ebrahimi Rostaghi 2013).

In the northern Zagros forests, livelihoods include animal husbandry and traditional agriculture. Animal husbandry has a long tradition, and the leaves of local oak trees are used to provide livestock fodder. Overgrazing is one of the most significant human disturbances (Zhou et al. 2011, Hu et al. 2016, Schulz et al. 2016, Gebregergs et al. 2019), and grazing exclusion can help with the recovery of degraded ecosystems and enhance carbon sequestration (Qiu et al. 2013, Hu et al. 2016, Ma et al. 2016, Atsbha et al. 2019, Gebregergs et al. 2019, Liu et al. 2020). Grazing, cutting down trees, collecting fodder and firewood and harvesting other crops from sacred groves are all forbidden by local community laws (Plieninger et al. 2020). The Zagros sacred groves represent an opportunity to see what the Zagros forests might look like in a less disturbed state. Here, we compare the carbon content of the sacred groves and silvopastoral lands to improve understanding of the capacity of Zagros oak forests to sequester carbon.

Methods

Study site description

The study area includes sacred groves and silvopastoral lands in Baneh County (Zagros Mountains, Iran; 35°48′02″–36°11′40″N and 45°32′45″–46°10′25″E; Fig. 1). The climate is semi-humid and cold. The total annual precipitation is 600–800 mm. Dominant tree species are

Figure 1. Examples of a sacred grove and silvopastoral land in Hange Jal village.

the oaks *Quercus brantii* Lindel, *Quercus libani* Olive *and Quercus infectoria* Olive. This study focused on the villages of Hange Jal, Booien Olya, Nejo, Yaghoub Abad and Gashkese, in each of which cemeteries more than 1 ha in area were selected as sacred groves. Silvopastoral areas were chosen from the forests surrounding these stands that had the same physiographical characteristics as the sacred groves. The land use of the forest is subject to *Galazani*, which involves gathering the branches and leaves of oak trees to feed livestock in the cold season, livestock grazing and other usages, such as harvesting the wood, by forest residents (Fig. 1).

Sampling design

We used nested concentric plots (ICIMOD et al. 2010, Karki et al. 2016), each including a large circular plot (250 m^2 with an 8.20m radius) for tree measurements, a larger sub-plot (100 m^2 with a 5.65-m radius) for saplings, a smaller sub-plot (3.14 m^2 with a 1.00-m radius) to count regeneration (seedlings) and the smallest sub-plot (0.56-m radius) for leaf litter, herbs, grasses and soil samples (Fig. 2). Sampling centres were determined using a systematic random method, and 20 plots were surveyed in each site (10 plots in sacred groves, 10 plots in the silvopastoral lands, study total of 100 plots).

Measurement of forest carbon stock

In both land-use areas, the diameter at breast height (DBH) and height of individual trees (DBH $\geq$5 cm) were measured. All trees that were measured were documented and identified to the species level. In the laboratory, the wood-specific densities (ρ) of the different tree species in each land use were measured. Above ground tree biomass (AGTB), aboveground sapling biomass (AGSB), mass of leaf litter, herbs and grass (LHG) and mass of dead wood and fallen stumps (DWS) were calculated using the allometric equations of Chave et al. (2005) and ICIMOD et al. (2010). Belowground biomass (BGB) was calculated using the equation of Cairns et al. (1997). Soil organic carbon (SOC) was measured in 100 soil samples taken from depths of 0–15 and 15–30 cm. The percentage of SOC was determined using the Walkley and Black (1934) method (Nosetto et al. 2006, Amanuel et al. 2018). The SOC stock was then calculated using the formulae of ICIMOD et al. (2010) and Karki et al. (2016). The total carbon content (tC ha^{-1}) within each land use was then estimated from the sum of the above variables (ICIMOD et al. 2010, Karki et al. 2016, Sumarga et al. 2020). The total forest carbon stock was converted into a carbon dioxide (CO_2) equivalent by multiplying by 3.67 (Pearson et al. 2007).

SPSS version 23 was used for all analyses. The data and residuals were tested for normality. After assessing the homogeneity of variance, *t*-tests were used to compare the mean values of the variables between the two land uses.

Results

The studied variables were significantly different between the sacred groves and silvopastoral lands (Table 1). Aboveground and belowground tree biomass values in the sacred groves were *c.* five times greater than in the silvopastoral areas. In the silvopastoral areas, the values of herbs and grass, leaf litter and dead and fallen wood were much lower than in the sacred groves (Table 1). Total

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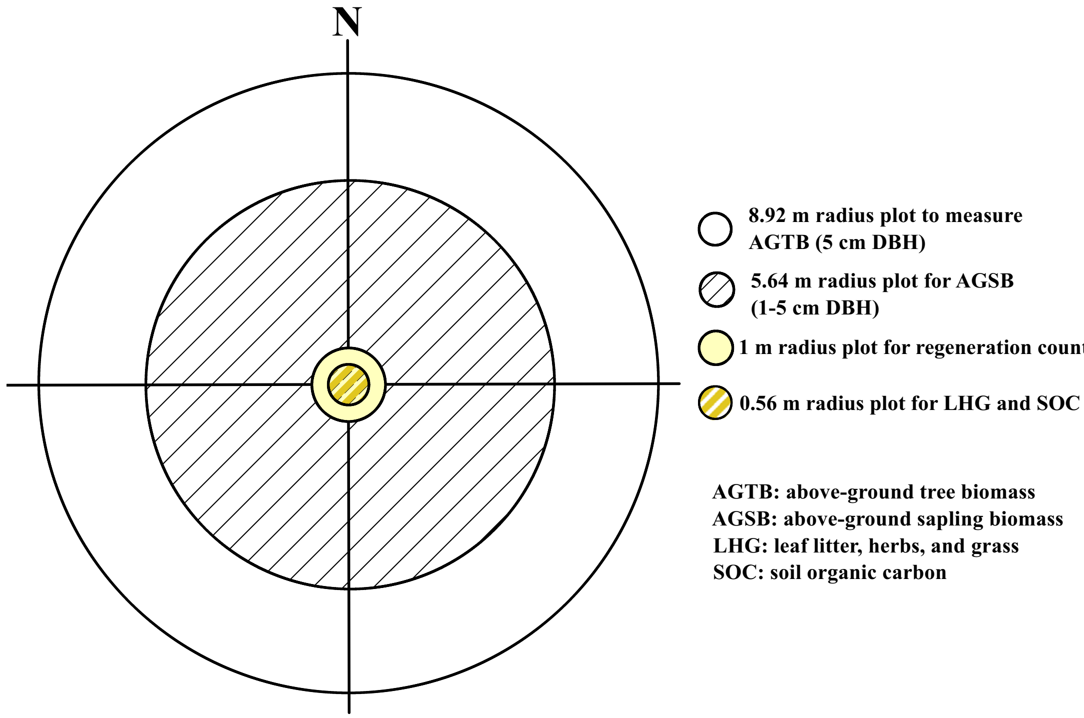

Figure 2. Concentric nested circular plots. DBH = diameter at breast height.

forest biomass and total carbon in the sacred groves were five- and three-fold greater, respectively, than in the silvopastoral lands (Table 2).

Biomass

The mean total biomass values of the sacred groves and silvopastoral lands were 453.8 and 89.4 t ha^{-1}, respectively (Table 1). However, the proportions of the biomass in each of the pools were similar between the land uses; most of the biomass was in AGTB and the least was in AGSB (Table 1). The DWS biomass was substantially greater in the sacred groves (Table 1). Although the LHG biomass was also much greater in sacred groves than in the silvopastoral areas, the percentage of LHG in the total biomass was greater in the latter.

Carbon content

The mean total carbon contents were 338.79 and 113.46 tC ha^{-1}, respectively, in the sacred groves and silvopastoral lands, and the carbon distributions among the carbon pools also differed (Table 2). AGTB and soil contributed most to the total forest carbon stock, while ABSB contributed the least in both land uses. The mean SOC was significantly lower (71.44 tC ha^{-1}) in the silvopastoral lands than in the sacred groves (125.49 tC ha^{-1}). Importantly, in silvopastoral lands the soil carbon (62.96% of total carbon) was greater than the total biomass carbon (37.04% of total carbon). The mean total sequestered carbon dioxide (CO_2) was 1243.36 tCO_2 ha^{-1} in sacred groves and 416.40 tCO_2 ha^{-1} in silvopastoral lands.

Discussion

We compared for the first time the biomass and carbon storage capacity of sacred groves in the Zagros forests with those of adjacent heavily used silvopastoral lands. Aboveground biomass and the total quantity of carbon in all carbon pools were substantially greater in sacred groves than in silvopastoral fields. In the sacred groves there were multi-storey tree cover, trees of greater height and diameter, denser canopy, more abundant leaf litter, greater deadwood, richer grass cover under the canopy and greater species diversity. These findings agree with earlier studies (Dibaba et al. 2019, Baul et al. 2021), suggesting that forest stands with high species diversity and trees with large diameters and heights may in themselves store more carbon. For example, in homestead forests in Bangladesh, Baul et al. (2021) inferred that when tree height and DBH increased by one unit each, the biomass carbon stock increased by 11 and 3 Mg C ha^{-1}, respectively. Dibaba et al. (2019) observed that larger trees with greater diameters have the greatest carbon stores in terms of biomass. Wegiel and Polowy (2020) demonstrated that the amount of carbon stored in plants is strongly related to their biomass. The greater the potential of aboveground and belowground biomass to produce carbon in diverse species and ecosystems, the more carbon is stored in tree trunks, leaf litter and soil.

Grazing exclusion work has shown that overgrazing is among the most significant of human disturbances impacting the performance of ecosystems and SOC stocks (Liu et al. 2020), reducing plant cover, biomass and ecosystem productivity (Atsbha et al. 2019). Grazing exclusion can help recover degraded ecosystems (Hu et al. 2016) and promote carbon deposition (Hu et al. 2016, Gebregergs et al. 2019). In the Zagros silvopastoral lands, animal husbandry is carried out using traditional methods; exacerbating the loss of grass cover on the forest floor, the branches and leaves of the trees in these forests are also used as fodder for the grazing of livestock through the pollarding system. Pollarding lowers tree production and growth capabilities within this land use (Soltani et al. 2020). Low foliage production, little leaf litter on forest floors, sparse grass cover, high soil erosion and compaction

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Table 1. Mean biomass values under the two land uses. The same superscript letters beside the means of any variable indicate no difference at the 1% level between attributes.

Forest component	Sacred groves		Silvopastoral lands		*t*-test		
	Biomass (t ha^{-1})	% total	Biomass (t ha^{-1})	% total	*t*	df	p
AGTB	348.63^{a}	76.82	70.97^{b}	79.38	8.79	98	0.000
BGB	63.30^{a}	13.95	13.61^{b}	15.22	9.27	98	0.000
AGSB	0.27^{a}	0.06	0.05^{b}	0.06	6.47	98	0.000
LHG	12.59^{a}	2.77	4.58^{b}	5.12	7.70	98	0.000
DWS	29.04^{a}	6.40	0.20^{b}	0.22	4.06	98	0.000
TFBI	453.83^{a}	100.00	89.41^{b}	100.00	9.67	98	0.000

The same Roman letters beside means of any parameter indicate no difference at the 5% level between two land uses.
AGSB = aboveground sapling biomass; AGTB = aboveground tree biomass; BGB = belowground biomass; DWS = dead wood and fallen stumps; LHG = leaf litter, herbs and grass; TFBI = total forest biomass.

Table 2. Mean total carbon content and composition percentages by type under the two land uses.

Forest component	Sacred groves		Silvopastoral lands		*t*-test		
	Mean carbon content (t ha^{-1})	% total	Mean carbon content (t ha^{-1})	% total	*t*	df	p
AGTB	163.86	48.37	33.36	29.40	8.79	98	0.000
BGB	29.75	8.78	6.39	5.64	9.27	98	0.000
AGSB	0.13	0.04	0.02	0.02	6.47	98	0.000
LHG	5.92	1.75	2.15	1.90	7.70	98	0.000
DWS	13.65	4.03	0.09	0.08	4.06	98	0.000
TBC	213.30	62.96	42.02	37.04	9.67	98	0.000
SOC	125.49	37.04	71.44	62.96	5.97	98	0.000
TC	338.79	100.00	113.46	100.00	10.53	98	0.000

AGSB = aboveground sapling biomass; AGTB = aboveground tree biomass; BGB = belowground biomass; DWS = dead wood and fallen stumps; LHG = leaf litter, herbs and grass; SOC = soil organic carbon; TBC = total biomass carbon; TC = total carbon.

of the soil surface result in low biomass and carbon inputs and storage levels that are much lower than predicted in the silvopastoral areas. Under local community rules, grazing is prohibited in sacred groves, and this is evidently one of the main contributors to the increased carbon observed in the sacred groves. Tsegay and Meng (2021) also found that exclosure of forests plays a fundamental role in sustaining sinks of carbon, and Speed et al. (2014) concluded that grazing exclusion can increase aboveground carbon stocks, albeit at a low rate. Dong et al. (2021) suggested that grazing exclusion increased aboveground and belowground biomass in semi-arid grasslands and that this contributed to increased SOC concentration. In the Zagros forests, the mean carbon pools in sacred groves were significantly greater than in the silvopastoral lands. These sacred groves give an idea of what the biomass and carbon storage levels and distributions might be in restored Zagros forests. Tsegay and Meng (2021) and Gebregergs et al. (2019) demonstrated that aboveground and belowground carbon stocks were significantly greater under grazing exclusion. Sacred groves also have much greater aboveground and belowground carbon stocks. Grazing and tree cutting are prohibited in the Zagros sacred forests, resulting in much greater biomass and carbon storage in trees and soil than within silvopastoral fields.

The present results indicate that Zagros forests are currently far from their natural state; grazing and overexploitation are prominent drivers of this devastation. In the northern Loess Plateau of China, overgrazing has had a detrimental impact on plant development and soil carbon supply, plant cover, height, lead litter, aboveground and belowground productivity and soil carbon stock, all of which declined with increased grazing intensity (Zhu et al. 2018). Other studies, such as that of Limpert et al. (2021), have indicated that grazing exclusion increases the concentration of carbon in the soil and lowers carbon emissions.

Renhui et al. (2022) demonstrated that plant density, SOC and total nitrogen significantly increase with grazing exclusion; this grazing exclusion also strengthen the relationships between plant variables and SOC. The present results and those from other grazing exclusion studies (Nosetto et al. 2006, Qiu et al. 2013, Speed et al. 2014, Conant et al. 2017, Liu et al. 2020) point to the necessity of restoring silvopastoral lands, balancing grazing and preventing the degradation and overexploitation of these forests. However, grazing has variable effects on SOC depending on the soil type, geography and climate (Wade et al. 2022), and in different areas livestock grazing may require different management strategies to ensure optimal carbon sequestration.

Negative anthropogenic impacts on carbon storage have been reported. For example, Zhu et al. (2021) showed that emissions from the land could increase with deforestation. Shaw et al. (2021) demonstrated that anthropogenic and natural disturbances changed a study area from a net carbon sink into a net carbon source, and Hoover et al. (2021) suggested that mean aboveground live tree carbon accumulation rates could increase considerably when anthropogenic disturbances are excluded. Our findings are consistent with those from these previous investigations, suggesting that the major differences between biomass and carbon in the two analysed applications were attributable to anthropogenic disturbances.

The proportions of each carbon pool in the overall amount of carbon stored were also substantial. In the sacred groves, two-thirds of the carbon were in aboveground and belowground pools, while one-third was in the soil. In contrast, in silvopastoral lands, the soil accounted for *c.* two-thirds of the total carbon, the remainder being in belowground and aboveground pools. This indicates a decrease in tree density and seedlings and a reduction in regeneration in the silvopastoral lands. The amount of soil carbon in sacred groves was *c.* 1.8 times that of silvopastoral lands. The change in the amount of soil carbon sequestration depends on the amount of carbon entering the soil through plant debris and the amount of carbon lost through decomposition (Rice 2004). Singh et al. (2003), Rice (2004), Varamesh (2009), Salehi and Noormohammadi (2012) and Pahlavan Yali et al. (2016), amongst others, have pointed to the relationship between SOC sequestration and vegetation percentage, leaf litter, crop residues, land use and management. The significant difference of soil carbon in the present two land-use areas was also attributable to the difference in the return of organic matter to the soil; this was reduced in the silvopastoral lands because, in such lands, in addition to livestock grazing, the production capacity of the main element – trees – is removed due to pruning, reducing the production of foliage and leaving the forest floor bare of leaf litter and grass (Moradi & Shabanian 2022).

Sacred groves with high carbon reserves are part of the Zagros forests. In fact, if the Zagros forests were less degraded, they would be in a similar situation to the sacred groves today, and these forests could have a greater impact on carbon sequestration. Although preventing deforestation is necessary for the mitigation of climate change, it is not sufficient to achieve such mitigation (Erb et al. 2018). Sacred groves can protect forest ecosystems and might help reduce climate change through carbon sequestration (Shrestha et al. 2016). The Zagros sacred groves currently store 827 000 kg CO_2 ha^{-1} more than the silvopastoral lands, and this is a sign of the high level of degradation in the forests of the study area.

Conclusions

The Zagros forests offer a useful model of what happens when forests are seriously damaged. The significant differences in biomass and carbon stocks between the sacred groves and silvopastoral lands indicate the potentially great value of restoring these forests. Here, the sacred groves are the most significant sites for biodiversity conservation and for carbon storage, as more formal types of protected areas have frequently failed in these areas (e.g., forest genetic resources under the management of the Department of Natural Resources and Watershed Management of Kurdistan Province in the study area or protected areas under the management of the Department of Environment Protection in the Zagros forests). The number of sacred groves in the forests of the northern Zagros forests is significant; these forests contain essential carbon reserves and high levels of biodiversity that are of great environmental importance. The Zagros forests of western Iran occupy a vast and important area, and the potential role of this natural and valuable ecosystem in storing carbon and perhaps helping to reduce climate change is becoming more apparent.

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Ethical standards. None.

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