Supplementary Materials:

Paper Title: Spatial Co-benefits of Forest Biomass Density and Structural Diversity in Indonesia with GEDI

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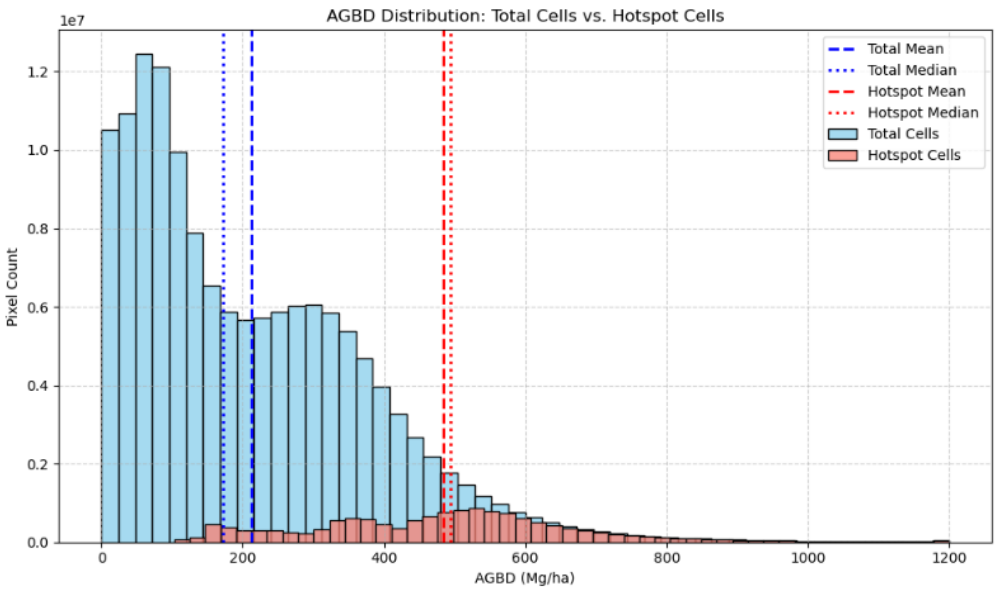
Supplementary Results 1: Distribution of biomass (AGBD) and structural diversity (WSCI) hotspot values

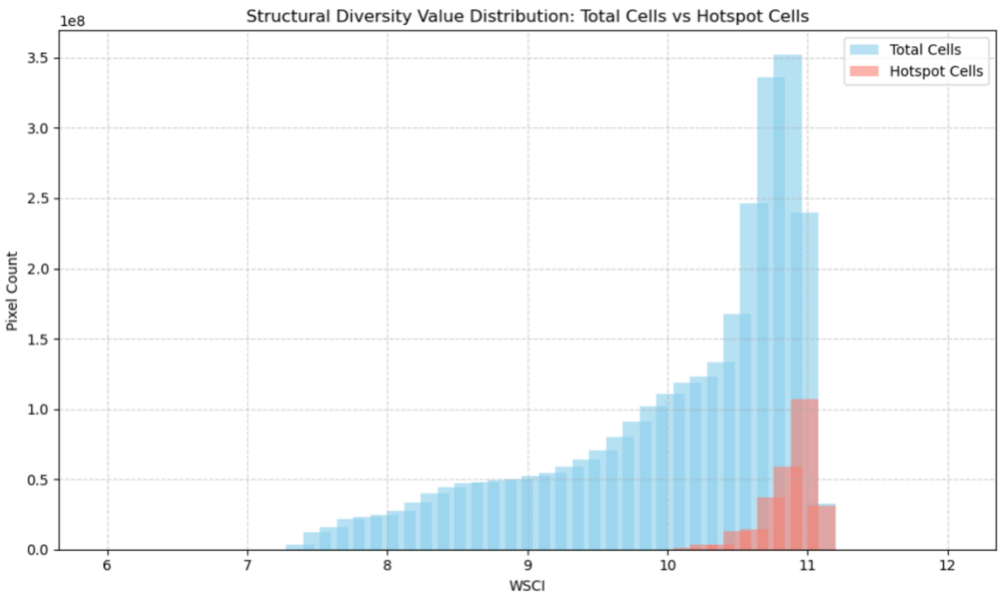
The distribution of aboveground biomass density (AGBD) hotspot values spans a wide range of approximately 100 to 1200 Mg ha^{-1}, with a mean of 484.53 Mg ha^{-1} and a median of 494.48 Mg ha^{-1}. This variability reflects strong ecological heterogeneity across Indonesia's ecoregions, driven by differences in forest structure, stand maturity, and varying levels of anthropogenic influence. Lower biomass values are generally associated with more open-canopy or disturbed forest types, whereas higher values correspond to mature, intact tropical forest systems. The

highest frequency of AGBD hotspot values is concentrated between 500 and 600 Mg ha^{-1} (Supplementary Figure S1).

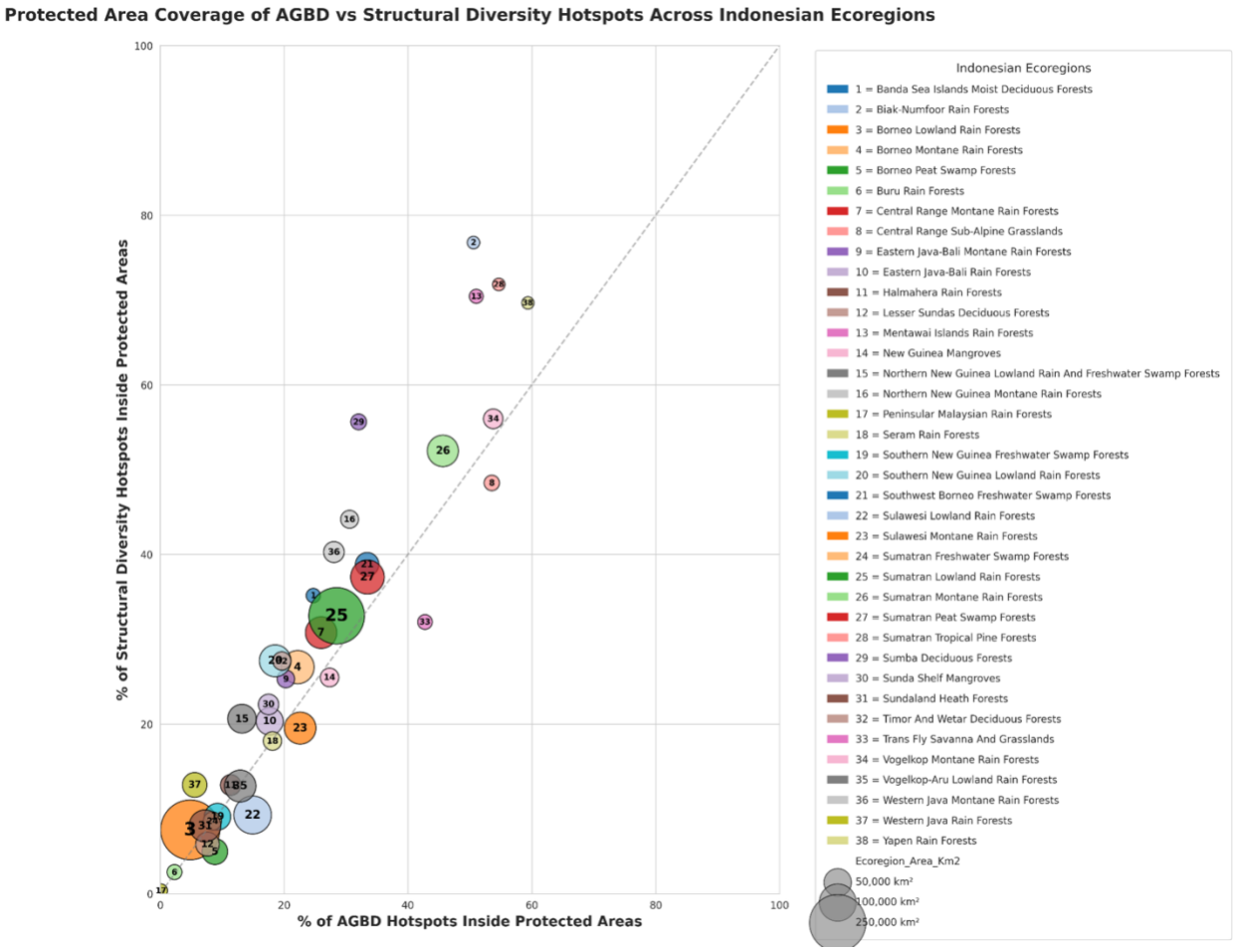


Supplementary Fig. S1* : *The Histogram shows AGBD values distribution across all the AGBD hotspots compared to the total cell distribution in all the Indonesian ecoregions.

Structural diversity (WSCI) hotspot values range from 10.44 to 11.39, capturing variation in canopy three-dimensional complexity across forest types (Supplementary Figure S1). These values are consistent with previously reported ranges for structurally complex tropical forests in GEDI L4C-derived analyses [52], indicating that the identified hotspots correspond to high structural heterogeneity forest conditions.



Supplementary Fig. S2 : The histogram shows WSCI hotspot values from GEDI-L4C fusion product based Structural Diversity hotspots which corresponds with tropical forest biomes WSCI distribution from GEDI L4C product [52]***.***

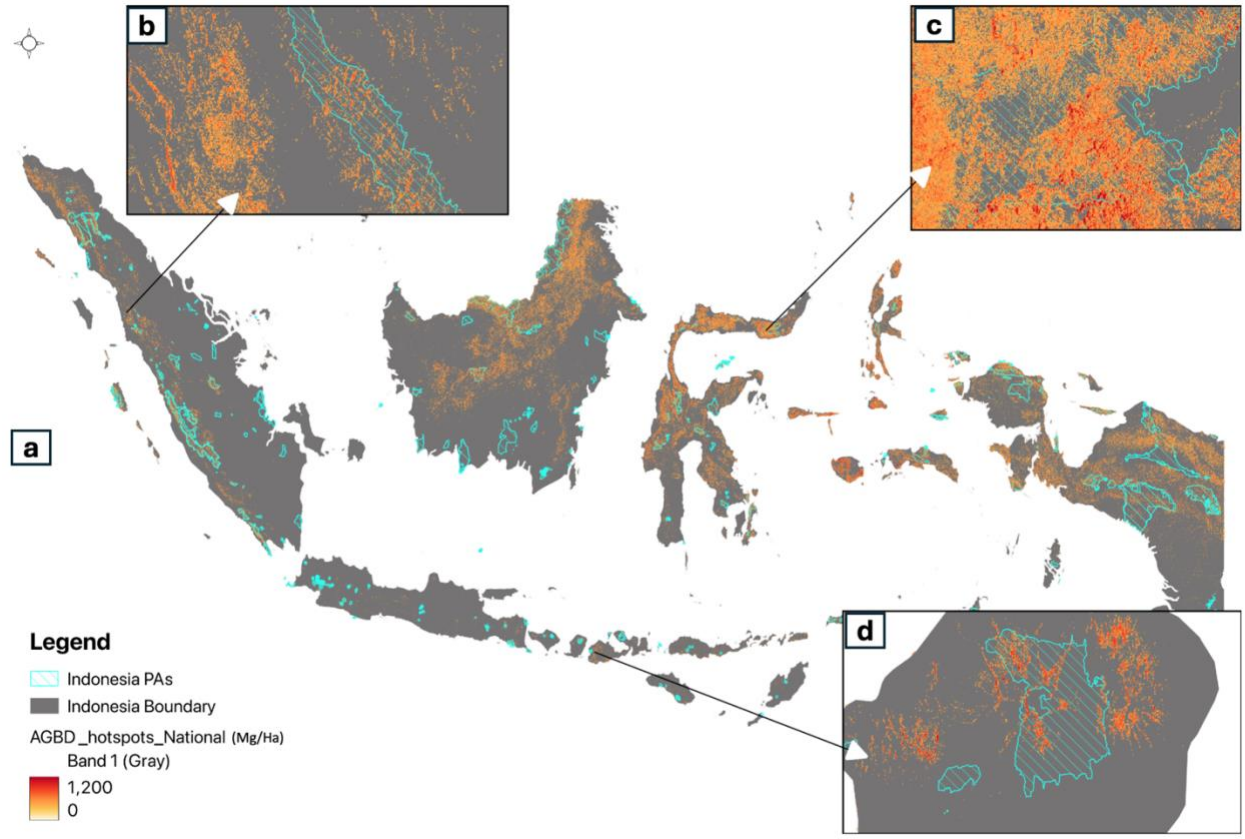


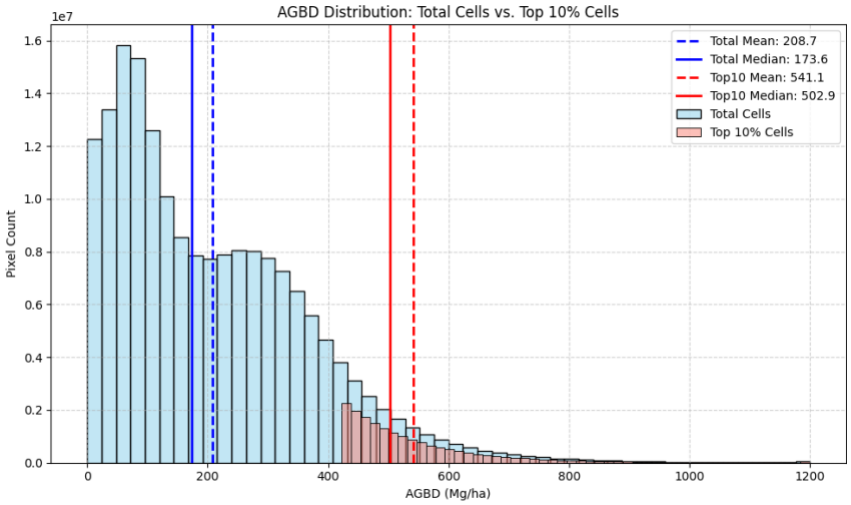
Supplementary Fig. S3: Percentage comparison between AGBD hotspots and Structural Diversity (WSCI) hotspots per ecoregion of Indonesia in Protected Areas (PAs).

Supplementary Results 2: Sensitivity of hotspot detection to spatial scale (ecoregion vs national thresholds)

National threshold level Hotspots and Co-Benefit Areas:

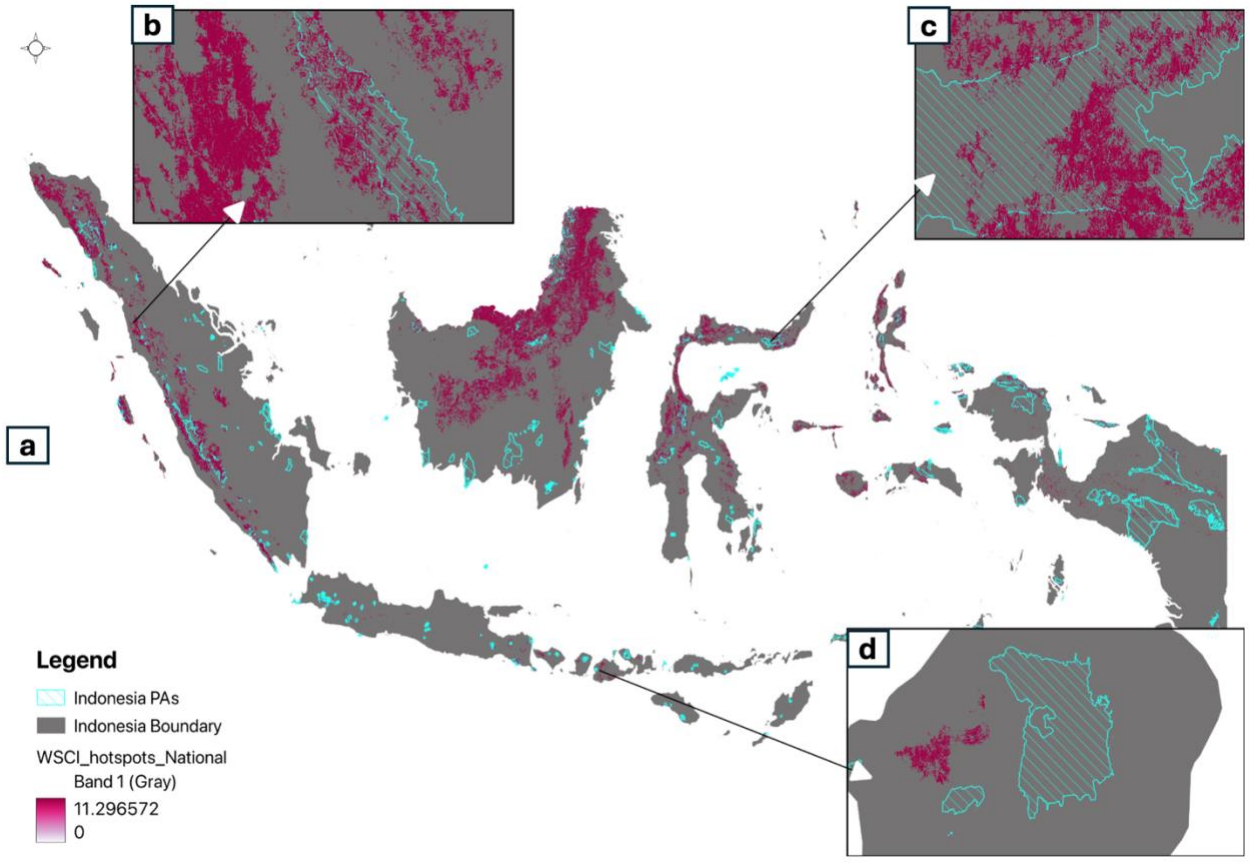
Approximately 36% of ecoregion-defined hotspots are not captured when applying a country-wide 90th percentile threshold, highlighting scale-dependent differences in hotspot identification and the importance of ecoregion-specific thresholds for capturing locally significant high-AGBD areas (Supplementary fig. S4).

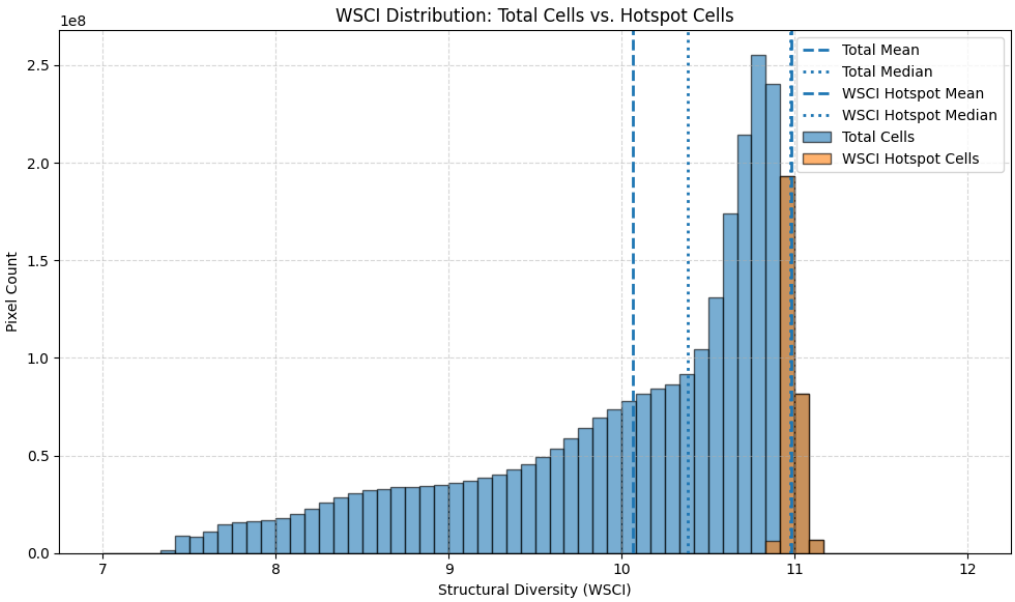




Supplementary Fig. S4.: National-level AGBD hotspots across Indonesia, defined as grid cells exceeding the 90th percentile (top 10%) of AGBD values. Hotspots represent areas of highest carbon stock relative to the national distribution.

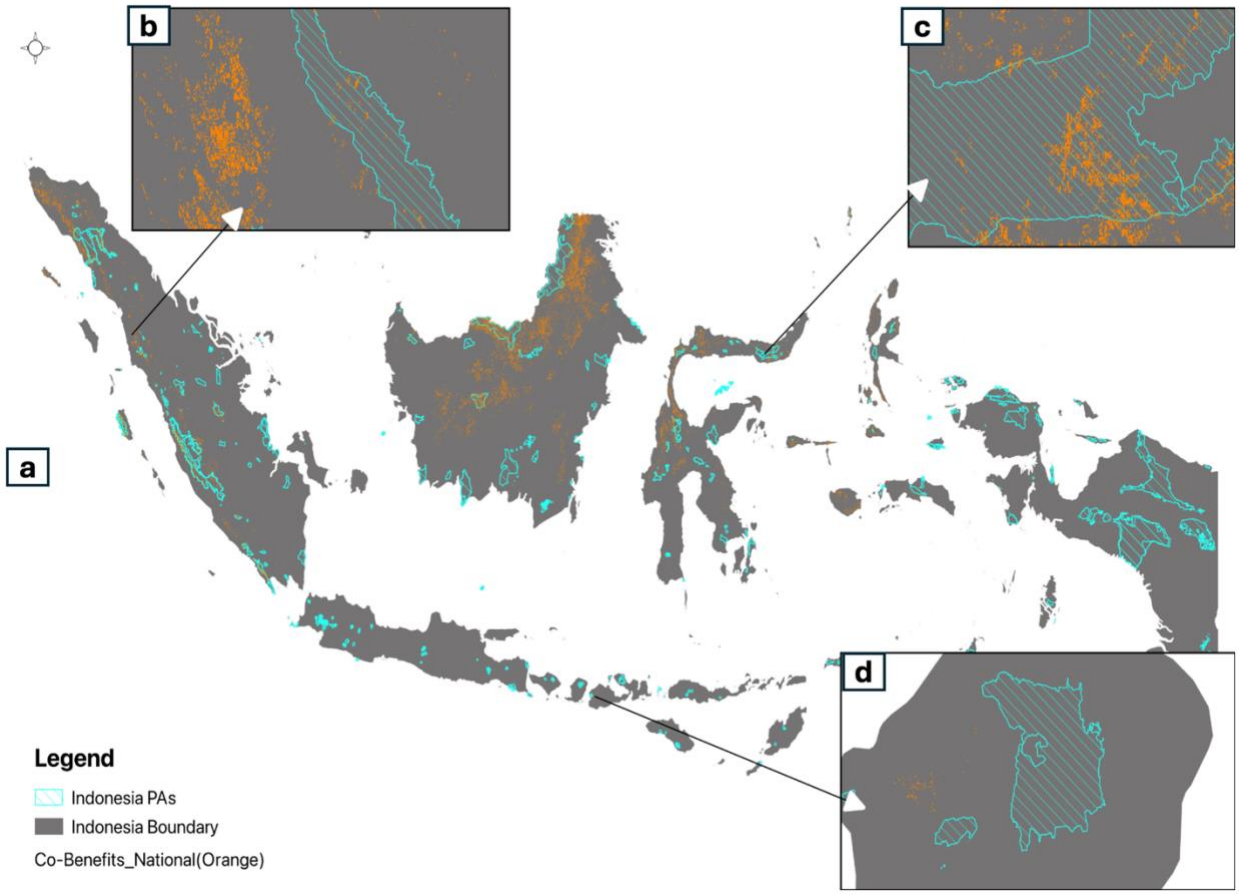
For structural diversity hotspots, results show that 53.06% of ecoregion hotspots overlap with national-level hotspots, while substantial areas are uniquely identified by each approach (~79,000 km² for ecoregion-only and ~82,000 km² for national-only hotspots) (Supplementary fig. S5). This partial overlap indicates scale dependence in structural diversity detection and supports the use of ecoregion-specific thresholds to capture spatial heterogeneity in forest structure.





Supplementary Fig. S5.: National-level structural diversity hotspots across Indonesia, identified using the 90th percentile (top 10%) of waveform structural complexity index (WSCI) values. These areas represent forests with the highest structural complexity at the national scale.

Only ~22% (~20,000 km²) of ecoregion-defined co-benefit hotspots are captured using national thresholds, while ~69,700 km² are omitted, indicating substantial underrepresentation of locally important high-carbon and structurally diverse forests at the national scale (Supplementary fig. S6). Conversely, ~10,200 km² (33.7%) of national-level hotspots fall outside ecoregion-defined co-benefit areas, further highlighting scale-dependent inconsistencies in hotspot delineation.

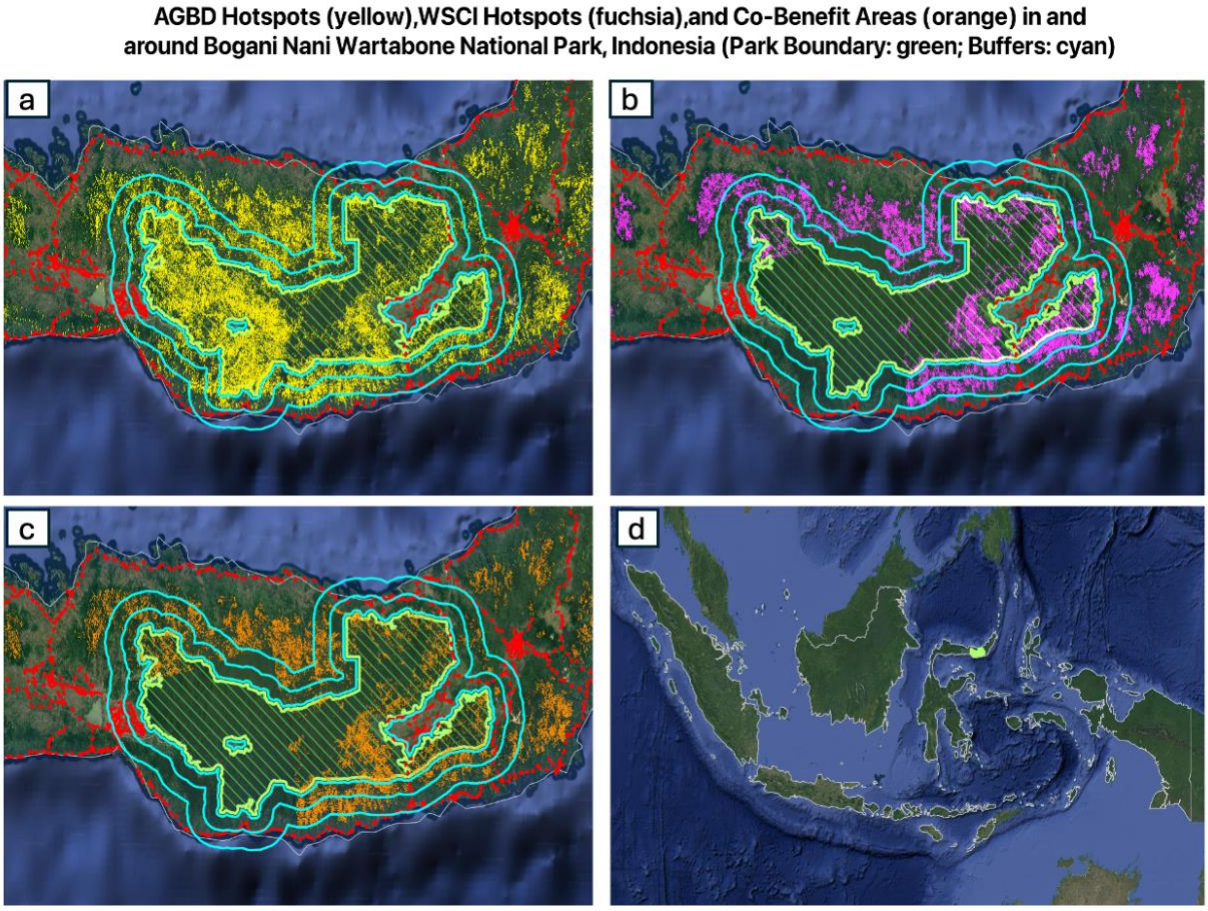


Supplementary Fig. S6.: National-level co-benefit areas across Indonesia, derived from the spatial overlap of AGBD and structural diversity hotspots. These areas indicate regions where high carbon stock and high structural complexity coincide based on national threshold.

Supplementary Results 3:

Supplementary Figure S7 shows a relatively strong alignment between protected area (PA) boundaries and aboveground biomass (AGB) hotspots(panel a), indicating that a substantial proportion of high-carbon forest is effectively captured within Bogani Nani Wartabone National Park. In contrast, structural diversity (WSCI) hotspots(panel b) and co-benefit areas(panel c) exhibit much weaker spatial correspondence with the PA, with most occurring outside the park boundary and extending into surrounding landscapes. This indicates that while the PA network in this region is effective in safeguarding carbon-rich forest areas, it is less representative of structurally complex forests and their intersection with high biomass conditions. The spatial separation between biomass-dominated protection and structurally diverse but unprotected

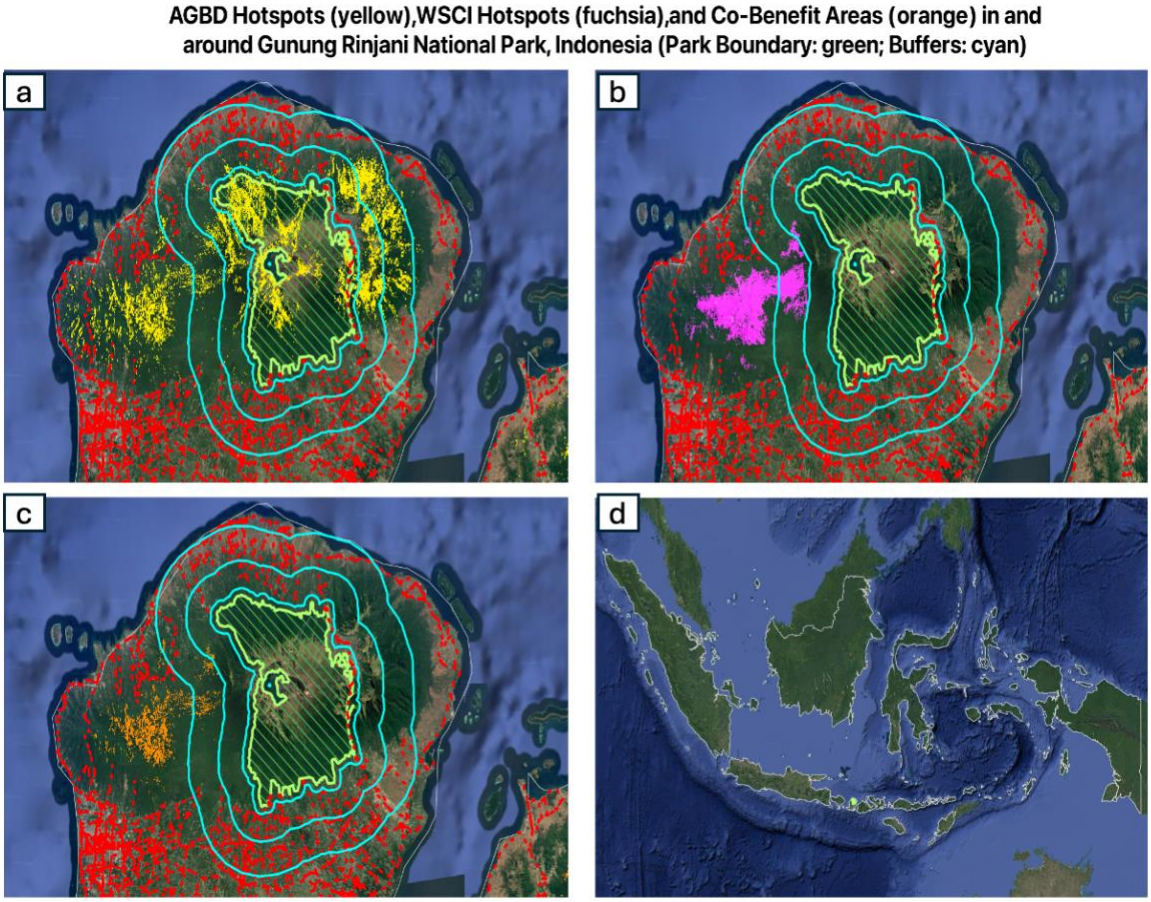
forests highlights a potential limitation of PA placement in capturing multiple dimensions of forest ecosystem value.



Supplementary Figure S7: ***The maps show AGBD hotspots (yellow), WSCI hotspots (fuchsia) and Co-benefit areas (orange) of Bogani Nani Wartabone National Park of Indonesia with the buffer zones(1km, 5km, 10km; color- cyan) and nearby major roads(red).***

Supplementary Figure S8 reveals a contrasting pattern, where only a limited number of aboveground biomass (AGB) hotspots fall within Gunung Rinjani National Park(panel a), while structural diversity (WSCI) hotspots are predominantly located outside the PA boundary but within its surrounding buffer zones(panel b). Notably, co-benefit areas are largely absent from the PA interior, with only sparse occurrences in nearby buffer regions, indicating minimal spatial overlap between high-carbon and high-structural-complexity forest within the protected boundary(panel c). This pattern suggests that, in this landscape, structurally diverse forests are not effectively encompassed by the current PA configuration, and that high-value co-benefit areas are largely

unprotected. The concentration of WSCI hotspots in proximity to, but not within, the PA further suggests that expansions or boundary adjustments could substantially improve conservation coverage of structurally complex forest ecosystems in this ecoregion.



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