REGIONAL DISPARITIES IN FOREST AND BIODIVERSITY INDICATORS IN VIETNAM: EVIDENCE FROM FOREST GROWTH AND CONSERVATION AREAS

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Abstract. Research at the regional level remains limited, leading to inconsistent policies and uneven development outcomes that weaken the effectiveness of forest conservation. This study addresses this gap by examining the relationship between the Annual Forest Growth Rate (AFG), Population Size on Protected Forests (PSF), and Nature Conservation Areas (NCA) in Vietnam, a country that has experienced significant reforestation but still faces regional disparities. Using original data (2012–2022) and standardized scores, we combine raw and normalized indicators to compare six Vietnamese regions with selected countries and global benchmarks. Results reveal clear differences. The Northern Midlands and Mountains (NMM) and the North Central and Central Coasts (NCC) have high AFG and low PSF, indicating successful reforestation and governance reforms. Conversely, the Southeast and the two delta regions experience high PSF and low or negative AFG, highlighting conflicts between conservation efforts and urban–industrial growth. The Central Highlands present a paradox: while large areas of forest cover remain, natural forests continue to decline. Overall, Vietnam ranks among the fastest-growing countries in terms of forest expansion, but national averages conceal significant regional disparities. Policies tailored to specific regions, from mangrove protection in delta areas to enhancing forest quality in mountainous zones, are essential for achieving long-term ecological and climate benefits.
Keywords: *forest governance, natural conservation, protected areas, Vietnam, regional comparative analysis*

Introduction

Forests and biodiversity are vital foundations of ecological sustainability. They deliver a wide range of ecosystem services crucial for human well-being, such as carbon sequestration, water regulation, soil protection, and habitat provision (Brockerhoff et al., 2017; FAO, 2020). The conservation of forest ecosystems also closely aligns with global development priorities, especially Sustainable Development Goal (SDG) 13 on Climate Action and SDG 15 on Life on Land (Kroll, 2015). Additionally, the positive interactions between biodiversity and carbon stocks within forests emphasize the potential for synergistic management strategies that both combat climate change and preserve ecological integrity (Lecina-Diaz et al., 2018). Despite their importance, most current studies are conducted at relatively small spatial or short temporal scales and often lack comprehensive data coverage. Limitations in high-resolution spatial and temporal information, particularly in belowground ecosystems or remote landscapes, continue to restrict the robustness of biodiversity and ecosystem assessments (Birkhofer et al., 2015; Townsend et al., 2018; Richard et al., 2021).

Vietnam offers a key case for studying the relationship between forest growth and biodiversity conservation. After experiencing extensive deforestation in the mid-twentieth century, Vietnam reversed these trends in the 1990s through a mix of

reforestation efforts, expanding plantations, and policy reforms, including land titling and the implementation of Payments for Forest Environmental Services (PFES) (Meyfroidt and Lambin, 2008). As a result, national forest cover now exceeds 40%, with notable growth in several mountainous areas (Cochard et al., 2020; Phan and Hufnagel, 2025b). This progress highlights the impact of governance reforms, community participation, and market-based tools in shaping forest outcomes. Research indicates that reducing poverty, improving local governance, and managing demographic pressures are crucial for maintaining forest cover and preventing degradation (Khuc et al., 2018). Alternative governance models, such as community-based approaches, are found to be more effective in preserving ecosystem services than purely state-driven systems like PFES or REDD+ (Duc et al., 2018). However, studies on forests, protected areas, and conservation in Vietnam face several significant limitations that hinder the reliability and broad applicability of their findings. Official forest data and land-cover maps tend to be coarse and rarely undergo independent validation, raising concerns about the accuracy of biodiversity and carbon assessments (Meyfroidt and Lambin, 2008). Governance remains largely centralized, with government agencies holding most decision-making power in initiatives like REDD+, which limits the influence of non-state actors (Pham et al., 2014). The protected areas system suffers from insufficient funding, limited stakeholder engagement, and poor integration with broader economic development plans (ICEM, 2003). Moreover, access to Vietnamese research is restricted by language barriers, as much of the literature is available only in Vietnamese or grey sources, with an emphasis on national or thematic studies (Tung et al., 2022). Collectively, these issues reveal critical gaps in data quality, methodological consistency, and the inclusion of diverse governance perspectives.

Therefore, this study aims to fill important knowledge gaps by conducting a regional analysis of forest growth and conservation indicators in Vietnam. By combining raw and normalized data, the analysis enhances comparability both within Vietnam's regions and with international standards. The paper offers several significant contributions. First, it provides one of the few systematic assessments of regional differences in forest growth and conservation in Vietnam, highlighting disparities between regions that are hidden by national averages. Second, it places these findings within a broader international context, clarifying how Vietnam's performance compares to global benchmarks. In doing so, the study not only strengthens the empirical basis for conservation policies in Vietnam but also provides methodological insights for incorporating regional indicators into larger sustainability evaluations.

Materials and methods

Indicators and multivariate analysis

This study examines three indicators related to forest growth and conservation:
(i) PSF – population size on protected forest areas, representing human presence and dependence on forest protection zones; Unit: persons/ha

$$PSF = \frac{\text{The population size}}{\text{Protected forest area}} \qquad (Eq.1)$$

Source: GSO; Data.worldbank.

(ii) AFG – annual forest growth rate, indicating the pace of forest recovery and reforestation efforts

$$AFG = \frac{Forest\ area_{present} - Forest\ area_{past}}{Forest\ area_{past}} \qquad (Eq.2)$$

Source: Ourworldindata.org.

(iii) NCA – nature conservation areas, denoting the spatial extent of biodiversity conservation sites. Unit: Percent (%)

$$NCA = \frac{Total\ nature\ conservation\ areas}{total\ land\ area} \times 100 \qquad (Eq.3)$$

Source: VNGSO: General Statistics Office of Vietnam; Data.worldbank.

These indicators reflect both the ecological changes of forest cover and the social and spatial pressures on protected ecosystems.

Original statistics on AFG, PSF, and NCA were collected for Vietnam and comparator countries over the periods 2012–2022 (AFG), 2012–2017 (PSF), and 2022 (NCA).

These raw indicators represent the actual observed values of forest growth, population supported by protected forests, and nature conservation areas, respectively.

Normalization

To ensure comparability across countries and time, the raw data were normalized to a common 0–100 scale using min–max standardization (Drewnowski, 1972):

$$X' = \frac{X - X_{min}}{X_{max} - X_{min}} \times 100$$

where X′ is the normalized score and X is the original value. This normalization preserves the relative differences between countries while removing the influence of unit magnitude and scale disparities.

Hierarchical cluster analysis (HCA)

Hierarchical Cluster Analysis (HCA) was employed to classify regions and countries into groups with similar ecological and socio-forestry characteristics, based on Euclidean distance and Ward's linkage method.

Comparing raw and normalized indicators helps distinguish between absolute performance (raw data) and relative positioning (normalized scores), thereby providing a clearer interpretation of spatial disparities and development gaps. Data processing and visualization were performed using PAST 4 software.

Data source and study scope

Data were obtained from two complementary sources. The data were gathered at both national and regional levels. For Vietnam, regional statistics came from the General Statistics Office (GSO) and relevant ministries, while international data were sourced from Our World in Data, the World Bank, and other official repositories.

Unlike AFG and PSF, the NCA indicator was available only for the most recent year (2022). Therefore, it represents the current state of conservation coverage rather than its temporal dynamics.

PSF and AFEG data were collected for 2012 and 2022, denoted as PSF12 and PSF22, as well as AFG12 and AFG22, respectively, representing the beginning and ending years of the study period.

Study scope

The analysis includes six major socio-ecological regions (*Fig. 1*) of Vietnam: Red River Delta (RRD), Northern Midlands and Mountains (NMM), North Central and Central Coasts (NCC), Central Highlands (CH), Southeast (SE), and Mekong River Delta (MRD), as well as the entire country (VN). For international comparison, neighboring countries such as Thailand (Thai), Laos, Malaysia (Mala), Singapore (Sing), and China (CN) are considered, along with broader regions like Asia, Europe, and Africa, and selected countries including Australia (Aus), Canada (CA), and the United States (US), as well as global averages.
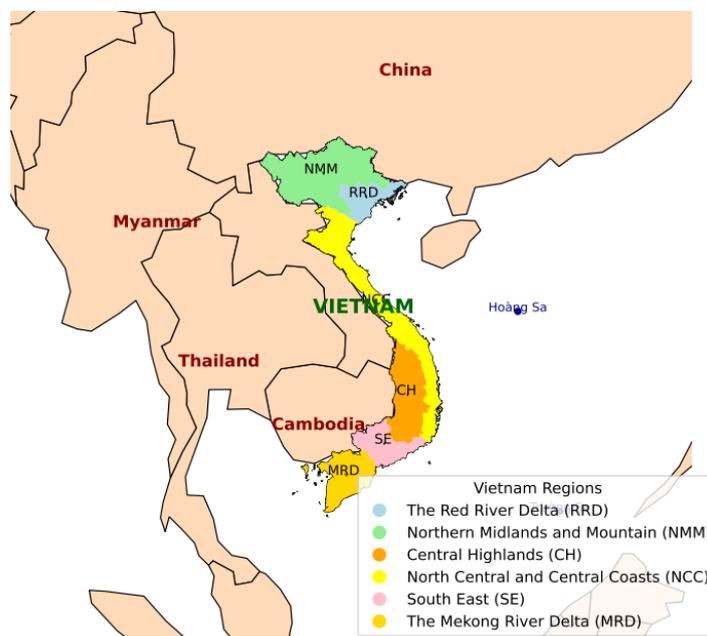

Figure 1. Six regions in Vietnam (Phan and Hufnagel, 2025b)

Results

Descriptive statistics of original data

This section presents the original data for three indicators: Population size by protected forest area (PSF), which shows the number of people per conservation zone and highlights concerns about human living conditions related to green space preservation; Annual forest area growth (AFG). It also includes the Nature Conservation Areas (NCA) with a snapshot of six regions in 2022.

Previous analyses (Phan and Hufnagel, 2025a) indicated that Singapore had the highest population density per protected forest hectare, with consistently increasing

figures over the past decade. While Vietnam regions have fewer PSF than Singapore, but significantly more than other regions and countries, especially in the Mekong River Delta (MRD), the Red River Delta (RRD), and the Southeast (SE). In contrast, positive forest growth was primarily driven by the Northern Midlands and Mountain (NMM) and North Central and Central Coast (NCC) regions, where extensive reforestation programs have been implemented. The heavily populated and agriculturally intensive RRD and MRD showed negative AFG, while the SE region exhibited a mixed trend, partly reflecting the pressures of urbanization (Phan and Hufnagel, 2025a).

Overall, Vietnam's national average remains positive, largely due to the strong growth in the northern regions. At the international scale, the EU achieved the highest AFG, highlighting its consistent efforts in forest expansion. This change may reflect revisions in reporting and land classification under the EU Biodiversity Strategy and Forest Europe framework, rather than a sudden ecological expansion. Several neighboring countries, such as Laos, Malaysia, and Thailand, displayed inconsistent growth patterns with periods of notable forest loss. Australia recorded a strongly negative average AFG, indicating substantial forest decline over time.

Figure 2 displays the NCA in 2022, highlighting the highest NCA in the SE. This is an interesting result considering SE has relatively high PSF but inconsistent AFG with both negative and positive trends.
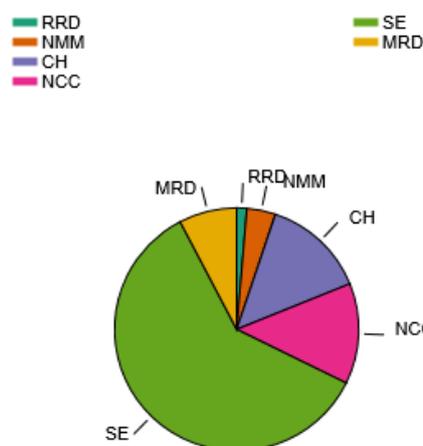

Figure 2. *Nature conservation areas (NCA) in Vietnam's six regions in 2022, representing the current spatial pattern of biodiversity protection and forest conservation*

Since official data on NCA are available only for 2022, this indicator reflects the current spatial distribution of conservation areas rather than a temporal trend. While long-term regional statistics are not yet available, the 2022 snapshot provides useful baseline information for assessing spatial disparities in conservation coverage across Vietnam's six regions.

Overall, the original data reveal a clear spatial difference: northern regions (NMM, NCC) lead to national forest gains, while densely populated deltas and the Southeast experience higher human pressure per protected hectare and have limited or negative forest growth. This spatial gap between forest recovery and conservation coverage emphasizes the need for region-specific management and more statistical testing of indicator relationships. These differences provide a contextual baseline for the subsequent comparison of normalized indicators, which capture relative disparities across countries and regions.

Standardized indicators and multivariate analysis

The indicators for PSF and AFG are calculated in a standard format on a 1-100 scale to monitor how these two indices interact across regions over time. *Figures 3* and *4* show the stability and volatility PSF (2012–2022) and AFG (2012–2017), respectively.
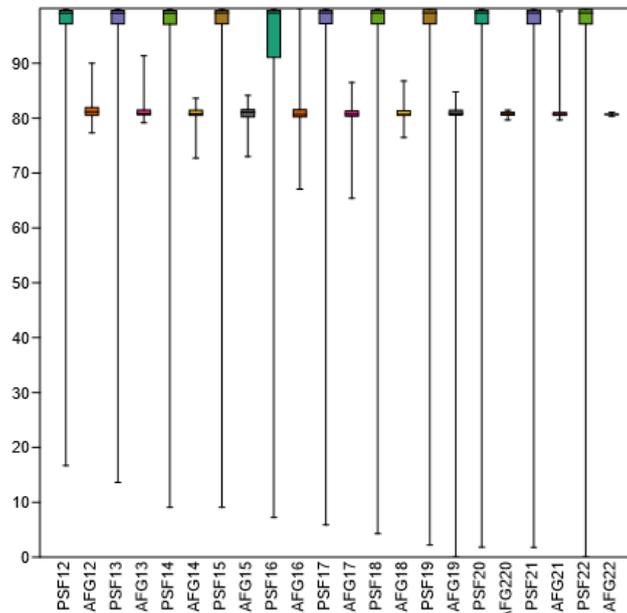

Figure 3. Boxplots of standardized PSF and AFG in the period of 2012–2022

Details: Boxplots in *Figure 3* show that the PSF indices (from PSF12 to PSF22) have a much narrower range of fluctuations compared to AFG. The PSF boxes are high and close together, indicating that PSF has a high average score and remains relatively stable over the years. Conversely, AFG is more volatile, as shown by the large amplitude of oscillation depicted by the whiskers of the box plot. This suggests that AFG can experience strong growth in some years and sharp declines in others, reflecting the instability of forest growth.
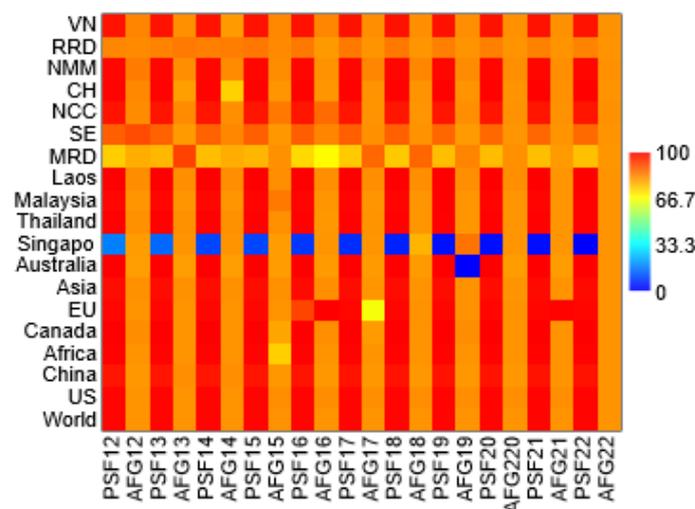

Figure 4. The Heatmap of standardized PSF and AFG in regions in the period of 2012–2022

Figure 4 enhances the boxplot results by showing a heatmap of standardized PSF and AFG values from 2012 to 2022. The consistent warm colors in PSF across regions and countries confirm its stability over time, while the greater variation in AFG is shown by alternating warm and cool tones. This visualization highlights the contrast between the steady human pressure on forests and the more volatile trends in forest growth.

Figure 5 shows the Hierarchical Cluster Analysis (HCA). Three deltaic and economically developed regions (SE, MRD, RRD) form a cluster with high PSF scores and low or negative AFG. These patterns are similar to those seen in high-density countries, such as Singapore. In contrast, the NMM and NCC regions cluster together, characterized by high AFG and low PSF, reflecting concentrated forest growth in mountainous areas.
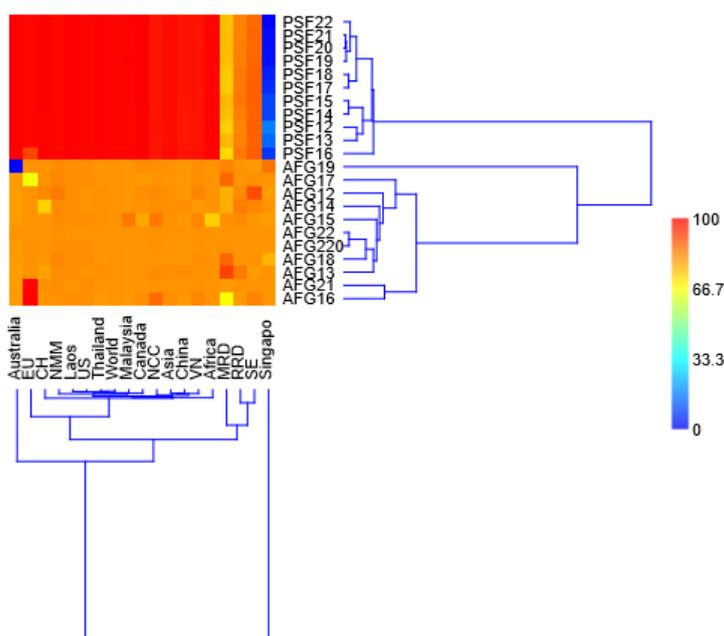

Figure 5. *The HCA results of regions of AFG and PSF over the years*

Compared to other countries, *Table 1* shows that Vietnam's average standardized AFG score of 81.3 is among the highest, outpacing Australia (54.4) and the US (80.6). Within Vietnam, forest growth is mainly found in the Northern and Central regions, while the Delta and Southeastern regions experience higher population pressure and weaker growth performance.

Table 1. *Descriptive statistics of standardized PSF and AFG (2012–2022)*

Region/country group	PSF (mean ± SD)	PSF (min-max)	AFG (mean ± SD)	AFG (min-max)
VN	97.64 ± 0.07	97.48 - 97.69	81.3 ± 0.83	0 - 82.8
RRD	83.4 ± 0.63	82.5 - 84.36	80.72 ± 1.32	80.1 - 84
NMM	99.17 ± 0.02	99.12 - 99.18	81.54 ± 0.8	81 - 83.74
CH	99.64 ± 0.02	99.6 - 99.63	80.65 ± 2.52	72.7 - 82.28
NCC	97.2 ± 0.1	97.1 - 97.46	83.3 ± 1.68	80.57 - 86.03
SE	87.21 ± 0.58	86.07 - 87.75	80.64 ± 2.9	79.73 - 90.01
MRD	75 ± 1.37	71.71 - 76.24	81.05 ± 6.29	67.06 - 91.36
International average*	99.43 ± 25.79	0 - 99.98	80.69 ± 8.61	0 - 100

SD: standard deviation

Overall, Vietnam's forest growth mainly occurs in the Northern and Central mountainous regions, while the Delta and Southeastern areas face challenges from population pressure and inefficient forest development. Vietnam is a notable example of forest growth (high AFG), but it also experiences significant population pressure on remaining forests (high PSF), especially in key economic regions.

Discussion

Based on the analysis of AFG (Annual Forest Growth Rate), PSF (Population Size on Protected Forest Area), and NCA (Nature Conservation Areas), we found that the relationship between these indicators in Vietnam's regions is complex. While the normalized data show that AFG and PSF have varying levels of stability and volatility, the overall picture becomes more complicated when examining each region. These findings match previous studies about uneven development between Vietnam's regions as well as the effectiveness of evaluating the interaction between standardized indicators (Phan et al., 2024; Phan and Hufnagel, 2026). This section explains and discusses a series of contradictions that arise, challenging traditional ideas about forest conservation.

In regional conflicts and divisions, the most notable contradiction occurs in Southeast (SE). NCA data show that this region has the highest proportion of nature reserves in the country, a surprising finding given its role as a major economic hub. However, normalized data classify SE alongside regions with very high PSF and low or negative AFG, similar to delta regions. Because SE contains 10 large conservation areas, like Cat Tien National Park, which stands out as the 72nd protected area worldwide to earn the International Union for Conservation of Nature (IUCN) "Green List" status, reflecting a strong commitment to conservation. The Southeast hosts the largest number of industrial parks, with provinces such as Binh Duong, Dong Nai, and Ho Chi Minh City leading the country in both size and number. This is driven by significant industrial zones and a high population density, resulting in an extremely high PSF and low or negative AFG. As a result, the concentration of protected areas within such a highly developed region creates unique challenges. Pressure from nearby population centers and land conversion for industrial use make it difficult to promote positive forest growth outside protected zones and place intense stress on their boundaries. Khuc et al. (2018) argued that controlling population growth is crucial to reducing deforestation, a conclusion supported by the high-PSF and low-AFG figures for Vietnam's Southeast region. Land-use change in Vietnam's industrial and urban areas has been marked by rapid urban expansion and substantial conversion of agricultural land into built-up and industrial zones. Ho Chi Minh City experienced a 25% increase in urban land from 2000 to 2020, with projections suggesting residential land will dominate by 2050 (Tuan, et al., 2025). These challenges impact protected areas surrounded by urban and industrial landscapes, especially since Vietnam's protected areas are often small and isolated, separated by deforested or agricultural land (ICEM, 2003).

While the NMM and NCC regions continued to score highly on both PSF (low pressure) and AFG (high growth), the SE region had relatively high PSF scores but low AFG scores, even comparable to the lowland areas. This shows that large protected areas cannot counteract population and economic development pressures, leading to a decline in forest growth.

Second, the Northern Midlands and Mountain (NMM) and North Central and Central Coasts (NCC) show strong, positive AFG and low PSF, even though they have a smaller percentage of NCA than SE. This mainly results from lower population density,

especially in NMM. It also clearly reflects Vietnam's national reforestation efforts. Payments for Forest Ecosystem Services (PFES) policies or the Five Million Hectare Reforestation Program (5MHRP) help shift focus from forest protection to economic use, with good governance linked to ongoing natural forest conservation (Cochard et al., 2016). REDD+ has the potential to lower forest degradation in Vietnam, benefit local communities, and reduce carbon emissions, with possible financial advantages (Ngo et al., 2020). Therefore, the success of forest growth in the NMM and NCC regions results not only from natural conditions but also from effective policies that promote afforestation and forest preservation, creating a positive model of forest development that other regions can emulate.

Third, the Central Highlands (CH) has high forest cover, but its AFG is not as strong as that of the NMM, and its natural forests are degrading. The numbers point to a paradox in quality. This aligns with previous studies mentioned by Cochard et al. (2016): natural forest regrowth was highest in northern mountain provinces, especially from 1993-2003, while deforestation continued in the Highlands and Southeast Region. The high forest cover might be misleading, as natural, high-value forests are being lost to agricultural conversion (such as coffee and rubber), a process not always reflected in a simple AFG metric (Cochard et al., 2013). Forest cover in Dak Nong province, Vietnam, experienced significant changes from 2001 to 2023, with over 38% lost due to agricultural development, urban expansion, and cash crop cultivation (Nguyen-quoc et al., 2025). Additionally, unlike regions such as NMM, where production forest programs are prioritized, economic development policies in the Central Highlands have focused heavily on expanding coffee and rubber plantations. This creates direct competition for land, overshadowing national forestation initiatives in favor of immediate economic gains from industrial crops. Therefore, the low AFG in the Central Highlands is not only an environmental issue but also signals a conflict between economic and environmental priorities at the policy level.

Finally, negative AFG data highlight challenges in the Delta Regions (MRD, RRD), emphasizing the need to protect the remaining forests. Since these regions host the country's two largest political and economic cities, Hanoi and Ho Chi Minh, which feature intensive agricultural activity and high population density, they have historically and continue to show minimal natural forest cover and limited, often fluctuating, planted forest areas. This sharply contrasts with the forest regrowth seen in mountainous areas (Cochard et al., 2013). Additional factors include mangrove deforestation in the Mekong Delta, driven by the rapid growth of shrimp aquaculture, land conversion, and coastal erosion. In some provinces like Tra Vinh and Ben Tre, mangrove cover has decreased by up to 50% since the 1960s (Kozhikkodan et al., 2019). In summary, while mountainous regions like NMM and NCC support national forest growth, the situation in the two delta regions presents a fundamentally different challenge. Here, AFG is no longer the main indicator of success; instead, the priority is protecting the remaining forests from pressures from intensive agriculture, aquaculture, and urbanization. Preserving these vital mangrove and wetland ecosystems is essential, not only for biodiversity but also as natural barriers against coastal erosion and climate change impacts.

Conservation policies are recommended to address the unique challenges of each of Vietnam's regions:

- The Southeast Region: Because of the high density of protected areas and population, stricter enforcement of regulations within and around conservation zones is crucial to lessen pressure from urban development and industrial growth. Focus on creating buffer zones and green corridors to connect

fragmented forest patches, rather than only safeguarding isolated "islands of biodiversity."

- The Northern Midlands, Mountain, North Central, and Central Coasts Regions: While these areas have successfully promoted forest growth, future policies should focus on improving the quality and biodiversity of planted forests, not just expanding their extent. This includes encouraging the planting of native species and developing mixed-species plantations. Keep supporting effective policies like Payments for Forest Ecosystem Services (PFES) and REDD+ to ensure forests' long-term sustainability and to provide economic incentives for local communities.
- The Central Highlands Region: Implement policies that balance the economic benefits of perennial crops with the need to protect natural forests. This could include offering incentives for sustainable farming practices that do not involve converting forests. Shift the focus from achieving a high AFG metric to conserving the remaining high-value natural forests, as they are crucial for biodiversity and ecosystem services.
- The Delta Regions (Mekong River Delta and Red River Delta): Recognize that AFG is not a relevant metric for these areas. Policy goals should be redefined to prioritize the strict protection and restoration of existing mangrove and wetland ecosystems, rather than large-scale reforestation. Treat mangrove and coastal forests as essential infrastructure for climate change adaptation, and allocate resources to prevent coastal erosion and protect against storm surges. Enforce stricter regulations to prevent the conversion of these critical ecosystems for aquaculture and urban development.

Conclusion

This study emphasizes the complex interaction between forest growth, population pressure, and conservation efforts across Vietnam's six major regions and several selected countries. By using both raw and normalized indicators, the analysis uncovers significant regional differences that challenge traditional assumptions about forest management.

The Northern Midlands and Mountain (NMM) and North Central and Central Coasts (NCC) stand out as success stories, where low population pressure and effective policy tools like PFES and REDD+ have promoted positive forest growth. These regions show that targeted incentives and governance reforms can lead to sustainable reforestation. In contrast, the Southeast highlights a paradox: it contains some of the country's largest and most esteemed protected areas, yet faces high population density, rapid industrial growth, and negative forest changes outside conservation zones. Similarly, the Central Highlands reveal that high overall forest cover can hide ongoing natural forest degradation, as economic policies supporting industrial crops like coffee and rubber often override conservation efforts. Meanwhile, the two Delta regions emphasize the limitations of afforestation metrics, where mangrove loss and urban development present entirely different conservation challenges.

These findings indicate that Vietnam cannot depend on one-size-fits-all strategies. Instead, conservation must be customized to regional contexts: boosting enforcement and connectivity in industrial zones; improving forest quality in reforested areas; balancing agriculture with forest protection in the Highlands; and focusing on preserving mangroves and wetlands in delta regions. Such tailored regional approaches are essential not only for

maintaining Vietnam's ecological assets but also for aligning with international frameworks.

Data availability statement. The data that support the findings of this study are available on request from the corresponding author.

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