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**Restoring the Banni grasslands: a model for combating invasive species,  
supporting natural ecosystem and empowering pastoral communities**

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**Abstract**

The Banni grassland is Asia's largest grassland ecosystem, harbors unique flora and fauna, and supports over 8000 pastoral households. The pastoralists herd an indigenous buffalo breed "Banni" and have been practicing a semi-nomadic style of pastoralism for more than 500 years. This unique protected grassland is dotted with seasonal wetlands, saline-mix highly nutritive grass species, and some good patches of *Acacia nilotica* trees in some villages. In recent decades, encroachment particularly by the invasive species *Prosopis juliflora*, threatens this biodiversity hotspot by invading 50% of land. Woody shrub encroachments, converting the grasslands into woodland, is a trend witnessed globally, and harms unique biodiversity and traditional livelihoods of indigenous communities. Community Forest Management Committees (CFMCs) under the Forest Right Act 2006 have taken a multi-pronged approach to restore Banni grasslands. Through brush management techniques, they have restored over 3000 hectares across 18 villages in the last four years. The post monsoon grassland surveys were conducted by Sahjeevan's team using the random quadrat sampling method and data was analyzed to assess changes in the vegetation cover affected by invasive species. These efforts have shown remarkable recovery in vegetation cover of herbs and grasses up to 91%, species diversity up to 12 times, and biomass production up to 3.4 times in restored plots compared to invaded areas. Additionally, removal of this exotic invasive species in Nani Dadhdhar village has not only supported growth of the native tree *A. nilotica* but also amplified the population of it fourfold in the past four years. In Dedhiya village, biochar, made in Kon-Tiki kilns from *P. juliflora* and incorporated in the soil increased yield of grasses and herbs by 1.87 times compared with untreated plots. Biochar not only helps boost soil health but also acts as a long-term (perhaps 2000-years) carbon sink and generates carbon credits. This restoration model exemplifies the power of community-driven conservation. It tackles invasive species, mitigates climate change and empowers pastoral communities, offering a blueprint for similar ecosystems worldwide.

## **Introduction**

The Banni Grassland in Gujarat, India, is Asia's largest grassland, known for its unique semi-arid ecosystem with seasonal marshes and diverse flora and fauna. It is home to tree species like *Acacia nilotica*(L.) Willd. ex Delile and *Salvadora persica*L.; and provides habitat for fauna adapted to its conditions, including the spiny-tailed lizard (*Saara hardwickii*) and desert fox (*Vulpes vulpes pusilla*)(Bharwada and Mahajan 2012; Nerlekar et al. 2022). This grassland supports 22 local communities spread in 48 villages. The pastoralists of this area are called 'Maldharis', whose livelihoods depend on animal husbandry. They have selectively bred the Banni buffalo and Kankrej cow, which are highly valued across India (Nerlekar et al. 2022; Ravi and Krishnan 2024). For the Maldharis, the grassland's diversity is vital to their pastoral practices and sustains their primary income source (Ghosh et al. 2015). However, over 50% of the grassland has been invaded by *Prosopis juliflora*(Sw.) DC., a non-native tree introduced about 140 years ago to combat desertification. *P. juliflora* now spreads at an estimated rate of 25 km<sup>2</sup> per year, disrupting native ecosystems (Ravi and Krishnan 2024; Tewari et al. 2000). Species such as *P. juliflora* have contributed to the uniformity of plant communities globally, causing alterations in native ecosystems and displacing local flora and fauna (Mungi et al. 2019; Simberloff et al. 2013).

## **Community-led Restoration Efforts**

To address the *P. juliflora* invasion, Community Forest Resource Management Committees (CFRMCs) formed under Forest Rights Act, 2006 have undertaken large-scale restoration efforts. These committees, empowered to conserve and manage forest resources, are working with Sahjeevan, an NGO focused on pastoralism and biodiversity conservation to clear *P. juliflora* from invaded areas since four years. Using brush management techniques, CFRMCs have restored over 3,000 hectares across 18 villages. Sahjeevan's team conducts post-monsoon surveys to monitor changes in vegetation cover and assess the success of restoration efforts.

## **The Role of Carbon Markets in Restoration**

Carbon markets have been instrumental in funding restoration efforts in the Banni grassland. These markets allow the trading of carbon credits, with each credit representing one tonne of reduced, sequestered, or avoided carbon dioxide or greenhouse gases (Climate Promise 2022). In Banni, the biomass from uprooted *P.juliflora* was converted into biochar, generating carbon credits that were sold on international platforms. Biochar is produced through the pyrolysis of organic material in low-oxygen conditions, transforming plant waste into a stable form of carbon. When integrated into soil, biochar enhances soil fertility and provides long-term carbon storage with a mean residence time of about 2,000 years (Glaser et al. 2009; Kuzyakov et al. 2009). Biochar was also applied to grasslands in Dedhiya village to examine its impact on the natural regeneration of native grasses and herbs, aiming to promote healthier vegetation recovery and soil quality in restored areas. The total area restored under this pilot was 1100 hectares, which translated into 1530 credits produced from 695 tonnes of biochar. Here, one tonne of biochar has generated 2.2 carbon credits, consequently, 1530 tonnes of CO<sub>2</sub> were sequestered from the 1530 carbon credits. This biochar is currently stored underground within a grassland area. Further research is underway to investigate the large-scale application of biochar to the soil of the Banni grassland. The revenue generated from selling these carbon credits was utilized to fund large-scale restoration efforts

## **Methods**

### **Sampling Design and Data Collection to check effect of restoration**

In this study, a random quadrat sampling method was employed to assess species diversity, vegetation cover, and biomass productivity using a 1 x 1 m frame for precise data collection. Five quadrats of these dimensions were randomly placed in either control plots (with *P.juliflora* present) and restored plots across 18 villages

and data was recorded. For biomass analysis, herbs and grasses within each quadrat were clipped, and samples were collected for productivity assessment.

### ***Assessment of Acacia nilotica Population***

Despite Banni's grassland ecosystem, Nani Dadhdhar village hosts a thriving patch of the native tree *A. nilotica*. Restoration efforts four years ago aimed to support this tree population. Recently tree population was surveyed, where trees were categorized into three height classes: up to 1 meter, 1-5 meters, and over 5 meters and counted, allowing us to estimate the population structure and growth distribution of *A. nilotica* across height classes (This native tree counting drive was conducted with the assistance of local youth from the village. Fifteen young participants were involved, each assigned a specific paint color (three different colors) corresponding to particular tree height groups. They counted and marked each tree to ensure no duplication occurred during the survey).

### ***Effect Assessment of Biochar Inoculation on Grassland Productivity***

In the restored plot of Dehiya village, a biochar inoculation experiment was conducted to evaluate its effect on grassland productivity. Biochar mixed with soil was applied in 2 x 2 m fenced cages to prevent grazing interference. Two types of cages were set up: one with biochar-treated soil with dosage of 4 kg/ 2 x 2 m and another as a control (untreated soil). Each cage type was replicated six times. After 45 days, plants grown within the cages were harvested and analyzed to assess biomass productivity.

### **Results**

Table 1 presents the ecological parameters assessed across 18 villages, comparing restored plots to control plots. The restoration efforts demonstrated significant improvements in vegetation cover, with *Gorewali* village achieving an impressive 91% cover, followed closely by *Mithadivillage* at 88.4%. Species diversity also benefited from restoration, with *Dedhiya* village exhibiting a remarkable increase of up to 12 times in species diversity. The removal of invasive species has reduced competition for resources among native flora, resulting in biomass production of native grasses and herbs increases of up to 3.4 times in restored plots compared to the invaded areas of *Adhiyang* and *Bhagadiya*.

The eradication of *P.juliflora* in Nani Dadhdhar village has facilitated the growth of *A. nilotica*, leading to a fourfold increase in its population over four years. The survey recorded 2,029, 1,665, and 711 individuals in height categories of up to 1 meter, 1-5 meters, and over 5 meters, respectively. Trees exceeding 5 meters are estimated to be five to six years old, while those under 1 meter are recent recruits established within the last year and a half. This highlights the positive impact of restoration efforts.

Innovative approaches have further strengthened these restoration models. In *Dedhiya* village, biochar produced from *P.juliflora* in Kon-Tiki kilns was applied to soil in experimental plots prior to the monsoon season. Post-monsoon data revealed biomass production of 164 g and 88 g per m<sup>2</sup> in treated and untreated plots, respectively, indicating a 1.87-fold increase in the yield of grasses and herbs in the biochar-treated areas compared to untreated ones.

### **Discussion**

The restoration of the Banni Grassland underscores the significant ecological and socio-economic benefits of controlling *P.juliflora* invasion. Our findings demonstrate substantial gains in vegetation cover, species diversity, and biomass productivity in restored plots, indicating the success of community-led restoration efforts. The removal of *P. juliflora* reduces resource competition, enabling native species to thrive, as

evidenced by the fourfold increase in *A. nilotica* populations in Nani Dadhdhar village. This native resurgence highlights the effectiveness of the restoration and suggests positive outcomes for ecosystem functionality and biodiversity.

Table 1: Ecological parameters assessed across 18 villages of Banni grassland

Sr. No.	Name of village	% Vegetation cover in restored plot	% Vegetation cover in control plot	Total cover increased (%)	Species diversity in restored plot	Species diversity in control plot	diversity increased (X)	Dry biomass production in restored plot (ton/ha.)	Dry biomass production in control plot (ton/ha.)	Productivity increased (X time)
1	Adhiyang	81	52	55.8	35	21	1.7	0.81	0.24	3.4
2	Pareti	44	35	25.7	13	8	1.6	-	0.38	-
3	Gorewali	65	34	91.2	32	14	2.3	1.41	1.04	1.4
4	Berado	62	44	40.9	13	9	1.4	0.33	0.34	1.0
5	Moti Dadhdhar	68.6	68.33	0.4	20	11	1.8	1.91	0.58	3.3
6	Mithadi	81	43	88.4	26	7	3.7	0.92	0.65	1.4
7	Lakhara	81	74.4	8.9	20	8	2.5	1.01	0.66	1.5
8	Sheth Vandh	66.7	52	28.3	27	16	1.7	0.93	0.79	1.2
9	Dedhiya	56	30	86.7	24	2	12.0	0.87	0.29	3.0
10	Nani Dadhdhar	63	58	8.6	24	8	3.0	0.58	0.20	2.9
11	Panavari	59.4	46.67	27.3	25	12	2.1	0.74	1.3	0.6
12	Vagura	78.4	63	24.4	25	9	2.8	-	0.82	-
13	Sherva	81.6	47.5	71.8	30	14	2.1	1.31	0.5	2.6
14	Mota Sarghu	95.4	80.7	18.2	6	4	1.5	0.38	0.42	0.9
15	Nava Sarghu	61.2	59	3.7	10	11	0.9	-	0.43	-
16	Bhagadiya	59.2	53	11.7	27	14	1.9	2.70	0.80	3.4
17	Chhachla	68.2	39.3	73.5	14	8	1.8	0.69	0.34	2.0
18	Gadiyado	92.4	79.7	15.9	30	19	1.6	0.90	0.94	1.0

Meta-analyses of biochar applications reveal significant biomass increases with 41% in woody plants and 10–30% in agricultural crops (Thomas and Gale 2015). Our findings also show biochar's effectiveness, boosting biomass yield by 1.87 times in treated plots and enhancing soil fertility for long-term carbon sequestration. This supports plant growth and aligns with global climate goals, promoting sustainable ecosystem restoration funded by the carbon market.

Our study aligns with existing research, which highlights the broader advantages of invasive species management for ecosystem services, such as clean air and water, and benefits to local livelihoods through resources like grazing (Medvecká et al. 2018; Vilà et al. 2011). The involvement of local communities, especially the Maldharis, is essential, as their knowledge complements scientific strategies and fosters

sustainable land management supported by literature, showing that community engagement is pivotal for long-term conservation success (Berkes 2004; Agrawal and Gibson 1999).

Future research should focus on long-term monitoring to assess ecosystem recovery, socio-economic impacts, and the risk of re-invasion. Policymakers should consider incorporating community-led restoration models into broader conservation strategies, promoting biodiversity conservation and supporting local economies. The successful restoration of the Banni Grassland demonstrates the potential of integrated management approaches to rehabilitate degraded ecosystems and secure community support for sustainable development.

## Conclusion

This study underscores the successful community-driven restoration of the Banni Grassland, highlighting significant ecological improvements following the removal of an invasive species *P.juliflora*. Restoration efforts have notably increased vegetation cover, species diversity, and biomass productivity, with a strong resurgence of native tree *A. nilotica*. The active participation of Maldhari communities has been crucial, leveraging their traditional knowledge for sustainable land management. Biochar application in grassland has further enhanced soil fertility and long-term carbon sequestration. Continuous monitoring and management by the community is essential to prevent re-invasion and ensure habitat sustainability. This model illustrates the potential of integrated restoration strategies, driven by local communities and supported by carbon credits, to enhance ecosystem resilience and support local livelihoods.

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