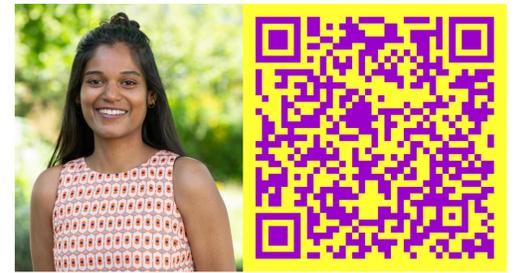


Prioritizing Nature based Solutions: A case study of multi decision criteria analyses of forest restoration in India

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A Context

Nature based solutions (NbS) are intrinsically multifaceted, resulting in a variety ecosystem benefits and human well being outcomes from conservation, restoration and management of ecosystems^[1]. To maximize return on investments from implementation of NbS, crucial information about where and by how a specific or combination of NbS is likely to contribute to various goals is useful for policy and decision making^[1]. Here, I used multi decision criteria analyses, to prioritize areas where forests can be restored resulting in biodiversity and climate change mitigation benefits, in India.

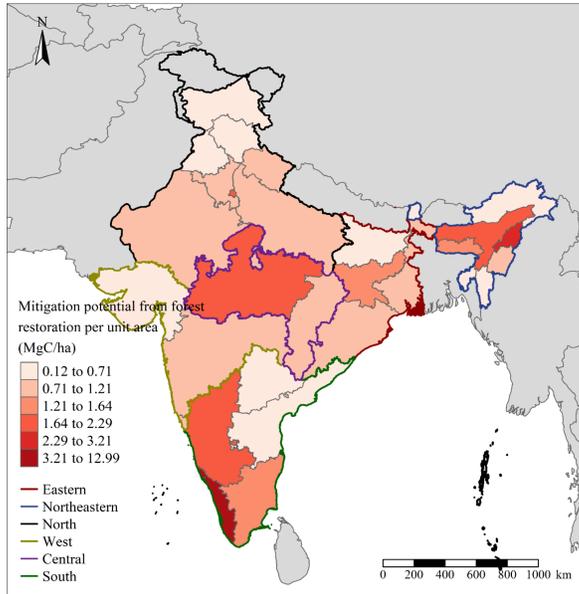


Fig 1 Climate change mitigation potential normalized by total land area in each jurisdiction. At the national scale, 388.5 TgC can be cumulatively generated from natural regeneration of forests in the restoration opportunity. The highest mitigation potential of 119.2 TgC is in southern India and the least mitigation potential of 37.3 TgC in the north east. Madhya Pradesh has the highest mitigation potential of 59.4 TgC and Mizoram has the least mitigation potential of 0.27 TgC.

B Methods

Mitigation Potential from natural regeneration of native forests
 (carbon sequestration rates)

Restoration Opportunity (7.5Mha)
 (biophysical constraints+ current LULC constraints)

Spatial Prioritization
 (using *prioritizR*)

Biodiversity
 (additional habitat area and rarity weighted index)

We used the framework of spatial action mapping to prioritize areas for forest restoration considering 4 criteria-

- 1) climate change mitigation benefits- quantified as the carbon sequestration rates from naturally generating native forests in the area of opportunity (Fig 1)^[2]
- 2) rarity weighted index of 44 forest dependent mammals and reptiles classified as endangered or critically endangered by the IUCN, using the area of habitat (Fig 2)^[3]
- 3) feasibility of natural regeneration of native forests estimated in the area of opportunity as the time taken to reach the closest city^[4]
- 4) probability of success of natural regeneration as the distance between area of opportunity and the closest area of natural forests^[5]

Area of opportunity of 7.5 Mha was estimated by first mapping the biophysical envelope of natural forests, using a machine learning framework and over 10,000 GPS points of various natural forest types. From this area, I spatially excluded all areas that cannot be restored to forests by accounting for security of food supply and not endangering non-forests ecosystems such as wetlands and savannahs.

I used integer linear programming algorithm, as implemented in *prioritizR* R package^[6], optimizing to a target of 17% of area based on India's National Biodiversity Action Plan while minimizing people impacted by naturally regenerating forests, to address loss of livelihoods and dislocation of people.

Fig 2 Distribution of additional habitat area created from natural regeneration in restoration opportunity. Each donut represents a species, in which the additional habitat area created is indicated by green, while the remaining habitat area is indicated by purple. There was an increase in habitat area by 50.2% for the Malabar long-tailed civet (*Viverra civettina*) and the lowest increase in habitat was by 0.37% for Nilgiri long-tailed tree mouse (*Vandeleuria nilagirica*). Other examples of additional area of habitat created shown below. There was no increase in habitat for 11 species (shown by the red border)



C Results

By using the spatial prioritization framework, I estimated 13.5% of the total restoration opportunity as priority that would minimize the population density being impacted by forest restoration (mean across all regions of 104.5 people/sqkm in prioritized opportunity versus national mean of the total restoration opportunity of 365.1 people/sqkm). This prioritized area considering the target and cost varied by region, with maximum prioritized area in northeastern India and the least in western India (Fig 3)

D Perspective

Multi decision criteria analyses is meant to be only one step in the process of developing effective NbS. This method is not meant to be prescriptive. However, it is one of many scientific techniques that can be used to assess trade-offs and synergies between ecosystem and societal benefits, thereby being useful in the decision making and policy arenas.

To truly integrate ecosystem benefits and human well being outcomes, intrinsic to NbS, I will further this work by incorporating socioeconomic criteria and respective optimization scenarios to understand trade-offs and synergies between ecosystem benefits and human well being from naturally regenerating forests, in India.

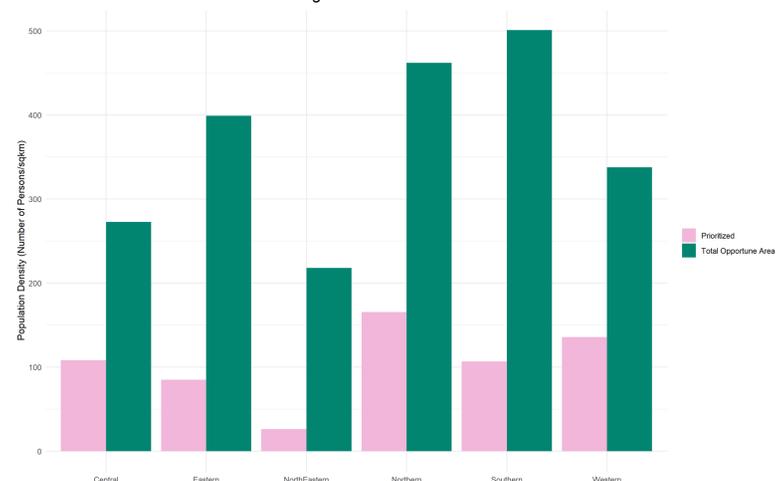
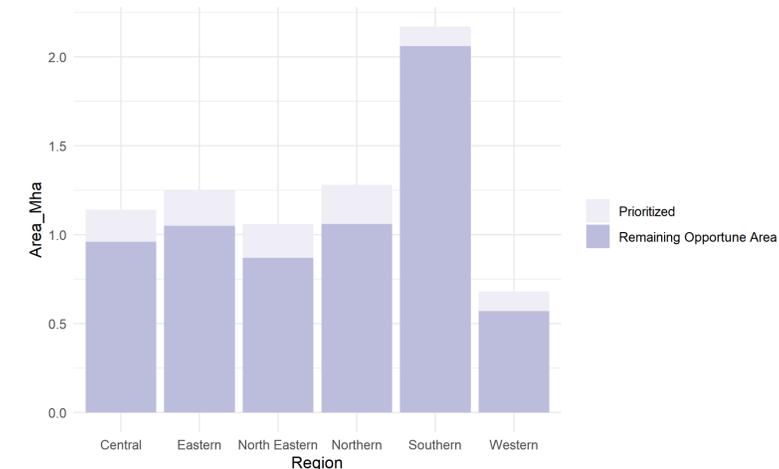


Fig 3 Distribution of prioritized areas and the remaining opportunity across regions shown in which 13.5% of restoration opportunity was prioritized, with limited variation across regions because of the sole target of 17% optimized (above). With the objective being minimization of population cost affected, nationally mean population density affected within the prioritized areas was 104 people/sqkm vs 365 people/sqkm in all the total restoration opportunity (below)

[1]- Seddon, Nathalie, et al. "Getting the message right on nature-based solutions to climate change." *Global Change Biology* 27.8 (2021): 1518-1546.
 [2]- Cook-Patton, Susan C., et al. "Mapping carbon accumulation potential from global natural forest regrowth." *Nature* 585.7826 (2020): 545-550.
 [3]-Brooks, Thomas M., et al. "Measuring terrestrial area of habitat (AOH) and its utility for the IUCN Red List." *Trends in ecology & evolution* 34.11 (2019): 977-986.
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 [5]-Crouzeilles, Renato, et al. "Achieving cost-effective landscape-scale forest restoration through targeted natural regeneration." *Conservation Letters* 13.3 (2020): e12709.
 [6]-Hanson JO, et al. (2021). *prioritizR*: Systematic Conservation Prioritization in R (R package version 7.0.1.)