Exploring challenges to conservation of stream-dwelling amphibians in the Western Ghats

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Introduction

Freshwater ecosystems globally have undergone drastic changes and are dealing with severe stressors such as habitat loss and fragmentation, flow-modification, pollution, climate change, invasives and overharvesting. This has altered both the structure and function of ecological communities that depend on these ecosystems. The commonly observed structural changes are a reduction in species richness, abundance, complexity and evenness (Armbrecht et al., 2005; Ernst et al., 2006; Walker et al., 2006; Cole et al., 2014). These changes are often irreversible, and there could be continued degradation of the ecosystem even if the initial stressor is removed (Rapport and Whitford, 1989; Cramer et al., 2008).

Amphibian communities are known to be especially susceptible to human induced disturbances (Lehtinen et al., 1999; Guerra and Araoz, 2015). At present, over one-third of all known amphibian species face risk of extinction and another one-third are data deficient (Adams et al., 2013). The threats to amphibians also show a high degree of overlap with regions of high amphibian richness and endemism (Gallant et al., 2007; Hof et al., 2011). Their distributions are also least represented within global protected area networks (Rodrigues et al., 2004). It therefore becomes essential to assess alternate habitats that can host diverse amphibian assemblages. Agroforests have been known to support a high proportion of the local amphibian diversity (Gardner et al., 2007; Faria et al., 2007). What remains less understood is the impact of management practices of agroforests on the community structure of amphibian diversity.

The Western Ghats in India are a very important hotspot for amphibian with over 200 species, of which 88% are endemic. This taxon has also been highly neglected in ecological research and many current research efforts are focused on disentangling basic taxonomy. Although few recent papers have started to explore the impact of anthropogenic disturbance such as agriculture, hydroelectric projects and logging, these studies are based on small sample size and spatial extent (Gurushankara et al., 2007; Balaji et al., 2014; Naniwadekar and Vasudevan, 2014; Seshadri, 2014). High rates of endemism, compounded by several amphibian species ranges that occur outside protected areas in the Western Ghats, make understanding their ecological range distributions and dynamics a critical conservation priority.

Our study focuses on understanding the patterns of amphibian community structure along streams in different land use types. We examine the difference and drivers of species richness and community evenness across tea and coffee agro-plantations in the Anamalai Hills of the Western Ghats.

Methods

Study Area

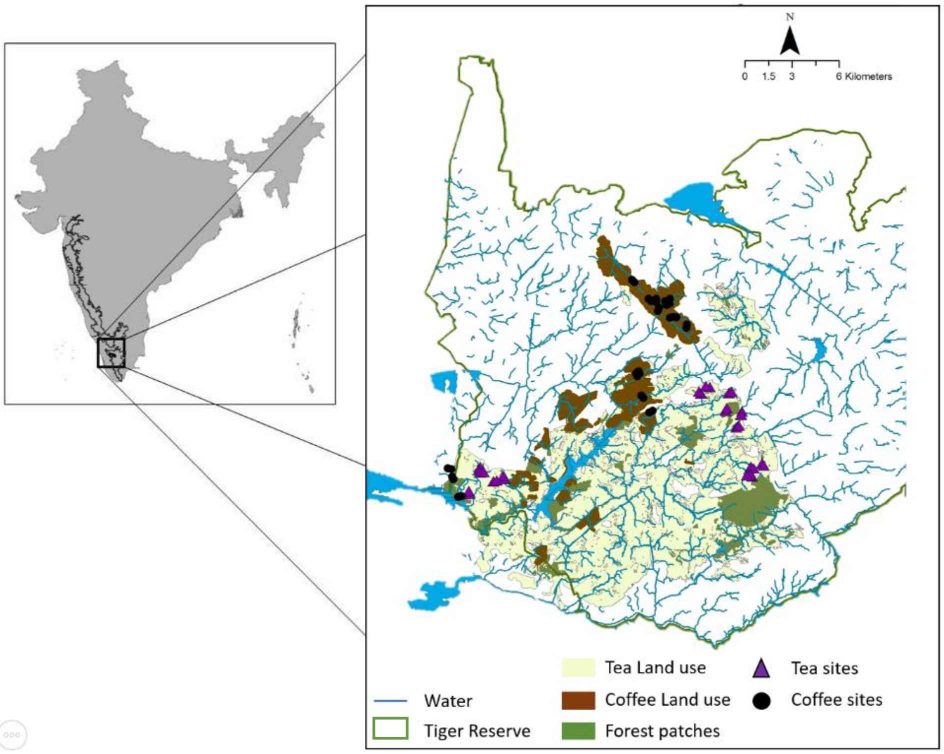


Fig 1: Map of Valparai showing surveyed sites

The Western Ghats of India is one of the eight 'hottest' of the global biodiversity hotspots with the highest human density of any hotspot in the world (Myers, 2000; Cincotta, 2003). It is a mountain chain stretching over 1600 km along the west coast of peninsular India with a mixture of evergreen, moist-deciduous and dry-deciduous forest types. However, In the 20th century alone, the region has experienced a 40% reduction in forest cover, and a four-fold increase in the number of forest fragments across the landscape (Menon and Bawa, 1997). Moreover, only nine percent of the Western Ghats is protected in reserves, while most of the remaining 91% is dominated by human-use landscapes such as secondary forests, pasture, agriculture and rural build-up.

Within this hotspot, our study site was in the Valparai plateau in the southern state of Tamil Nadu. It consists of the Anamalai Tiger Reserve surrounded by plantations of tea, coffee and cardamom. The native habitat ranges from mid elevation tropical rainforests and high-elevation shola forests and grasslands. However, just within the twentieth century, the region witnessed a conversion of nearly 220 km^2 of tropical forests into these agro-plantations (Mudappa and Raman, 2007). Of these alterations, tea is the most modified habitat consisting of monocultured farms with few exotic shade trees. Coffee however is shade grown, often under native forest trees. While the initial agro-plantations focused more on coffee and cardamom, it now consists of 76% tea.

Amphibian sampling

We randomly selected 60 stream segments of 100-meter length across the region, with 29 of these sites in coffee plantations and 31 in tea plantations. Each segment was sampled both along the stream and on a parallel transect at a 10-meter distance from the stream. All sites were sampled three times across the season to estimate detection probability for each species. The sampling was conducted by two observers between 6:30 pm and 9:30 pm using the audio and visual encounter survey method to record species. Covariate information such as water temperature, pH and Total Dissolved Solids, ambient noise and canopy density were measured at each site.

Analysis

We used a hierarchical multi-species occupancy modeling approach to examine the effect of land-use type and elevation on species richness and occurrence (Dorazio and Royle, 2005; Dorazio et al., 2006). The model uses the binomial encounter data $y_{i,j,k}$ where a detection of species '*i*' at site '*j*' during sampling occasion '*k*' is $y_{i,j,k}=1$, and a non-detection is $y_{i,j,k}=0$. This data generation is a Bernoulli process with the probability distribution $y_{i,j,k}$ ~ Bernoulli ($p_{i,j,k} \times z_{i,j}$), where $p_{i,j,k}$ refers to the probability of detection of species '*i*' at site '*j*' and sampling occasion '*k*' and $z_{i,j}$ is a latent variable that denotes the true presence of a species '*i*' at site '*j*'. This latent variable is modelled as $z_{i,j}$ ~ Bernoulli ($\Psi_{i,j}$), where $\Psi_{i,j}$ is the probability of occurrence of species '*i*' at site '*j*'.

The model also incorporates linear species and site-specific effects in estimating probability of occurrence and detection. These are written on the logit-scale as logit ($\Psi_{i,j}$) = $u_i + \beta_j$ and logit ($p_{i,j}$) = $v_i + \alpha_j$, where u_i and v_i are species-level effects and β_j and α_j are site-level effects on occurrence and detection respectively. Further, we modelled a positive correlation between species occurrence and detection, thus allowing for the estimation of these parameters for rare species. The two models we ran both for the terrestrial and stream community data were:

1. logit ($\Psi_{i,j}$) = $u_i + \beta_j$ * $landuse_j$

Where land use was a dummy variable coded as 1 for coffee and 0 for tea

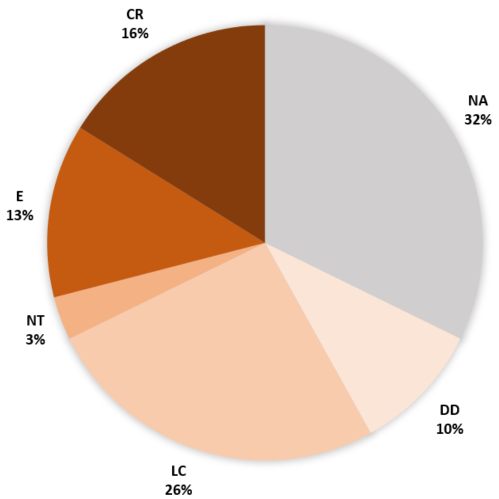
2. logit ($\Psi_{i,j}$) = $u_i + \beta_j$ * $elevation_j$

The sums of $z_{i,}$ was used as the measure of species richness at each site 'j', and mean z_j was used to rank species based on occurrence for community evenness.

All analysis was conducted in program R Studio and the Bayesian models were run by calling in JAGS on R using the package 'R2jags'.

Results

We recorded a total of 33 species belonging to 16 different genera of amphibians across the 60 sites surveyed. Of these 29 are endemic to the Western Ghats and and a further subset of 7 are endemic only to the Anamalai Hills.

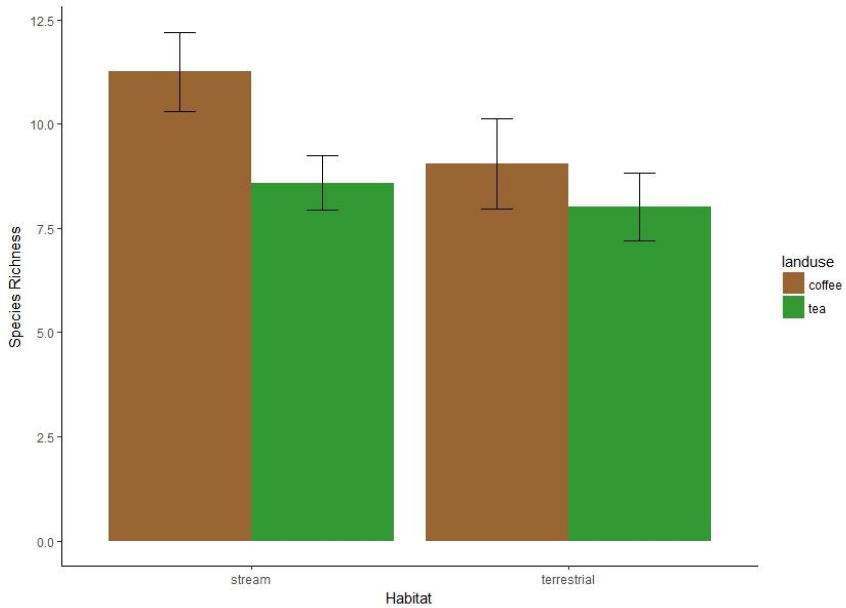


Nearly a third of all the species found in the study are not yet listed in IUCN Red List because they have just been described in the last five years. Another third has a highly threatened status.

IUCN Codes used here are: NA – Not Listed; DD – Data Deficient; LC – Least Concern; NT – Near Threatened; E – Endangered; CR – Critically Endangered.

Fig 2: IUCN Red List status of the species recorded in our study

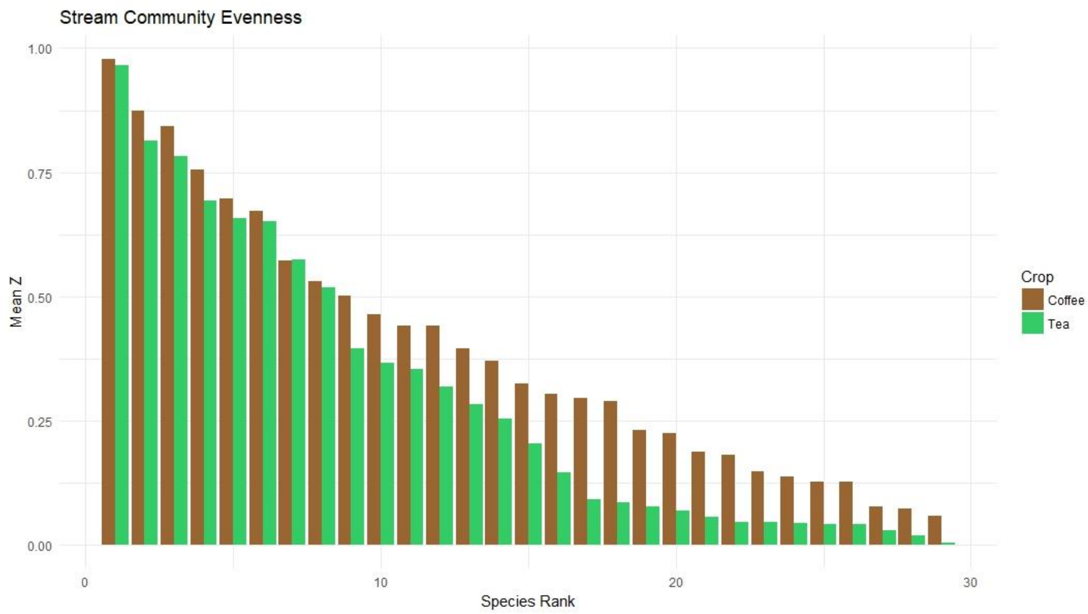
Community level responses to land use types



Mean species richness was higher in coffee than in tea for both habitats but the difference was significant only for the stream amphibian community. The terrestrial community shows a much more similar level of diversity across land use types.

Fig 3: Species Richness across habitats and land use types

We ranked species from the highest to the lowest probability of occurrence as surrogate for the rank abundance curve. In both stream and terrestrial habitats, we found that the coffee land use has a more gradual decline in probability of occurrence across species rank when compared to tea. Also, the terrestrial amphibian community in tea appeared to be predominately dominated by seven species. This indicates that coffee supports both higher alpha diversity of amphibians as well as a great evenness in community structure.



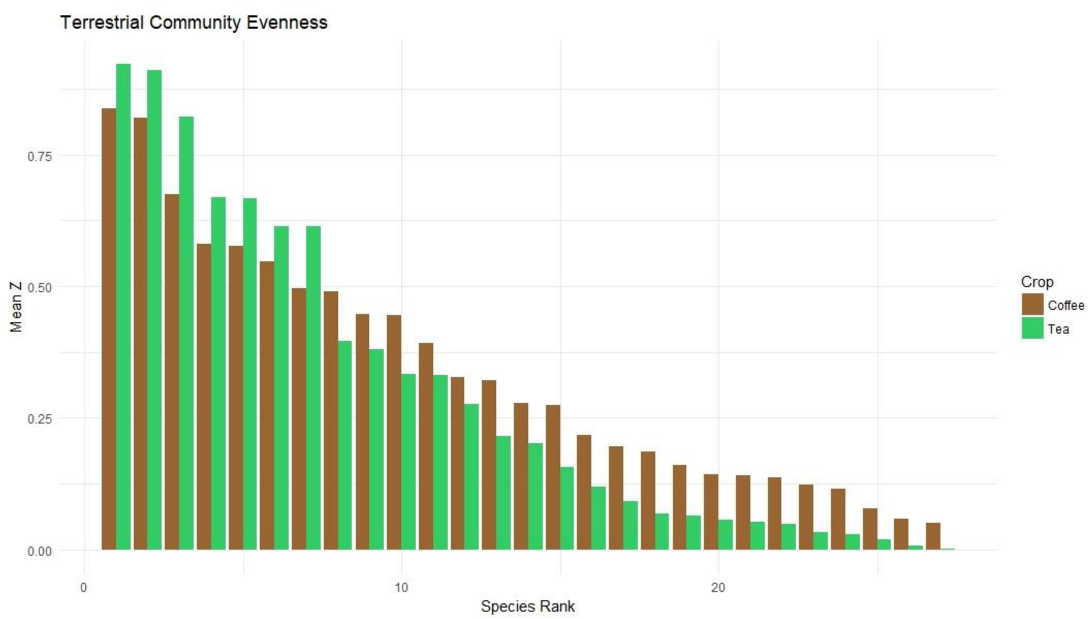


Fig 4: Community Evenness across habitats and land use types

Species-specific responses to land use types

Our results suggest that overall, 16 species had significant positive relationship with coffee over tea land use. On the other hand, only 5 species showed a significant association with tea over coffee. These five species - *D. melanostictus* (Ψ_{tea}=0.67), *I. doni* (Ψ_{tea}=0.61), *P. wynaadensis* (Ψ_{tea}=0.91), *R. anili* (Ψ_{tea}=0.92) and *R. ponmudi* (Ψ_{tea}=0.67) are either common, generalist species or those that prefer open canopy habitats. In the figure below, the results can be interpreted as coffee-associated species if the mean and error bars are above the '0- effect' line. Those that are below this line are tea-associated species.

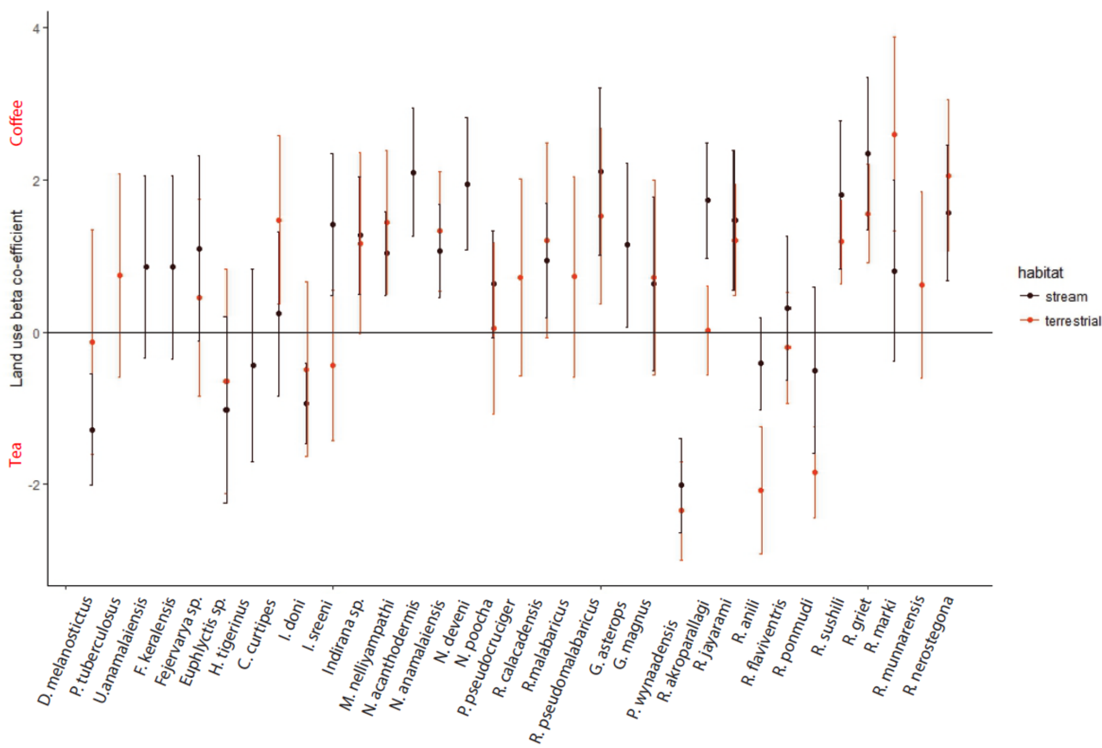


Fig 5: Mean and SE of species-specific beta coefficient of land use

Species-specific responses to elevation

We found that there was no mean community level response in probability of occurrence with elevation. However, there were evenly-matched and significant species-specific responses. Around 13 species showed strong positive relationship with elevation while 12 species showed strong negative responses with elevation. In Fig 6., the species with means and errors above the

‘0-effect’ line are those that prefer higher elevations while those below the line prefer lower elevations.

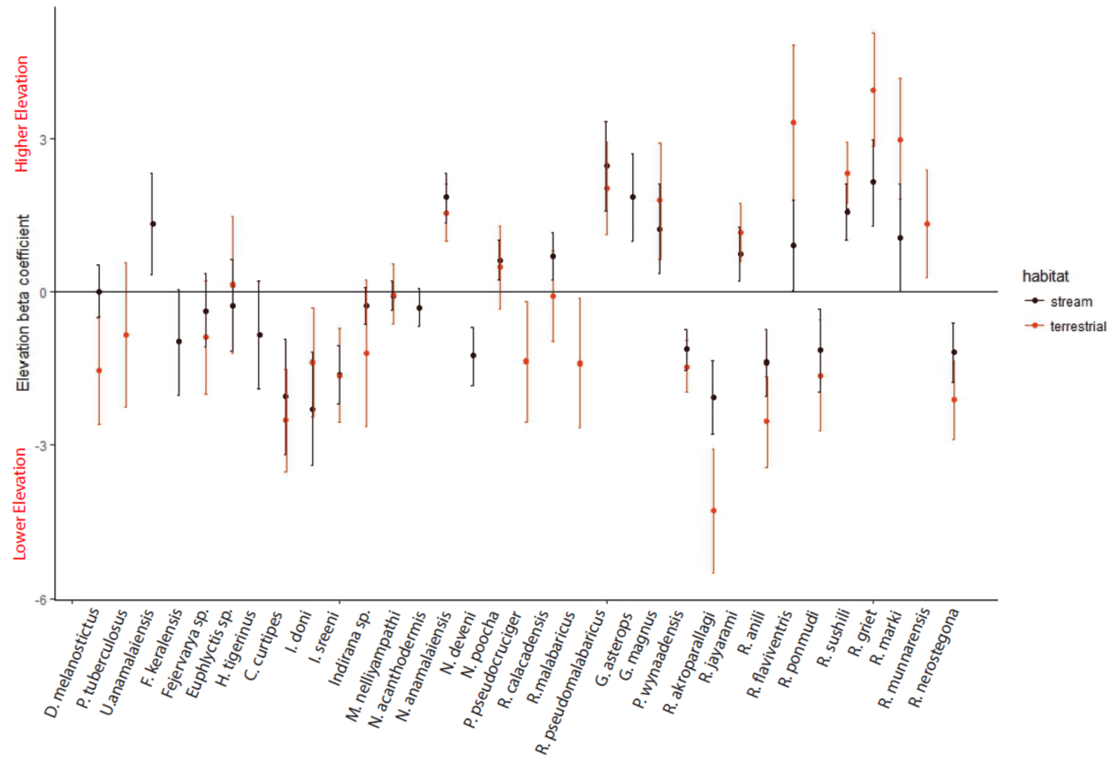


Fig 6: Mean and SE of species-specific beta coefficient of elevation

Conclusion

Global land-use change has become a dominant feature that alters diversity, species distributions and shapes antagonistic and mutualistic interactions in multi-species assemblages. Yet, these modified habitats have their own biodiversity conservation value. Our study finds that agro-plantation landscapes do play an important role in preserving native amphibian diversity in the Western Ghats. However, the structure of these communities is shaped by human decisions on land-use management. For instance, the canopy grown coffee plantations are less modified from the original forested habitats of this region. Hence, they host an amphibian assemblage of higher diversity and evenness compared to the drastically modified tea plantations.

We also find that there are species-specific responses to habitat and biogeographic variables, and that some generalist species may actually prefer more modified habitats like tea. Finally, some species that are listed as highly endangered by the IUCN list, are seen to have fairly wide distributions and high probability of occurrence even in these human-dominated landscapes. These can be down-listed based on our results. On the other hand, some species are truly rare and are restricted to specific microhabitats. These are at times categorized as Data deficient or not listed at all and require attention. Our study enhances the understanding of amphibian species and community ecology in a hyper-diverse global hotspot. These results can be used to inform local land management decisions, policy regulation and biodiversity conservation in human-modified landscapes.

Future Directions

The ecological data from this study can be used to explore more fine-scale questions about amphibian community structure. For instance, we can determine the effect of other habitat and landscape covariates on species presence and richness such as heterogeneity of land use upstream of the surveyed regions, the difference in community composition in stream versus terrestrial habitats, life-history traits that drive species-specific responses to habitat change and spatial cooccurrence and competition patterns in the community.

However, beyond ecological explorations, the study has the capacity to directly influence management and policy for freshwater ecosystems in private lands. This needs to be done in a manner that is economically viable for the land owners. The future plans from this project is to identify stream reaches that would benefit from developing riparian buffers and restoring the natural forest habitats. To do this, we mean to conduct socio-economic surveys of land-owners in the regions and understand their perceptions towards riparian conservation. Next, we will develop an economic optimization model that will identify restoration sites such that biodiversity conservation is maximized while the economic costs to land owners is minimized. A management policy based on these criteria are most likely to be sustainable and provide ecosystem services for both biodiversity and society alike.

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