

Carbon – Biodiversity - Land System Nexus Across Scales: MSA and Biomass Metrics Across the Brazilian Cerrado and the Sertão Veredas Peruaçu Mosaic

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Abstract

Accelerating conversion of natural habitats threatens the interconnected goals of biodiversity conservation and climate change mitigation agendas, particularly in the Brazilian Cerrado, a global biodiversity hotspot undergoing rapid agricultural expansion. Although protected area mosaics have been promoted as integrated landscape governance strategies, empirical evidence of their effectiveness in simultaneously conserving biodiversity and carbon stocks across spatial scales remains limited. This study evaluates the carbon-biodiversity-land system nexus by quantifying the effects of land use and land cover change on biodiversity and carbon stocks, between 2012 and 2023 at two complementary scales: the Brazilian Cerrado biome and the Sertão Veredas-Peruaçu Mosaic (SVPM). We integrated annual land cover maps from MapBiomas, aboveground woody biomass estimates, and the Mean Species Abundance (MSA) indicator derived from the GLOBIO 4 model to assess spatial patterns of biodiversity integrity and carbon storage. At the biome scale, the Cerrado experienced widespread ecological degradation, with MSA declining across 6.57% of its area, directly affecting 9.23% of total aboveground biomass stock. In contrast, the SVPM exhibited greater ecological resilience, limiting MSA loss to only 2.39% of its territory while maintaining 97.6% of its carbon stock. These findings demonstrate that integrated, landscape-scale governance can reduce the coupling between agricultural expansion, biodiversity loss, and carbon depletion. By linking biodiversity integrity and biomass conservation across scales, this study provides empirical evidence that protected area mosaics represent an effective socio-ecological governance approach for strengthening nature-based climate solutions in highly threatened tropical savannas, while identifying opportunities to further enhance their long-term conservation performance.

1. Introduction

The 21st century is defined by three intersecting crises: climate change, biodiversity loss, and land system transformation. Rather than operating in isolation, these crises are linked by tight ecological feedback. For instance, recent global syntheses demonstrate that biodiversity loss directly reduces terrestrial carbon sequestration capacity by up to 30%, undermining the resilience of vital carbon reservoirs. Despite these critical linkages, scientific research and international policy frameworks (e.g., the Paris Agreement and the Kunming-Montreal Global Biodiversity Framework) have historically treated carbon and biodiversity in silos.

In South America, this disciplinary and policy fragmentation has yielded concerns. Deforestation and fragmentation in the Amazon Basin have converted large portions of the world's premier rainforest into a net carbon source, emitting approximately 0.3 to 0.5 Gt C yr (Gatto *et al.*, 2021). Adjacent to the Amazon, the Brazilian Cerrado - the world's most biodiverse savanna and a global biodiversity hotspot - is undergoing an even more rapid land transformation. The Cerrado holds carbon stocks in its woody biomass and deep soils. However, driven by global commodity markets for beef and soy, over 45% of its original cover has been converted, leaving a highly fragmented landscape dominated by agricultural monocultures (Strassburg *et al.*, 2017).

Furthermore, addressing the carbon–biodiversity–land use through the nexus approach requires navigating complex spatial synergies and trade-offs. While carbon storage and biodiversity conservation can offer mutual co-benefits, optimizing land use for a single metric often leads to undesired environmental outcomes. For instance, in open-canopy ecosystems like the Cerrado, carbon-centric climate mitigation strategies, such as afforestation with exotic monocultures, can severely degrade endemic biodiversity and disrupt local hydrological cycles (Veldman *et al.*, 2015). Conversely, the unchecked expansion of agricultural frontiers simultaneously decimates both belowground carbon sinks and species habitats. Therefore, spatially mapping where high carbon density intersects with ecological integrity is essential to prioritize nature-based solutions that deliver genuine "win-win" conservation outcomes rather than displacing one crisis to solve another (Soto-Navarro *et al.*, 2020).

To resolve these trade-offs, landscape-scale governance models like "mosaics of protected areas" have been put forward to reconcile intensive agricultural production with conservation networks. The Sertão Veredas-Peruaçu Mosaic (SVPM), spanning 1.8 million hectares in Minas Gerais and Bahia, stands as a premier example of integrated participatory territorial management.

While previous literature has evaluated carbon or biodiversity dynamics separately, there is a critical gap in spatially explicit, multiscale analyses that integrate both metrics to assess governance efficacy. This paper addresses this gap by analyzing land-use transitions, biomass density, and the Mean Species Abundance (MSA) index from 2012 to 2023. By establishing analysis with two spatial extents, the Cerrado biome and the SVPM landscape, we might contribute to the discussion of whether integrated landscape management through mosaic of protected areas can successfully safeguard the carbon–biodiversity–land nexus.

Maintaining biodiversity and carbon sinks in native vegetation of Cerrado are fundamental pillars for supporting life and human well-being. However, human activities have driven an unprecedented socio-ecological crisis, marked by climate change and the accelerated loss of natural habitats (Brondízio *et al.*, 2019; IPBES, 2019). Changes in land use and land cover are the main drivers of this degradation, altering the spatial configuration of landscapes, isolating wildlife populations (Fahrig, 2003), and converting natural ecosystems, which previously acted as carbon sinks, into significant sources of greenhouse gas (GHG) emissions (IPBES, 2019). Given the climate emergency and the need for biodiversity conservation, it is imperative to align economic development with sustainable land management (Epple *et al.*, 2016).

To mitigate these impacts, the adoption of governance arrangements that promote multifunctional landscapes emerges as a promising strategy. In Brazil, mosaics of protected areas represent an integrative territorial management scale, in theory able to reconcile the productive use of land with the maintenance of conservation networks. The Sertão Veredas-Peruaçu Mosaic (SVPM), located between northern Minas Gerais and southwestern Bahia, stands out nationally for its effective management and governance (Herrmann, 2015). By encompassing a diverse matrix of conservation units, indigenous lands, and properties with anthropogenic uses, the SVPM constitutes an ideal sample of the Cerrado to

assess how integrated management has been containing deforestation in the face of systemic pressure on the biome.

Although literature acknowledges the isolated impacts of land conversion, there is a lack of studies in the Cerrado that spatially integrate metrics of biodiversity integrity and carbon storage at multiple scales (biome versus landscape). Understanding how land use processes simultaneously affect these two environmental agendas is essential to optimize public policies and target resources to areas that can simultaneously benefit both biological and climatic aspects.

In this context, this article aims to spatially analyze the impacts of land use and land cover transitions on biodiversity and carbon stocks in the Cerrado, establishing a counterpoint with the landscape management scale of the Sertão Veredas-Peruaçu Mosaic. This is achieved through the integration of MapBiomas data, biomass estimates (Zimbres *et al.*, 2021), and the Mean Species Abundance (MSA) metric derived from the GLOBIO 4 model (Schipper *et al.*, 2020). The study aims to show the synergies and trade-offs resulting from the expansion of the agricultural frontier, providing quantitative data for territorial management that reconciles climate and biodiversity agendas.

2. Materials and methods

The key steps of the methodology are summarized in the flowchart below (Fig. 1) and further detailed in the following subsections.

2.1. Characterization of the Study Area

The study was conducted at two contrasting spatial scales: the Cerrado scale, encompassing the entire biome, and the landscape scale, represented by the Sertão Veredas-Peruaçu Mosaic (SVPM). The Cerrado occupies approximately 24% of the Brazilian territory and is characterized by a gradient of savanna, forest, and grassland formations with high levels of endemism (Ribeiro & Walter, 2008). The SVPM, located between northern and northwestern Minas Gerais and part of southwestern Bahia, covers approximately 1.8 million hectares. Recognized by the MMA Ordinance No. 128/2009, the Mosaic integrates 14 conservation units (CUs) of different categories and indigenous lands, configuring itself as an integrated management territory recognized for its high governance effectiveness and for reconciling biodiversity conservation with sustainable use by traditional communities (Herrmann, 2015).

2.2. Mapping Land Use and Land Cover Dynamics and Carbon Storage

For the temporal quantification of land use, annual land cover map series from the MapBiomas Project (Collection 8.0), generated from Landsat satellite images with a spatial resolution of 30 meters, were used. The analysis time frame covered the period from 2012 (initial year) to 2023 (final year). In a GIS environment, a transition matrix was generated that allowed the identification of the main conversion patterns in a comparative way between the spatial scales analyzed.

The ecosystem service of carbon storage was quantified based on continuous mapping of Aboveground Woody Biomass (AGWB) for native Cerrado vegetation, developed by Zimbres *et al.* (2021). The mapping, generated from the integration of primary data – obtained through field inventories – and modeling, expresses biomass density in tons per hectare (t/ha) above the ground. The spatially distributed biomass data were overlaid onto land-use transition polygons, making it possible to identify the amount of biomass associated with different land use and land cover classes.

2.3. Biodiversity Valuation Assignment

The impacts of landscape changes on biodiversity were quantified using the Mean Species Abundance (MSA) metric, an indicator of ecological integrity derived from the GLOBIO 4 model (Schipper *et al.*, 2020). The MSA value is an indicator of ecological integrity that ranges from 0 (equivalent to a totally degraded ecosystem) to 1 (equivalent to a preserved ecosystem), expressing the proportion of the abundance of remaining species in relation to an undisturbed reference condition. MSA values from the GLOBIO 4 model were correlated with land use and land cover classes from MapBiomas. The difference between the MSA values between the initial (2012) and final (2023) classes allowed for the spatialization of areas of biodiversity loss, gain, or maintenance in the landscape.

2.4. Integrated Analysis and Correlation of Tradeoffs

The methodological integration consisted of the spatial intersection between land-use transition matrices, MSA variation gradients, and woody biomass density. This step sought to identify trade-off patterns, quantifying the percentage of stored biomass that was made vulnerable in areas with MSA loss, highlighting areas of overlapping sensitivity to climate and biodiversity agendas at the biome and landscape scales.

3. Results

3.1. Dynamics of Land Use and Land Cover Transition

Between 2012 and 2023, land use and land cover (LULC) changes exhibited distinct conversion dynamics across the analyzed spatial scales. At the broader Cerrado biome scale, the dominant landscape trajectory was the conversion of native vegetation to agricultural land use. Specifically, the primary transition in absolute terms was the conversion of Savanna Formations to Pasture, resulting in the suppression of approximately 2.98 million hectares. This was followed by transitions to a Mosaic of Uses, which accounted for 1.95 million hectares.

At the local landscape scale, delimited by the Sertão Veredas-Peruaçu Mosaic (SVPM), transition trajectories were qualitatively consistent with biome-wide trends, with the conversion of Savanna Formations to Pasture remaining the primary driver of change. However, the intensity of this transition differed significantly between scales: while the Cerrado biome lost 3.35% of its natural area directly to agricultural expansion, the SVPM restricted this conversion to 1.51%, which is less than half of the biome-average rate.

3.2. Variation in Biodiversity Integrity (MSA)

The spatial-temporal analysis of Mean Species Abundance (MSA) revealed a more pronounced decline in biological integrity at the biome scale compared to the mosaic scale. Within the Cerrado biome, 6.57% of the analyzed territory exhibited a negative change in MSA, indicating widespread native vegetation loss and habitat degradation. Conversely, areas showing positive MSA trends (indicative of active or passive ecological regeneration) were restricted to just 1.87% of the biome.

The SVPM demonstrated greater stability, as 2.39% of its territory registered a negative MSA balance, a rate nearly three times lower than the biome average, highlighting the landscape’s resilience to degrading forces. However, only 0.66% demonstrated positive MSA trends.

3.3. Vulnerability of Biomass Stocks

The spatial intersection of biodiversity integrity (MSA) and carbon storage highlighted a critical vulnerability in aboveground carbon pools, particularly at the biome level.

- In the Cerrado biome, 9.23% of the total aboveground woody biomass was concentrated in areas undergoing active degradation (characterized by a declining MSA trajectory).
- At the SVPM scale, only 2.40% of the local biomass stock was located within areas experiencing biodiversity decline.

This indicates that carbon stocks within the SVPM are more secure and less exposed to degradation-driven emission pathways than those across the wider biome.

3.4. Multi-Scale Comparative Summary

To facilitate a direct comparison of the indicators across the two analyzed scales, the key metrics are synthesized in Table 1 below.

Table 1 Comparative summary of LULC transitions, biodiversity integrity (MSA), and biomass vulnerability between the Cerrado Biome and the SVPM (2012–2023).			
Metric / Indicator	Cerrado Biome	SVPM	Ratio / Comparison
Direct conversion of native vegetation to agriculture (%)	3.35%	1.51%	~ 2.2x lower in SVPM
Area with declining biodiversity integrity (Negative MSA, %)	6.57%	2.39%	~ 2.7x lower in SVPM
Area with regenerating biodiversity (Positive MSA, %)	1.87%	0.66%	~ 2.8x lower in SVPM
Biomass stock vulnerable to ecological degradation (%)	9.23%	2.40%	~ 3.8x lower in SVPM

3.5. Widespread Net Degradation and Temporal Dynamics of Biodiversity Integrity

The temporal analysis of Mean Species Abundance (MSA) reveals a clear, systemic trend toward biodiversity degradation across both analyzed spatial scales between the baseline and end-line periods. This downward trajectory reflects the continuous anthropogenic pressure exerted on the biome, primarily driven by the expansion of the agricultural frontier and the resulting fragmentation of natural habitats.

3.5.1. Declining Mean Biodiversity Integrity

Over the analyzed period, both study regions experienced a systematic reduction in average biodiversity integrity. At the biome scale, the mean MSA value declined from 0.57 to 0.51, a drop that seems to indicate erosion of habitat quality and species abundance. Within the Sertão Veredas Peruaçu Mosaic (SVPM), the mean MSA value decreased from 0.61 to 0.57. While this reflects a parallel downward trend, the SVPM not only maintained a higher baseline of ecological integrity but also experienced a less severe rate of decline. This suggests that the integrated governance and the network of protected areas within the mosaic act as a partial buffer against the regional vectors of deforestation, even if they cannot entirely isolate the landscape from macro-regional pressures.

3.5.2. Expansion of Highly Degraded Areas

A critical indicator of this widespread degradation is the substantial expansion of land falling into the lowest biodiversity integrity class (MSA = 0.05), which typically corresponds to areas fully converted for intensive agricultural or pastoral use. Across the Cerrado biome, the proportion of landscape transitions terminating in this lowest MSA category nearly doubled, rising from 9.1% to 16.3%. This alarming increase underscores a systemic transition toward simplified, highly degraded landscapes that impose severe socioecological trade-offs by maximizing provisioning services at the expense of habitat support and ecological resilience. In contrast, while the SVPM is not immune to these land-use dynamics, the expansion of highly degraded areas was more contained, growing from 8.3% to 11.5%. This containment highlights the effectiveness of the mosaic's conservation strategies in preventing the complete conversion of natural vegetation, thereby contributing to the safeguarding of critical ecological functions.

3.5.3. Dynamics of Loss, Stability, and Gain

An evaluation of the transition trajectories further exposes the structural imbalance of land-use dynamics, where biodiversity loss consistently outpaced ecological gain across both spatial scales. In the Cerrado biome, 32.9% of all land-use and land-cover (LULC) transitions resulted in a net loss of biodiversity integrity, overshadowing the 23.5% of transitions that exhibited a positive, regenerative trajectory. Consequently, while 43.6% of the territory remained ecologically stable, the overall dynamic is characterized by a net MSA value deficit.

The SVPM presented a highly dynamic landscape that seems to hold a greater capacity for ecological recovery. Within the mosaic, 29.2% of transitions showed positive biodiversity gains, a notably higher rate of regeneration compared to the biome average. This is likely attributable to active conservation management, natural regeneration in protected zones, and the enforcement of environmental regulations within the territory. However, this regenerative capacity is juxtaposed with a transition loss rate of 36.5% and a spatial stability of 34.4%. Although the SVPM fosters greater ecological restoration, the net balance remains negative, driven by dominant degrading transitions in its permeable matrix. This dynamic highlights a critical management challenge: even within robust conservation mosaics, passive protection is insufficient. Reversing the current deficit requires scaling up active restoration efforts to outpace the persistent pressures of land conversion.

The figures below show the patterns of MSA value gain or loss by land cover transition type registered in the Cerrado as a whole (Fig. 2) and in the SVPM (Fig. 3).

3.5.4. Summary of Temporal Biodiversity Trends

To compare the shifting baselines and transition dynamics across both scales, key metrics have been synthesized in Table 2.

Table 2 Temporal dynamics of Mean Species Abundance (MSA) and transition directions in the Cerrado Biome and the SVPM.			
Metric / Indicator	Cerrado Biome	SVPM	Trend / Comparison
Baseline Mean MSA	0.57	0.61	Higher baseline integrity in SVPM
End-line Mean MSA	0.51	0.57	Parallel decline observed in both regions
Prevalence of Highly Degraded Land (MSA = 0.05) - Baseline	9.1%	8.3%	Comparable starting levels of severe degradation
Prevalence of Highly Degraded Land (MSA = 0.05) - End-line	16.3%	11.5%	~ 1.8x increase in Cerrado vs. ~1.4x in SVPM
Transitions Resulting in Net Loss (%)	32.9%	36.5%	Loss occurring across more than a third of both regions
Transitions Resulting in Net Gain (%)	23.5%	29.2%	Regeneration dynamics are slightly stronger in SVPM

4. Discussion

The accelerated conversion rates of savanna formations to agricultural land use confirm that the Cerrado biome remains under continuous pressure from the expanding agricultural frontier, a historical process that has severely fragmented the landscape. The regional loss of 6.57% in biodiversity integrity

(MSA) calculated in this study directly reflects the impact of these anthropogenic disturbances. The systematic suppression of natural habitat not only threatens endemic Cerrado taxa but also systematically disrupts the inseparable nexus between land use, biodiversity conservation, and regulation of the carbon cycle.

The diverse formations of vegetation in the Cerrado function as crucial, dynamic reservoirs able to store aboveground and belowground biomass and soil organic carbon (SOC). As globally synthesized by Niti *et al.* (2026), savanna and natural grassland systems can store between 80 and 205 Mg C ha⁻¹ in total, with a dominant fraction allocated belowground. The removal of this vegetation cover abruptly converts these terrestrial sinks into net sources of greenhouse gas (GHG) emissions.

More than just an immediate volumetric loss of carbon, the biological degradation observed more prominently at the Cerrado biome scale (declining from a mean MSA of 0.57 to 0.51). Recent evidence indicates that the loss of taxonomic and functional diversity intrinsically reduces the capacity of ecosystems to sequester and stabilize carbon over the long term. Under the lens of niche complementarity, biologically diverse communities optimize resource partitioning across vertical and horizontal spaces, maximizing net primary productivity and generating chemical litter diversity. Landscape homogenization and the loss of functional redundancy destabilize these pathways, leaving remaining carbon stocks highly vulnerable to water stress, temperature anomalies, and catastrophic wildfires. Therefore, in the Cerrado, biodiversity degradation and carbon emissions are not merely parallel consequences of deforestation; the erosion of biological integrity is itself a driver of weakened climate resilience across the biome.

Within this scenario of widespread degradation, the contrast with the ecological indicators observed in the interior of the Sertão Veredas-Peruaçu Mosaic (SVPM) highlights the transformative role of integrated and territorialized conservation networks. While the Cerrado biome lost 3.35% of its natural area directly to agriculture, the SVPM restricted this loss to 1.51%, keeping the vulnerability of its local biomass stocks at significantly lower levels (2.40% compared to 9.23% in the biome). This stability is justified by the efficacy of the governance model adopted by the Mosaic. By articulating Conservation Units (CUs) of different categories and indigenous territories under an active advisory council and a Conservation-Based Territorial Development Plan, the SVPM operationalizes what recent literature defines as multilevel, community-based governance.

As highlighted by Niti *et al.* (2026), conservation and restoration strategies that neglect local governance and land tenure security tend to generate socioeconomic conflicts and implementation failures. Conversely, territories under indigenous and community-led management exhibit drastically lower deforestation rates and higher biological integrity. By reconciling the safeguarding of traditional territories with sustainable management, the SVPM not only mitigates the expansion of the agricultural frontier but also reduces enforcement costs and strengthens regional identity, establishing a model of socio-ecological sustainability where nature conservation coexists with livelihood security.

The findings of this study carry direct implications for the formulation of territorial public policies and the fulfillment of global targets. Historically, climate and biodiversity agendas have been treated in isolated, sectorial silos. This fragmentation frequently results in contradictory policies, such as promoting fast-growing monocultures for carbon mitigation (e.g., homogenous reforestation of exotic species). Although such plantations yield rapid short-term aboveground biomass gains, they compromise habitat diversity, lack stability under environmental stress, and deplete soil organic carbon stocks over the long term compared to native, biodiverse ecosystems. The results obtained in the SVPM, where 97.6% of the biomass remains protected in areas free from declining biological integrity, validate mosaics as ideal units for the integrated management of multifunctional landscapes.

Given the severe climate projections for the Cerrado, territorial planning policies must move beyond the exclusionary dichotomy of strict protection versus intensive production. The pathway to sustainability lies in the coherent integration of Nationally Determined Contributions (NDCs) under the Paris Agreement with the Kunming-Montreal Global Biodiversity Framework and the Sustainable Development Goals (SDGs 2, 13, and 15). Therefore, conserving areas that concentrate high concomitant values of MSA and biomass - such as the core conservation zones and indigenous territories of the SVPM - must be prioritized strategically. Preserving biological integrity should not be treated as a secondary objective, but rather as the functional and mechanical pillar that secures the physical permanence of stored carbon within the Cerrado biome.

The high rates of conversion of savanna formations to agricultural uses confirm that the Cerrado remains under continuous pressure from the advance of the agricultural frontier, a historical process that has severely fragmented the landscape (Klink & Moreira, 2002; Joly *et al.*, 2019). The regional loss of MSA calculated in this study (6.57%) demonstrates the negative impact of anthropogenic disturbances on the landscape. The loss of natural habitat exacerbates the risks associated with biodiversity loss, reflected in the reduction of MSA values, which is even more relevant for endemic Cerrado taxa; in addition to decreasing the landscape's capacity to provide fundamental ecosystem services, including carbon storage.

The vegetation of the Cerrado is able to retain vast stocks of woody biomass and carbon in the soil (Zimbres *et al.*, 2021). The removal of this cover, in addition to impacting the sink function, abruptly increases local emissions (Davidson *et al.*, 1995; Lal, 2011). Recent modeling, such as that demonstrated by Weiskopf *et al.* (2024) indicate that the decline in biological diversity itself intrinsically reduces the functional capacity of the ecosystem to store carbon. Lower taxonomic and functional diversity implies underutilization of resources and lower rates of primary productivity (Balvanera *et al.*, 2006). Thus, deforestation in the Cerrado not only affects the climate agenda by emitting carbon immediately but also establishes a positive feedback loop: the loss of biodiversity weakens the structural ecological processes of the biome, which, in turn, loses resilience in the face of ongoing climate change (Epple *et al.*, 2016).

In this context, the contrast with the indicators of the Sertão Veredas-Peruaçu Mosaic highlights the relevance of integrated protection networks. The suppression contained to 2.39% of the area in the SVPM corroborates the proposal that well-managed mosaics function as tangible barriers against the depletion of natural resources, with the use of instruments such as the Conservation-Based Territorial Development Plan and the maintenance of an active advisory council. This stability is supported institutionally by the high rates of management and governance effectiveness achieved by the SVPM at the national level (Herrmann, 2015). The reconciliation of socioeconomic development with the conservation of natural areas and the preservation of traditional territories contributes to strengthening climate and nature agendas while strengthening regional identity, supporting the idea that participatory approaches are essential for sustainability (Cunha & Lima, 2017).

However, despite outperforming the biome baseline, the SVPM still operates under a net ecological deficit. A critical question emerges from this dynamic: while this rate of biodiversity loss is comparatively lower, can it be considered satisfactory? With the spatial footprint of regenerating areas restricted to merely 0.66% of the mosaic's territory, the ongoing degradation (2.39%) continues to outpace ecological recovery. Therefore, merely slowing the rate of biological erosion is arguably insufficient for a territory specifically governed to harmonize conservation and sustainable development. These patterns highlight that while the mosaic's passive conservation framework successfully prevents large-scale degradation, achieving a net-positive ecological balance will require targeted, active restoration policies within its anthropized matrix.

The results of this study demonstrate that the global climate and biodiversity agendas must be jointly addressed in territorial planning (Schipper *et al.*, 2020). The efficiency demonstrated by the SVPM in protecting 97.6% of its biomass in areas free from biodiversity decline validates the effectiveness of mosaics as landscape management units (Herrmann & Costa, 2015). Given the severe predictions for the future of the Cerrado (Cavalcanti *et al.*, 2010), public policies for territorial management need to overcome the dichotomous model of strict protection versus intensive production, fostering multifunctional landscapes that simultaneously ensure the carbon stocks and wildlife populations necessary for long-term health and prosperity.

Therefore, protecting areas with high concomitant values of MSA and biomass (such as those observed within the Conservation Units and indigenous territories of the SVPM) is fundamental. Strategic management at a mosaic scale enables the maintenance of multifunctional landscapes, simultaneously reconciling global commitments to carbon retention and halting biodiversity loss. Biodiversity preservation acts as a mechanical pillar for maintaining ecosystem productivity, emphasizing that conservation actions based solely on spatial area must incorporate the qualitative dimensions of biological integrity.

Despite the SVPM's demonstrated ability in containing agricultural expansion and stabilizing local biomass pools, continuous targeted efforts are required to further strengthen its conservation performance and secure its long-term ecological resilience. First, as highlighted by Niti *et al.* (2026),

managing a complex mosaic landscape requires moving beyond passive boundary preservation to active, transdisciplinary management that systematically addresses local, site-specific trade-offs. To achieve this, the SVPM must establish a robust ground-validation network, integrating soil organic carbon inventories, microbial biomass assays, and community-led biodiversity surveys, to complement remote sensing data, thereby enabling planners to identify real-time vulnerabilities in carbon and biodiversity pools that satellites cannot resolve from space. Second, the mosaic's governance framework must overcome persistent policy fragmentation by more explicitly aligning its Conservation-Based Territorial Development Plan with national climate targets (such as Brazil's NDCs) and international commitments like the Kunming-Montreal Global Biodiversity Framework. Finally, sustaining this protective buffer over the coming decades requires reinforcing the legal security of traditional territories and co-designing equity-sensitive governance schemes (such as local Payment for Ecosystem Services or community forestry programs). Providing direct benefit-sharing to forest-dependent and indigenous communities is essential to offset the powerful economic temptations of the agricultural frontier, ensuring that local stewardship remains the primary line of defense for the Cerrado's irreplaceable ecological heritage.

5. Conclusion

The accelerated conversion of the Cerrado biome simultaneously compromises the biodiversity and carbon stock of the biome. The research results highlight three central conclusions.

First, the continued expansion of agricultural and livestock farming in the Cerrado biome has resulted in a decline in the Average Species Abundance Index (MSA) in 6.57% of the analyzed territory, directly jeopardizing 9.23% of all aboveground woody biomass stored in these transition zones.

Second, the Sertão Veredas-Peruaçu Mosaic (SVPM) has proven to act as a protective shield. Integrated management practices restricted the loss of protected areas to 2.39% of its area and safeguarded 97.6% of its total biomass stock in ecosystems protected from reduced biological integrity. The results indicate greater capacity in maintaining ecosystem services in multifunctional landscapes, where networks of protected areas interact with a permeable and sustainable agricultural matrix (Kremen & Merenlender, 2018). This systemic approach, applicable to governance instruments such as conservation mosaics, ensures both the maintenance of large carbon stocks and biodiversity hotspots, as well as the well-being and prosperity of traditional communities that manage the territory in an integrated way.

The protection of terrestrial carbon stocks is intrinsically dependent on the maintenance of biodiversity. Territorial arrangements that integrate protected areas, such as mosaics, reduce negative trade-offs and support the functional stability of ecosystems.

Given the current climate emergency, land-use planning policies should favor the implementation and strengthening of integrated conservation networks, which are consolidated as effective strategies to promote multifunctional landscapes, ensuring ecological resilience and compliance with international sustainability goals.

Declarations

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Author Contribution

D.V.: Conceptualization, Methodology, Formal analysis, Investigation, Writing - original and final draft. S.C.R.: Supervision, Validation, Writing - review & editing. D.C.A: Formal analysis, Data curation, Software. All authors contributed to the critical results and analysis of the work and approved the final manuscript.

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Data Availability

The data used for the mapping of the aboveground woody biomass (AGWB) of the Cerrado biome was obtained from the publication available at:

<<https://www.sciencedirect.com/science/article/pii/S0378112721007052>>.

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Figures

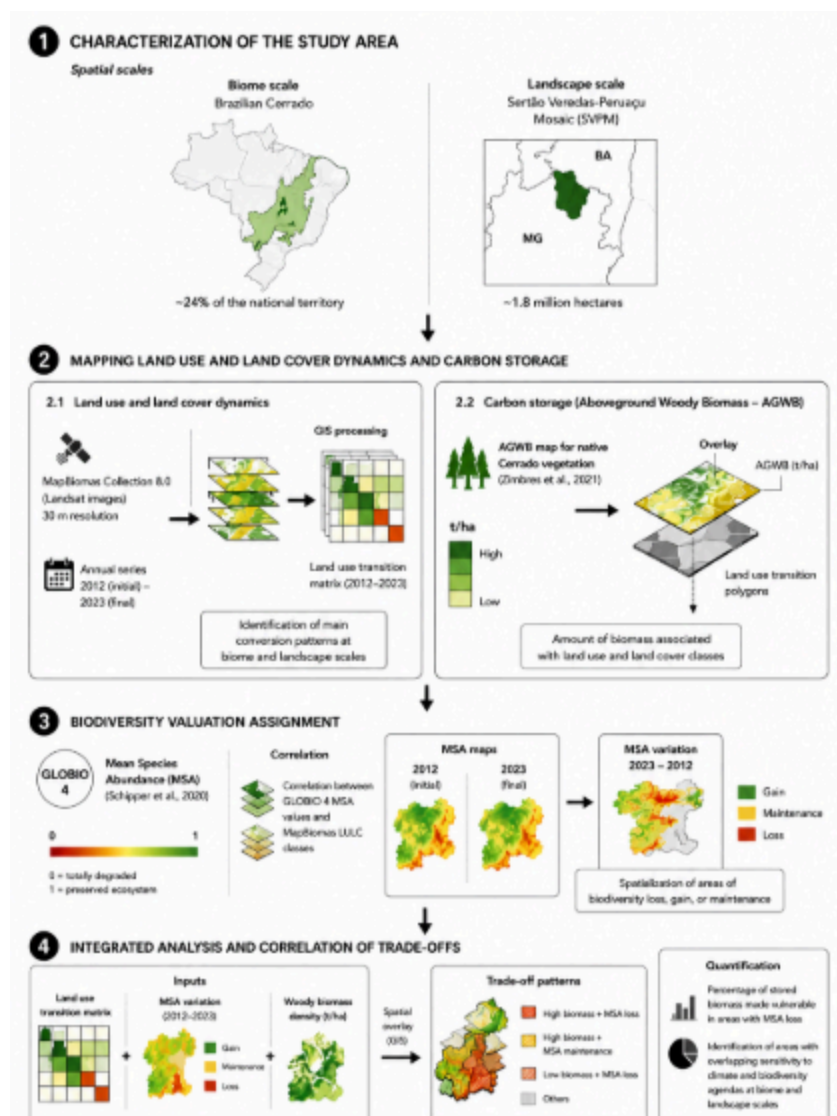


Figure 1

Methodological workflow.

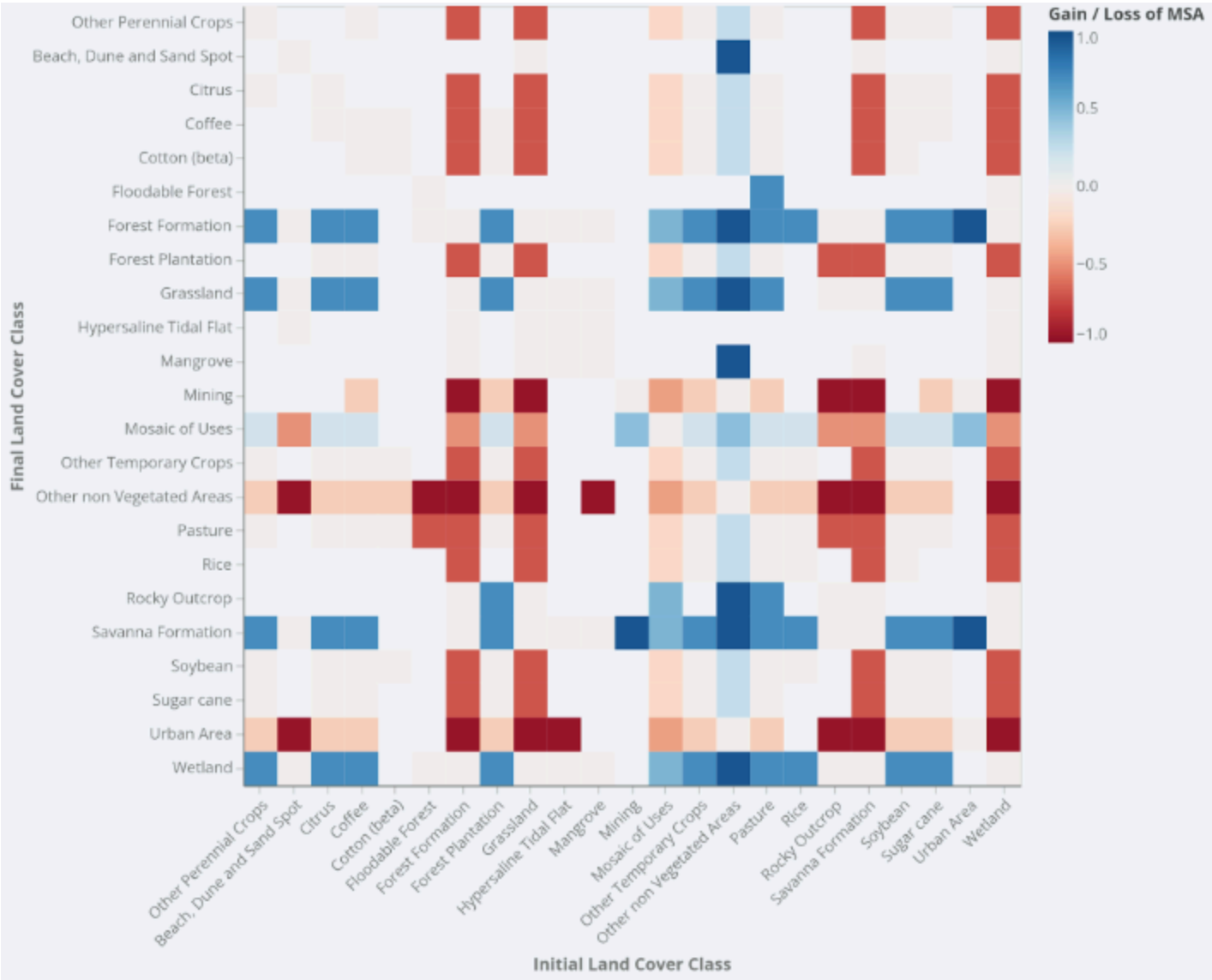


Figure 2

MSA Value transition heatmap – Cerrado.

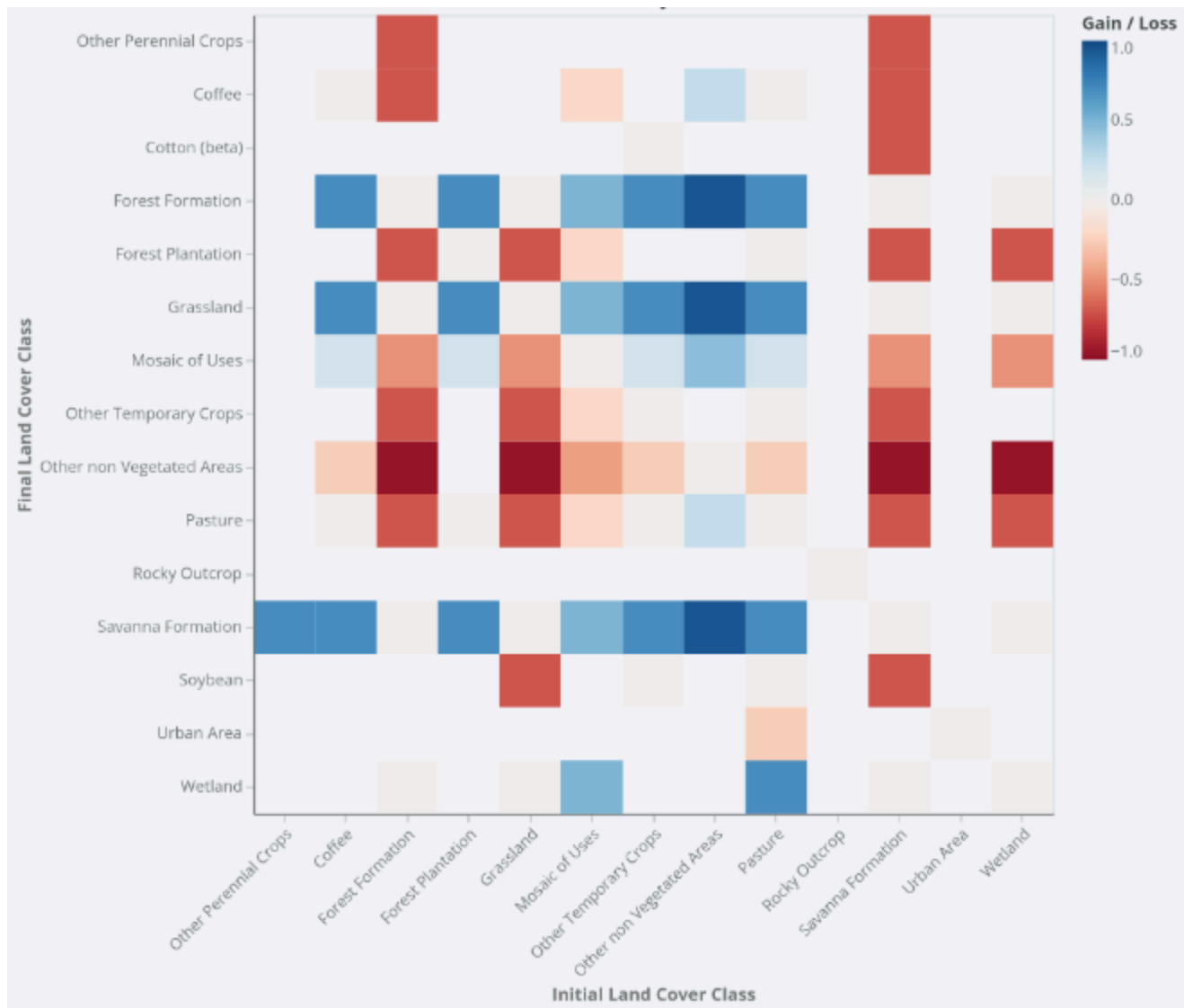


Figure 3

MSA Value transition heatmap – SVPM.