A Bolder Conservation Future for Indonesia: Conserving Biodiversity, Carbon And Unique Ecosystem In Sulawesi

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Abstract

As more ambitious protected area (PA) targets for the post-2020 global biodiversity framework is set beyond Aichi Target 11, new spatial prioritisation thinking is required to expand protected areas to maximise different environmental values. Our study focuses on the biodiversity and forest-rich Indonesian island of Sulawesi, which has a terrestrial PA network that covers 10% of the island. We run scenarios to identified areas outside the current PA network and their representativeness of conservation features. We use Marxan to investigate trade-offs in the design of a larger PA network with varying coverage targets (17%, 30%, and 50%) that prioritises forest area, karst ecosystem, and carbon value as conservation features. Our first scenario required PAs to be selected at all times, and it required larger areas to meet these targets than our second scenario, which did not include existing PAs. The vast Mekongga, Banggai, and Popayato-Paguat landscapes were consistently identified as high priorities for protection in the various scenarios. The final section of our analysis used a spatially explicit three-phase approach to achieve this through PA expansion, the creation of new PAs, and the creation of corridors to connect existing PAs. Our findings identified 13,039 km^2 of priority areas to be included in the current PA network, potentially assisting Indonesia in meeting the post-2020 GBF target if our approach is replicated elsewhere across Indonesia as a national or sub-national analysis like this study. We discuss various land management options through OECMs and the costs to deliver this strategy.

Introduction

Protected areas (PAs) are a mainstay conservation strategy for nature conservation (Jepson et al., 2017). While they may not be a perfect solution (Joppa et al., 2008; Rija et al., 2020; Tyrrell et al., 2019), PAs often represent the last strongholds of intact areas and provide a buffer against environmentally damaging developments (Gaveau et al., 2009; Grantham et al., 2020; Naidoo et al., 2019). Terrestrial PA targets are typically set as a percentage of total land area, despite the fact that focusing on quantitative aspects while ignoring qualitative aspects and robust indicators has resulted in criticism of this approach, which may fail to recognise differences in biodiversity richness, habitat types, and other environmental attributes (Adams et al., 2021; Banks-Leite et al., 2021). Nevertheless, over the past 10 years, most countries have been working towards the Convention on Biodiversity (CBD) Aichi targets, in particular Target 11, which calls for the protection of at least 17% of terrestrial and inland water areas (CBD, 2011). A forthcoming post-2020 Global Biodiversity Framework (GBF) will likely include a revised PA target of 30% of land conserved by 2030 (CBD, 2020) and an ambitious target of 50% by 2050 (Dinerstein et al., 2017; Wilson, 2016). This raises the question of how and where this can be achieved and how it can be done in a way that complements the current PA network in each country.

As a signatory to the CBD, the Government of Indonesia is working to achieve the various Aichi targets and may further commit to the new post-2020 GBF 30% target. However, with 21.3% of its land area already under some form of protection, Indonesia has surpassed the Aichi Target 11 for terrestrial protection (Dwiyahreni et al., 2021; MoEF Ditjen KSDAE, 2018). The Government of Indonesia is currently formulating a new set of national PA targets as part of its efforts to update its National Biodiversity

Strategy and Action Plan 2015–2020 in response to the post-2020 GBF. Setting meaningful targets for 2030 requires increasing the representativeness of PAs in Indonesia and their management effectiveness, rather than simply expanding the network by only using an area-based approaches. Here, we provide an Indonesian case study, using systematic conservation planning to explore how best to achieve the post-2020 GBF target by increasing the coverage and representativeness of important conservation features inside Sulawesi's PA network.

Sulawesi is the eleventh largest island in the world. It has been renowned for its biogeographical importance ever since Alfred Russel Wallace first explored it in the 18th century (Wallace, 1869). It is part of the Wallacea biodiversity hotspot (MacKinnon and MacKinnon, 1986; Myers et al., 2000) and one of the 200 global ecoregions for conservation (Olson and Dinerstein, 2002). Despite its proximity to the islands of Borneo and Java, Sulawesi's biodiversity is unique (Hunowu et al., 2020; Johnson et al., 2019), with 98% of its non-flying mammal species, 34% of its bird species, and 26% of its reptile species being endemic (MacKinnon and MacKinnon, 1986; Whitten et al., 1987). Its extensive forests and mangroves store and sequester globally significant volumes of carbon (Chen et al., 2018; Culmsee et al., 2010). The terrestrial area of Sulawesi spans 186,404 km^2, of which 18,822 km^2 (10.1%) is assigned within the island's PA network. Of the 79 PAs in Sulawesi, Lore Lindu National Park (NP) was the first to be designated (in 1982) and Gandang Dewata NP was the most recent (2016), indicating the government's willingness, commitment, and ambition to expand its PA network.

In this study, we conduct an island-wide spatial priority setting analysis for Sulawesi in order to inform protected areas planning and land-use management decision-making more broadly. A recent study by Zhu et al. (2021) identified synergies between carbon and biodiversity conservation planning at a broader scale across Asia, including Sulawesi. Cannon et al. (2007) carried out a similar study in Sulawesi, which was restricted to forest condition (old growth, good, fair, poor, and converted) and a data set from more than 20 years ago. This foundational study showed that the priority conservation areas at that time period were consistent with the areas chosen by the government and non-governmental organisations, with several priority areas identified outside of the PA system. Our analysis builds on these two studies by incorporating more recent and detailed data sets and using a spatial modelling approach that, in addition to forest condition, takes into account other critical ecosystem types and carbon stocks, with detailed data layers at a finer resolution, enabling site-specific management recommendations to be made. Our study aimed to identify priority areas by setting targets under different conservation planning scenarios by 1) performing a PA gap analysis; 2) selecting high-priority areas in addition to the current PAs; and, 3) identifying implementation opportunities and strategies for forest conservation in Sulawesi.

Materials And Methods

We used Marxan version 2.43 simulated annealing optimisation, with an iterative improvement method (Ball et al., 2009; Game and Grantham, 2008), to enable systematic conservation planning for Sulawesi. Our goal was to determine how to prioritise potential new conservation areas when faced with multiple candidate sites (termed Planning Units and referred to as PUs, hereafter). We used a hexagonal grid of 1.3 km^2 that served as the basic PUs within the landscape.

Study area

The human population of Sulawesi in 2020 is 19.9 million people, with the country's average annual increase of 1.25%/year (BPS, 2021). Two provinces in Sulawesi rank fifth (Gorontalo) and ninth (Central Sulawesi) amongst Indonesia's 34 provinces in terms of poverty (BPS, 2020). There are 13 different types of conservation areas (Table S1) and each fall under a different management authority. The Ministry of Environment and Forestry (MoEF) is responsible for National Parks, Nature, Wildlife and Game Reserves, Nature Recreation Parks, and Hunting Parks, whereas Forest Management Units (such as Grand Forest Park) are the responsibility of a provincial government agency.

The Wallacea biogeographic region, which includes Sulawesi, lost 10,231 km^2 of forest between 2000 and 2018 (Voigt et al., 2021). According to the government data, Sulawesi lost 373 km^2 of forest in 2017-2018 (KLHK, 2019). This loss is unevenly distributed across the island, with the highest rates having occurred in the lowland westerly and south-easterly parts (Supriatna et al., 2020). The threat of forest loss in Sulawesi, particularly in Central Sulawesi, is largely attributed to the occurrence of anthropogenic fires and past deforestation (Voigt et al., 2021). A more recent threat to conservation areas has emerged in the form of legal and illegal mining, especially nickel (Kadir et al., 2020). Most of this deforestation, and predicted future deforestation, is outside of the current PA network (Voigt et al., 2021). To effectively mitigate these threats and protect Sulawesi's species and ecosystems, an island-wide spatial prioritisation approach is urgently required.

Conservation scenarios and Priority Setting Objectives

Our goal was to identify potential protection areas across Sulawesi. Fine-scale resolution (1 km^2) species distribution maps do not exist for the study area and were not therefore included as a conservation feature. Our conservation values included forest types, high carbon storage, and karst ecosystem, the latter being a rare and threatened ecosystem type with high levels of species endemism (Albani et al., 2020; Clements et al., 2006; Coleman et al., 2019; Thomas et al., 2018). The target was met by balancing with the estimated cost of protection in each PU. We investigated three scenarios for identifying priority conservation areas. The first scenario aimed to protect 17% of the identified conservation targets based on conservation features such as carbon, karst ecosystem, and forest cover. This goal is based on Aichi Target 11, which calls for the protection of 17% of terrestrial and inland water by 2020. The second scenario, which is based on Target 3 of the post-2020 Global Biodiversity Framework (CBD, 2021), aimed to protect 30% of the identified conservation targets. The third scenario, based on the 'Half-Earth concept', set the most ambitious target because it aimed to protect 50% of the identified conservation targets in Sulawesi (Wilson, 2016; Dinerstein et al., 2017; Noss et al., 2012).

Conservation features

We developed nine conservation features and set targets based on the proportion of each feature under the three management scenarios (Table 1, Fig. S1). We classified conservation features into three categories: i) carbon stocks (i.e., above and below ground, ABG, terrestrial carbon and soil carbon), using a data layer developed by Soto-Navarro et al. (2020) to identify areas with high carbon stocks; ii) forest types defined from the Land Use Land Planning 2018 dataset (MoEF 2019); and, iii) karst ecosystem, using data derived from the same 2018 MoEF dataset. We combined primary dryland and secondary forest into a single forest cover layer and reclassified this based on their elevation range to include lowland (0–150 m asl), low elevation hill (150–500 m asl), medium elevation hill (500–900 m asl), sub-montane (900–1,400 m asl), lower montane (1,400–1,900 m asl), montane (1,900–2,500 m asl), and tropical upper montane/sub-alpine (> 2,500 m asl) (Laumonier, 1997).

Ecological condition

We created the cost layer by combining land use and land cover with the 'Forest Integrity Landscape Index' developed by Grantham et al. 2020 (Table S2). There is no standard approach for determining the amount of penalty and cost. We assigned a score in each PU that was proportional to how much of the area had been modified or is less naturally intact and degraded. For example, the land use and land cover data contain 22 distinct categories that are designated by the Government of Indonesia (MoEF, 2019). We ranked them according to their perceived natural habitat state: natural habitats, such as primary and secondary forests, were assigned a cost score of '1', highly modified habitats, such as plantations and farming areas, were assigned a score of '10', and shrubs were assigned a cost score of '5'. Eight of the 22 classes were left out of the analysis (i.e., settlement, bare land, water bodies, airport and seaport, transmigration area, mining concession, fishpond, and paddy field). The Forest Landscape Integrity Index combines observed and inferred forest pressure and fragmentation data to produce a continuous index ranging from 1 to 10, indicating the degree of anthropogenic modification (Grantham et al., 2020). We inverted the value of intact forests so that the most integrated had the lowest cost. Each feature's mean score was calculated and averaged. This value was then used to generate and allocate a single cost value to each PU (Fig S1). In the analysis, we set the cost of the boundary length to be constant (1). Using QMarxan, we then adjusted the Boundary Length Modifier (BLM) to find the best value that provides a compromise between the area's compactness and cost.

Gap analyses

To meet all conservation features targets, ensure connectivity between areas, and reduce the total cost of priority area management, we used Marxan v.4.0.6 to identify priority conservation zones (Fig. 1). To compare the spatial arrangement within and between scenarios, we used the kappa statistic (Zhang and Vincent, 2019). We defined a total of 140,906 PUs on mainland Sulawesi and its outer islands, with each PU being a 1.3 km^2 hexagon. We ran the analysis in Marxan for each scenario, beginning with the Species Penalty Factor (SPF) set to 1.

Representativeness OF Sulawesi’s protected area network

We ran each of the three protection scenarios under two variants: with PAs included (scenario a) and without (scenario b). PAs were included in order to identify new priority areas outside of those already protected. In the second variant, PAs were excluded to allow for spatial assessments based on representativeness, allowing for comparisons with existing PAs to assess their efficacy in meeting the conservation targets (Ardron et al., 2010). We included 79 PAs (Table S1) from the World Database on PAs (Bingham et al., 2019). We ensured these were accurate and aligned with the official MoEF PA list (Table S1). We based our recommendations to increase current PA coverage in Sulawesi on scenario ‘a’ that required all PAs to be included in the selection procedure. Nonetheless, because scenario ‘b’ is not biased towards the existing PAs, it is useful for highlighting gaps between the current PA network and the identified priority areas. If both scenarios select the same area, the weight is greater than if only scenario ‘a’ selects the area. We compared spatial similarities between scenarios using weighted kappa (κ) statistics, where 0 denoted no agreement, 0.01–0.20 low agreement, 0.21–0.40 fair agreement, 0.41–0.6 moderate agreement, 0.61–0.80 substantial agreement, and 0.81–1.00 the highest agreement (McHugh, 2012).

Identifying high-priority areas outside the current protected area network

Marxan works by continually repeating the analysis to identify planning units that best achieve objectives. Due to the nature of the algorithm often each run can be slightly different. Selection frequency is the sum of how many times a planning unit was selected across all the runes. Areas designated as a priority have a high degree of selection frequency of more than 75 out of every 100 iterations. We merged the priority areas from the three scenarios and devised a plan for sequential implementation to make meeting this goal more realistic. We began by identifying high priority areas outside of the current PA network, as determined by the 17% scenario, and then expanded on this for the 30% and then 50% scenarios.

Based on provincial delineation and governance structures, we divided the study area into six geographical clusters (Fig. 2): 1) North Sulawesi Province; 2) Gorontalo and Central Sulawesi Provinces, covering Nantu Wildlife Reserve (WR) in the east and Gunung Sojol in the west; 3) Central and West Sulawesi Provinces, extending from Pegunungan Tokalekaju in the north and connecting Lore Lindu National Park (NP) and Gandang Dewata NP as a large landscape, and Faruhumpenai Nature Reserve (NR) in the east; 4) Central Sulawesi Province's eastern region, which includes Balantak in the east, Gunung Lumut and Bangkiriang in the centre, and Morowali in the west; 5) Southeast Sulawesi Province, which includes the Routa Key Biodiversity Area (KBA) and Mekongga landscape in the north, and Buton Island in the south; and, 6) South Sulawesi Province.

The identified priority areas were overlaid on KBAs (CEPF, 2014) to evaluate them in the context of landscape conservation in Sulawesi. We overlapped the identified priority areas with current nature restoration in active concessions to assess the potential threats of establishing the priority areas as conservation areas. Priority areas that fall within the scope of a concession are regarded as being under threat of clearance. Using MoEF data, we identified plantation concessions: 1) Natural Forest Management Permit (*Hak Pengusahaan Hutan*); 2) Palm Oil Concession; and 3) Industrial Plantation Forest (*Hutan Tanaman Industri*). The mining concessions are public data made available by the Ministry of Energy and Mineral Resources' Directorate General of Mineral and Coal.

Results

All priority areas under the three targets in scenario 'a' (PAs must always be included) are more compact with less edge and have smaller mean boundary lengths (Table S3), whereas all scenarios where PAs are not obligatory to include (scenario 'b') have the lowest mean cost (Table S3). The total size of the priority areas is larger under scenario 'a,' but when only those from outside the current PA are considered, the solutions from 'b' variants are always larger in size (Table 1). For example, scenario 17% 'a' has a much larger priority area (20,924 km^2) than scenario 'b' (4,906 km^2), but when we considered only the areas outside the current PA network, scenario 'b' has a larger priority area (3,368 km^2) than scenario 'a' (2,322 km^2) (Table 1; Fig. 3).

Table 1
Size of the priority area (for planning units with a selection frequency >75) in scenarios 'a' and 'b'.

Scenario target	**Total priority area including PA (km^2)**		**Priority area outside current PA (km^2)**	
	a	**b**	**a**	**b**
17%	20,924	4,906	2,322	3,368
30%	31,582	27,771	12,980	21,296
50%	67,338	63,685	48,736	51,218

Under scenario 'b', the size of the priority area within those already designated as a PA is always smaller for all three targets. This is demonstrated by scenario 17% 'b' which met this target by selecting a significantly smaller area within the PAs (1,538 km^2) as a priority, as opposed to scenario 17% 'a', which select an area significantly larger (18,602 km^2) out of the current PA network of 18,822 km^2 (Fig. 3). Because of the small size of the total priority area within PA in scenario 'b' several of the established PAs were only partially or not at all selected.

The network of 79 PAs in Sulawesi includes 16.3% of the entire forest area coverage in 2018 (14,475 km^2) and 8.9% of all karst ecosystems (1,681 km^2), from the total available in the study area (Table S4). Of the island's 46,156 km^2 area with the highest quarter (top quantile) of soil carbon organic, only 17.6%

(8,109 km^2) is protected (located within current PA). The remaining area with top quantile soil carbon organic is not protected and is in clusters 2 and 3. Within these PAs, the sub-montane forest has the most coverage (20.1%; 3,805 km^2), while the low elevation hills forest has the least (11.7%; 2,945 km^2) (Table S4).

As demonstrated by the representativeness within the priority area, larger does not always imply better. Apart from scenarios with a 17% target, the representativeness of the target conservation features for the 30% and 50% target are higher in scenario 'b'. Scenario 'b' increased the representative of area with the top quantile for carbon storage to 17,734 km^2 (30% target) and 31,982 km^2 (50% target) (Table S4; Fig. 4), an increase from 17.6–38.4% and 69.3%, respectively. In scenario ‘b’, the protection of low elevation hill forest, as the forest type with the smallest area under protection, increased from 11.7–15.5% (3,893 km^2, 30% target) and 48% (12,024 km^2, 50% target).

Based on their irreplaceability, the analysis identified several priority areas (Fig. 5). The weighted Kappa statistic indicated the degree of agreement between the two scenarios was lowest for the 17% target (κ = 0.41). This differed most between scenario ‘b’, where PA inclusion is not mandatory in the selection process, that selected a smaller area inside the PA (1,538 km^2), compared to its equivalent under scenario ‘a’ that required 18,602 km^2 to meet the same target (Figs. 3 & 5). There was moderate concurrence between scenarios ‘a’ and ‘b’ for the 30% target (κ = 0.77) and high concurrence between these scenarios for the 50% target (κ = 0.92). Under scenarios ‘a' and ‘b,' the representativeness of priority areas was higher outside the PA network than inside. Focusing on the areas outside of the PA that we recommended be considered for inclusion in current PA network, the results showed that scenario 'b' has a larger area (Table 2).

Table 2
Recommended order for assigning protection to priority areas outside of Sulawesi's current protected area network.

Order	Scenario ‘a’ (km^2)	Scenario ‘b’ (km^2)
First	2,263	3,368
Second	10,776	17,926
Third	35,697	29,926
Total area	48,736	51,220

The total size of priority areas identified outside of the current PA network is 48,736 km^2 in scenario ‘a’ and 51,220 km^2 in scenario ‘b’ (Table 2). These vast areas would require nearly three times the current land area being allocated for PAs and in order to achieve this we propose a sequential three-stage implementation plan. The priority areas that are aligned with Aichi Target 11 are represented in the first order (17%). Scenario ‘a' identifies 2,262.9 km^2 for inclusion in the PA network, primarily through expanding the current PA network boundaries (Fig. 5).

The second order in scenario ‘a’ aligns with Target 3 of the first draft of the post-2020 GBF by: i) adding a buffer area to the existing PAs; ii) creating new stand-alone PAs; and iii) creating corridors that connect pre-existing PAs. Scenario ‘a’ focused on existing PA buffer zones, whereas scenario ‘b’ identified large stand-alone areas, such as Mekongga (1,576 km^2) in cluster 5, Banggai (1,004 km^2) in cluster 4, and Popayato-Paguat (1,299 km^2) in cluster 2 (Fig. 5). These three large areas were also identified in scenario ‘a’ but as a second order selection priority with a similar spatial configuration for Mekongga and Banggai, but with Popayato-Paguat forming a corridor connecting two nearby PAs and two KBAs.

Outside of the current PA network, the following conservation features were chosen for each cluster, for which we consider possible impacts from different land management sectors.

North Sulawesi (Cluster 1)

The main first order forest type selected was sub-montane forest, with scenario ‘b’ selecting the inner part of Karakelang WR and Bogani Nani Wartabone NP (BNWNP). The remaining first order areas in scenario ‘a’ were all PAs. The buffer of Karakelang WR and BNWNP, mostly consisting of low and medium elevation hill forest, was in the second order for scenarios ‘a’ and ‘b’. In the third order, the notable additions were most of Sangihe island and three patches of forest outside Gunung Ambang NR with high carbon stock (Fig. S2). Karst ecosystem was not a main feature in this cluster. An identified impact in this cluster is from the operations of the PT Tambang Mas Sangihe concession that covers half of Sangihe Island. The priority area identified along the northern boundary of BNWNP is located within the PT Huma Sulut Natural Forest Management Permit area, meaning that it may be logged in the future.

Gorontalo and Central Sulawesi (Cluster 2)

This cluster contained a large portion of the top quantile for carbon stock that was located outside of the current PA network. Overall, the priority areas cover all the high carbon areas. The first priority under scenario ‘b’ includes a patch of lowland elevation hill forest (360 km^2) as the primary habitat type (Fig. 5), while scenario ‘a’ mostly includes current PAs (Table S1: ID 14, 15, 19, 20, and 21). The remaining priority areas are a network of corridors that connect PAs and KBAs. In scenario ‘a’, a second order constitutes a forest area of 2,742 km^2. It is dominated by low and medium elevation hills (1,497 km^2) and includes a 1,299 km^2 corridor connecting Nantu WR and Panua NR, as well as the Papayato-Paguat KBA and Gunung Ile-Ile KBA (Fig. S2). The second order area in scenario ‘b’ (4,276 km^2) extends from Gunung Dako NR to Tinombala NR and includes the Buol-Tolitoli KBA. It is dominated by medium elevation hills (1,621 km^2). This cluster includes the logging concession areas (HPH) of PT Sentral Pitulempa and PT Taman Hutan Asri and the oil palm concessions of PT Inti Global Laksana and PT Cipta Cakra Murdaya.

Additionally, the PT Gorontalo Sejahtera mining concession area overlaps with the southern part of Panua NR.

Central Sulawesi (Cluster 3)

Outside of the PA network, the second order priority areas from scenario 'a' are a 3.223 km^2 area dominated by lower montane forest (1,114 km^2). These areas are in the buffer zones of Gandang Dewata NP (ID 37) and Faruhumpenai NR (ID 40), with standalone areas in the central Pegunungan Tokalekaju KBA and Pambuang KBA, the southern extent of Lore Lindu NP, and the northwest of Morowali NR. Under scenario 'b,' these last two areas were also chosen as first-order priorities. Potential impacts in this cluster include the overlap of Pegunungan Tokalekaju KBA with the Natural Forest Management Permit area of PT Satya Sena Indratama, Pambuang KBA with the Natural Forest Management Permit area of PT Inhutani I Mamuju, and Sulawesi Tengah Grand Forest Park with the mining concession PT. Citra Palu Mineral. Another area of this company's concession is in Luwu Utara, to the South of the Lore Lindu NP.

Eastern Sulawesi (Cluster 4)

The 1,004 km^2 Banggai landscape is a second-order priority area located in the western part of Lombuyan I and II WR is the most notable area in this cluster (ID 35). The most common habitat types are sub-montane forest (734 km^2), karst ecosystem (870 km^2), and a carbon-rich area. Around their respective borders, Bangkiriang WR and Morowali NR have first order priority areas. The Bangkiriang priority area is linked to a second order priority area (209 km^2) that includes a portion of the Bangkiriang KBA. The presence of several plantation concessions with Natural Forest Management Permits, includes PT. Bina Balantak Raya, PT. Dahatama Adi Karya, PT. Palopo Timber Company, and PT. Satyaguna Sulajaya, which straddles the large patch of Banggai, as well as the mining concession of PT. Sinar Makmur Cemerlang inside Bangkiriang KBA.

Southeast Sulawesi (Cluster 5)

The 1,576 km^2 Mekongga landscape is the most prominent feature in this cluster. It is a second order priority area that fully encompasses the Mekongga KBA's northern portion. Sub-montane forest (1,041 km^2) and karst ecosystem (1,158 km^2) are the most common here. There are mining concessions, notably on Kabaena Island that has multiple mining concessions that cover the entire island.

South Sulawesi (Cluster 6)

This cluster has the smallest priority areas outside of the PA network of any of the clusters. The third order is the largest type of priority area of scenario ‘a’ in this cluster. This area of 799 km^2 is dominated by montane forest and has the largest continuous forest patch (542 km^2) that overlaps with the Pegunungan Latimojong KBA, which contains Sulawesi's highest mountain (Mount Latimojong). Scenario 'b' has second order priority areas (178 km^2) outside of the PA network in the interior of the Pegunungan Latimojong KBA, which is dominated by tropical upper mountain and subalpine forest.

Discussion

The Sulawesi terrestrial PA network covers 10.1% of the island's land surface. Our study provides an approach to systematically enhance this network through three sequential stages, by incorporating new areas based on key environmental attributes, such as forest type, karst ecosystem, and carbon stock. Achieving the first order priority areas would increase the PA coverage by at least 11%, and the addition of the second order priority areas would expand this to 17%. Adding all of the areas identified from the first to third order would increase coverage to 36% of the island's land size (Table 2). These three levels of increase would necessitate additions of 12%, 57%, and 190% of land areas to the existing PA network.

Our results revealed that the current PA system protects less than 20% of the area that encompasses the three conservation features analysed. This lack of representation is illustrated through the identification of approximately 13,000 km^2 (first and second order areas combined) of the 30% target outside the current PA network. Assuming that all signatory Parties will adopt the CBD's 30% target, addressing the funding gap to achieve this is critical, yet challenging. Adding this estimated 13,000 km^2 area into Sulawesi's PA network will increase the top-quantile of carbon representation to 13,847 km^2, forested area to 26,629 km^2, and karst ecosystem to 5,580 km^2.

In the 1980s, Mackinnon and Mackinnon (1986) evaluated PA effectiveness in the Indo-Malayan Realm. They concluded that Sulawesi's PAs were generally inadequately protected, except for Dumoga-Bone NP (now BNWNP), Tangkoko Dua Saudara NR, and Lore Lindu NP. Our work reveals a shifting baseline in regard to the essential areas to be protected; it also benefits from detailed data layers and analytical techniques that have only become more recently available. There are considerable gaps in the areas identified as priorities in the PAs exclusion scenario compared to those considered when Sulawesi's PAs were established nearly 40 years ago. Of the six PAs listed by MacKinnon and MacKinnon (1986) as being crucially important, three were not recognised as priorities under scenario 'b' (Tangkoko Dua Saudara, Bantimurung, and Rawa Aopa). Nonetheless, our study and MacKinnon and MacKinnon (1986) both find LLNP and BNWNP as conservation priorities.

Tangkoko-Dua Saudara is a high priority area as it has high conservation value: it supports important populations of the Critically Endangered black-crested macaque (*Macaca nigra*) (Johnson et al., 2020). Our analysis did not include species distribution data due to their coarse nature, thereby excluding this area. The omission of Bantimurung-Bulusaraung NP from our priority list is perhaps explained by the fact that most of the karst ecosystem, the primary feature of this park, is already represented by the Mekongga and Banggai landscapes. Since it was gazetted, Rawa Aopa NP has lost almost half of its forest cover, thereby lowering it as a priority for selection and resulting in the selection of large landscapes, such as Mekongga. The PA exclusion scenario provides valuable information by highlighting important areas that lie outside of the current PA network. Our findings do not mean that the PAs not selected in our analysis lack conservation value, as they serve many other important purposes for endemic species and/or the provision of ecosystem services.

There is considerable overlap between the critical areas highlighted in our study (Fig. 5) and KBAs, which further validates the prioritisation exercise conducted by the Critical Ecosystem Partnership Fund (CEPF, 2014). KBAs are based on species data, whereas our analysis prioritises forest type, carbon, and critical ecosystems, notably karst. The KBA and priority areas highlighted in our study are not included within the existing PA network. The same situation was obtained when we assessed connectivity as one crucial aspect of PAs. Many priority areas identified in this study are also part of the KBA corridor. For example, KBA Bangkiriang and KBA Mekongga were identified by our study as being part of much larger areas - the Banggai and Mekongga landscapes. The islands of Sangihe and Talaud, which were identified in this study as a priority, are also part of the CEPF's priority corridor for North Sulawesi Province (CEPF, 2014).

The priority areas identified by our analyses provide an opportunity to understand where conservation gain, in terms of coverage and ecological representativeness, could be made to the current PA network in Sulawesi. For example, to achieve the 17% protection target, the priority first order selection areas are the existing PAs' buffer zones. We propose that the most feasible approach to conserve these areas is a government-led PA enlargement and buffer management strategy. Once this has been achieved, the next step will be to protect the second order priority areas, mainly by designating a corridor system in cluster 2 (Gorontalo and Central Sulawesi). Many PAs in cluster 2 (Gunung Dako NR, Tinombala NR, and Gunung Sonjol NR) would benefit from increased protection status beyond their current designations.

For a continuous large landscape that is not connected to any PA, notably Mekongga and Banggai, another type of protection is required. Parts of the two landscapes are part of Indonesia's watershed forest, also known as protection forest (*hutan lindung*), and are managed by the local government. They typically have lower protection status than PAs because there is no managerial body directly responsible for them and, as a result, no direct funding for protection. An Essential Ecosystem Area is another plausible option, although their size is generally much smaller than that of a PA. For example, in 2017 the Taman Keanekaragaman Hayati (Biodiversity Park) Oheo Essential Ecosystem Area in North Konawe Regency (MoEF Ditjen KSDAE, 2018), was established near the Mekongga landscape with a size of only 0.15 km^2. Given their size and importance, the Mekongga and Banggai landscapes may even merit national park status and the increased resources that this would bring. Another framework, such as indigenous/community lead/co-managed PAs and private ecosystem concessions, could be considered.

The post-2020 GBF Target 3 aims to protect at least 30% of all land and sea globally and will likely be adopted by all CBD signatories (CBD, 2021; Waldron et al., 2020). Under the Mitigation and Conservation Hierarchy (Milner-Gulland et al., 2021), our work would contribute towards the first of four steps — 'Refrain' — by avoiding impacts to, and retaining, biodiversity. Our work identifies a high priority area to be considered for protection. To achieve the target of increasing the existing 10% area protected in Sulawesi into 17%, 30%, and 50%, the principles of equity and collaboration with neighbouring communities need to be taken forward. One option would be through OECMs with long-term conservation effectiveness outside of the designated PA network (IUCN-WCPA, 2019). A community-led/managed conservation area (Alvard, 2000; Hilser, 2021) or private restoration concessions are part of the OECMs framework.

Increasing the coverage of protected areas is a first step towards meeting the target of being nature positive by 2030 set by the Global Goal for Nature (www.naturepositive.org). Following the first 'Retain' step, the Mitigation and Conservation Hierarchy's subsequent steps are to 'Reduce' the impact (e.g. agri-environment scheme), 'Restore' (e.g. ecosystem restoration), and 'Renew' (e.g. ecosystem creation or rewilding; Milner-Gulland et al., 2021). Reducing the environmental impact of mining and plantation concessions is a top priority. This is particularly important for the conservation of many species, especially the Cerulean paradise flycatcher (*Eutrichomyias rowleyi*): an IUCN listed critically endangered bird endemic to Mount Sahendaruman, Sangihe Island. This species is even more threatened as its only habitat now falls entirely under the PT Tambang Mas Sangihe gold mining concession, which encompasses half of the island. The Sangihe Island's significance was recognized as early as the early 80s by MacKinnon and MacKinnon (1986), who prioritised it for new reserve establishment.

The mitigation hierarchy's third step of restoring degraded areas aligns with the post-2020 target of restoring 20% of degraded terrestrial land and ensuring landscape connectivity. Indonesia may still fall short of this goal, with only 7.6% (1,917 km^2) of degraded lands on Sulawesi protected. The final mitigation hierarchy step of renewal, or rewilding, is still a foreign concept in Indonesia, but it is gaining popularity.

Our analysis aims to determine where and how to protect areas of highest priority for forest, carbon, and critical ecosystem types. We determined that the most plausible approach to accomplishing this was to combine three conservation features, constrained by another two cost layers, the Land Use Land Cover and integrated forest index. We did not, however, include a Sulawesi species distribution map due to a lack of reliable sources, which future endeavors might want to add to the approach. However, there is likely a strong positive association between rich biodiversity and high forest carbon stock areas (De Barros et al., 2014).

There is no magic number of protection percentage that will guarantee that PAs ensure the survival of ecosystem processes and biodiversity. However, in the case of relatively small, safeguarded areas, it appears safe to say that, in general, the higher the percentage target, the better. Decisions must be based on science while also considering equity for rural communities that rely on nature. In this Discussion, we look at potential governance models, such as a strictly PA, to safeguard these important, currently unprotected areas. Protection does not always imply a fenced park. Other more participatory alternatives, such as community or indigenous people involvement in conservation management, are now recognised as options under OECMs and may be effective in helping to secure Sulawesi's rich natural capital while providing critical benefits to its people.

Declarations

Data Source

All the data used is freely available to the public. The boundaries of protected areas can be found at https://www.protectedplanet.net/country/IDN. Sulawesi's Land Use, Land Cover, and Forest Cover can be found at https://tanahair.indonesia.go.id/portal-web/inageoportal/#/. The Forest Landscape Integrity Index can be found online at https://www.forestlandscapeintegrity.com/. Sulawesi's Karst Ecosystem layer can be found at https://psg.bgl.esdm.go.id/. Carbon data can be obtained from Soto-Navarro et al (2020). Furthermore, the polygon of priority areas, which is the study's output, is available at https://bit.ly/3qqn8LN.

Authorship contribution statement

The original idea and method were created by **WP** and **AC**, with conceptual contributions from **HG**, **SM**, **CSN** and **ML**. **WP** and **AC** compiled the data, **AC** run the preliminary analysis, and **WP** performed all data analysis with **HG** and **SM** providing validation. **WP** led the manuscript's writing, with all authors providing feedback on drafts. The final version of the manuscript was approved by all authors.

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Figures

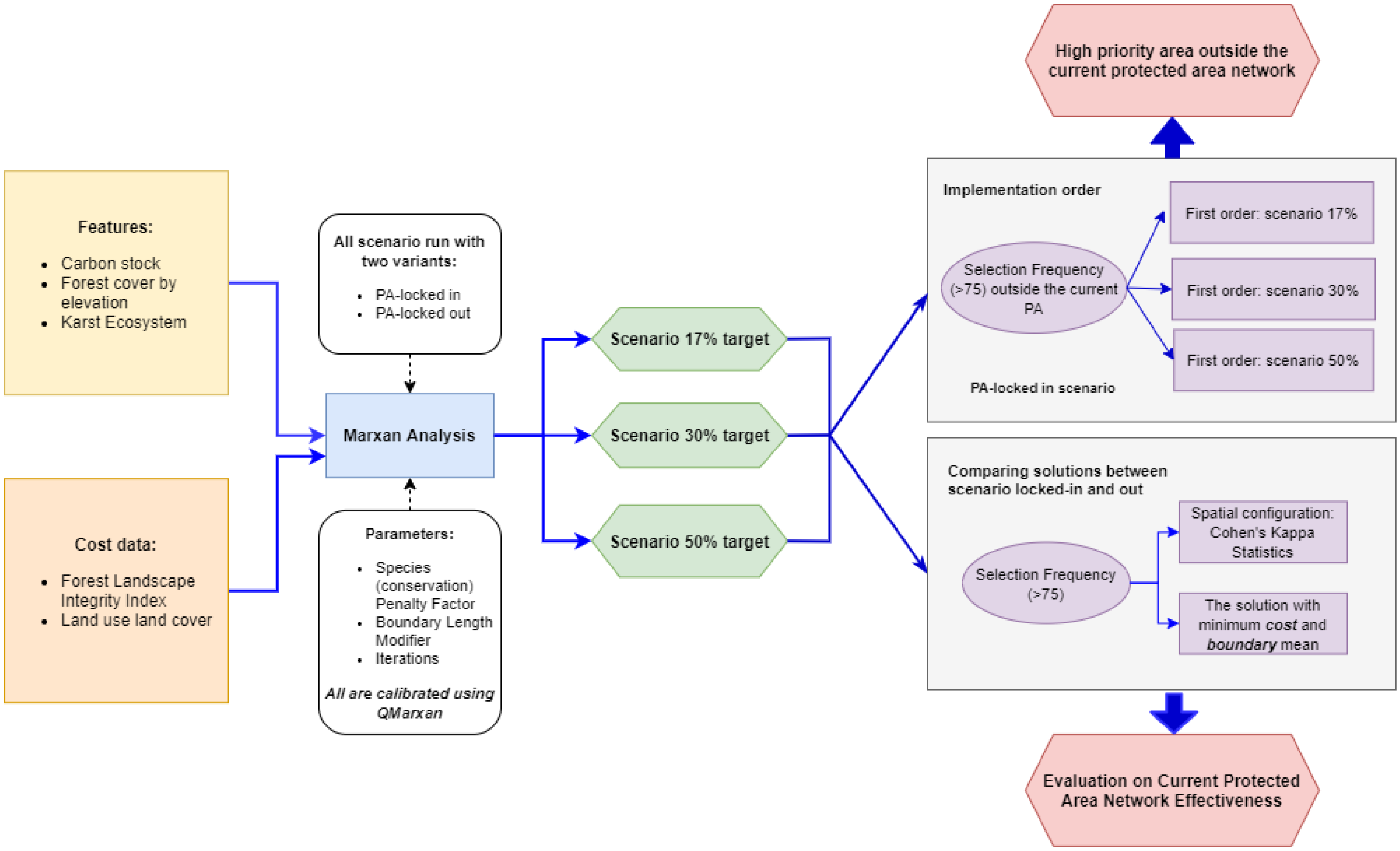

Figure 1

Workflow for identifying priority conservation areas in Sulawesi under three protection scenarios.

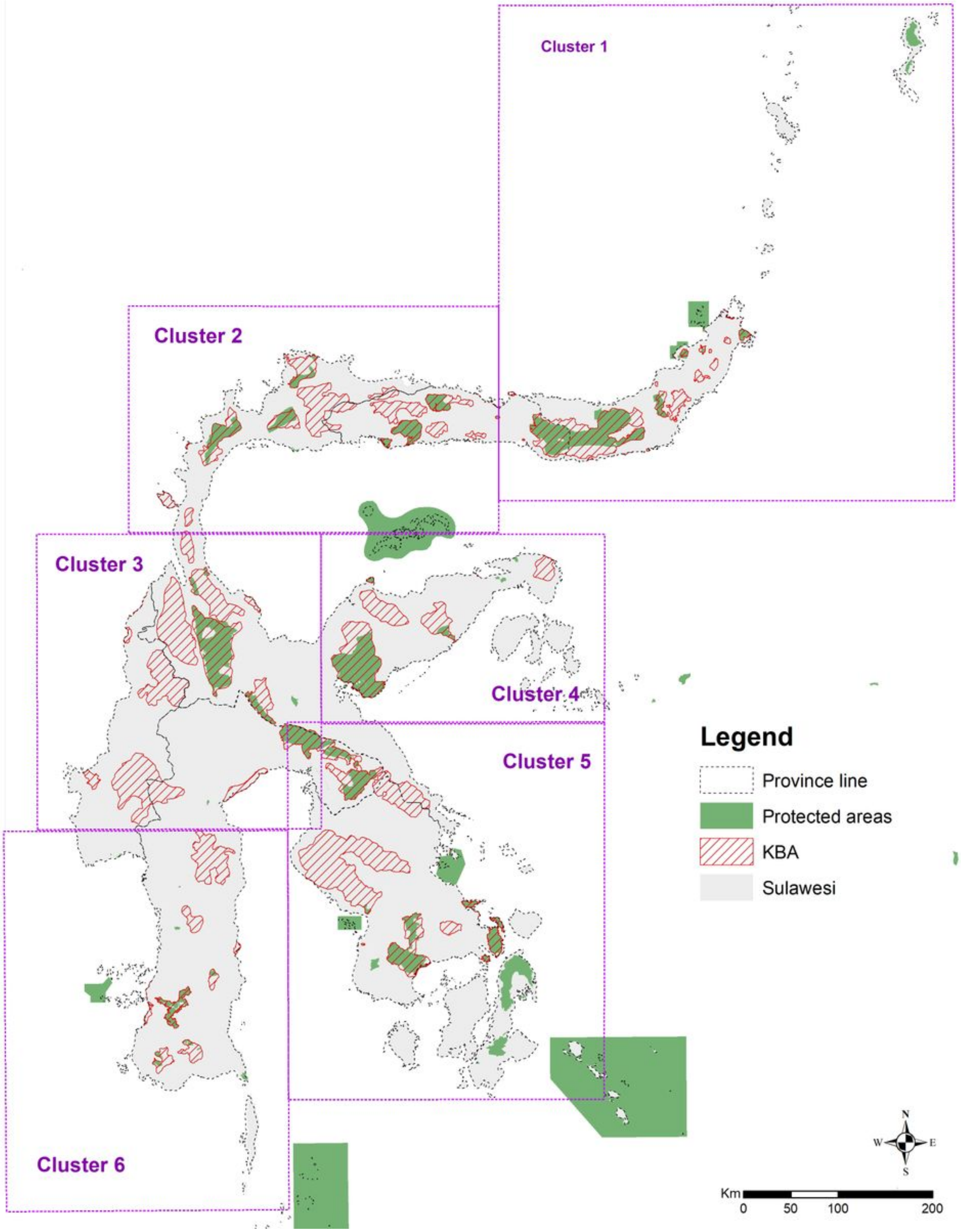

Figure 2

Geographic clusters we used in Sulawesi to define and identify new priority areas.

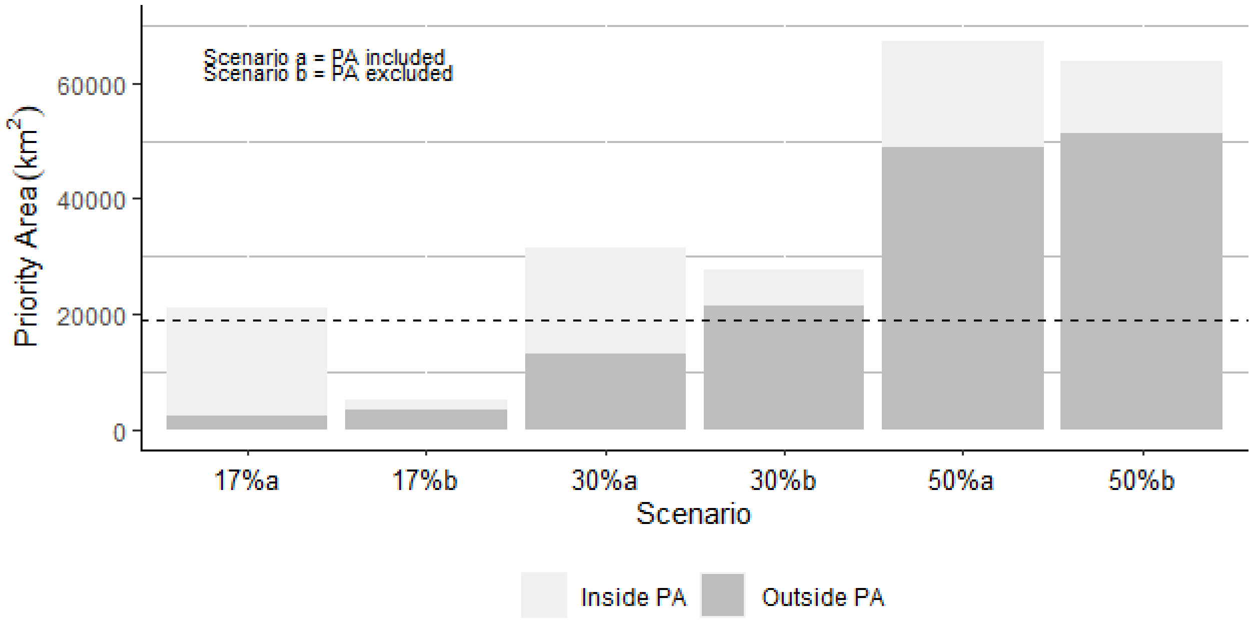

Figure 3

Sulawesi priority area size under six scenarios (two scenarios, ‘a’ and ‘b’, for the three protection targets of 17%, 30%, and 50%). The dashed line denotes the size of Sulawesi's current protected area network.

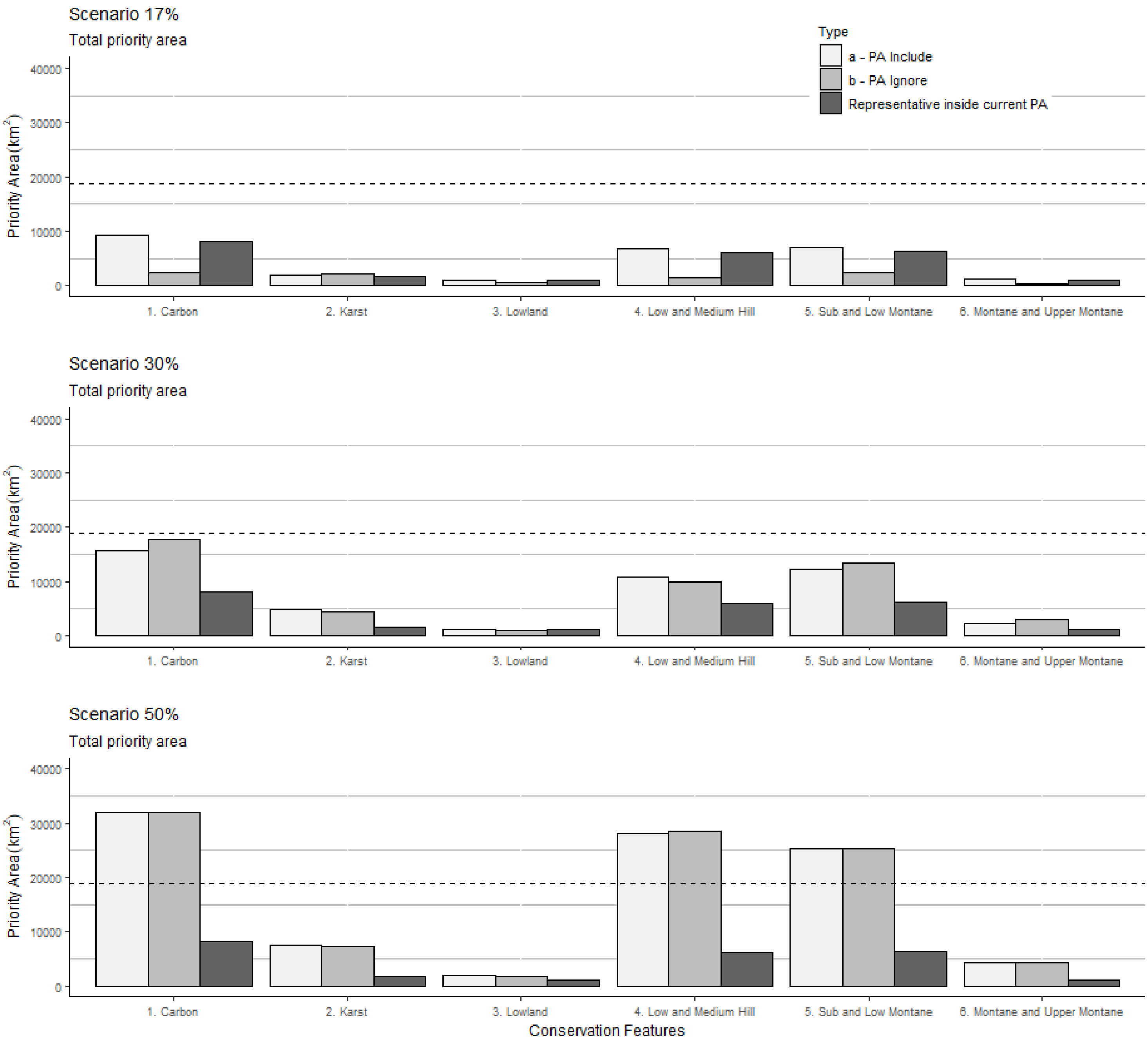

Figure 4

Sulawesi conservation features representativeness for all target scenarios (17%, 30%, and 50% protection target). The dashed line denotes the current protected area network area on Sulawesi (18,821.7 km^2).

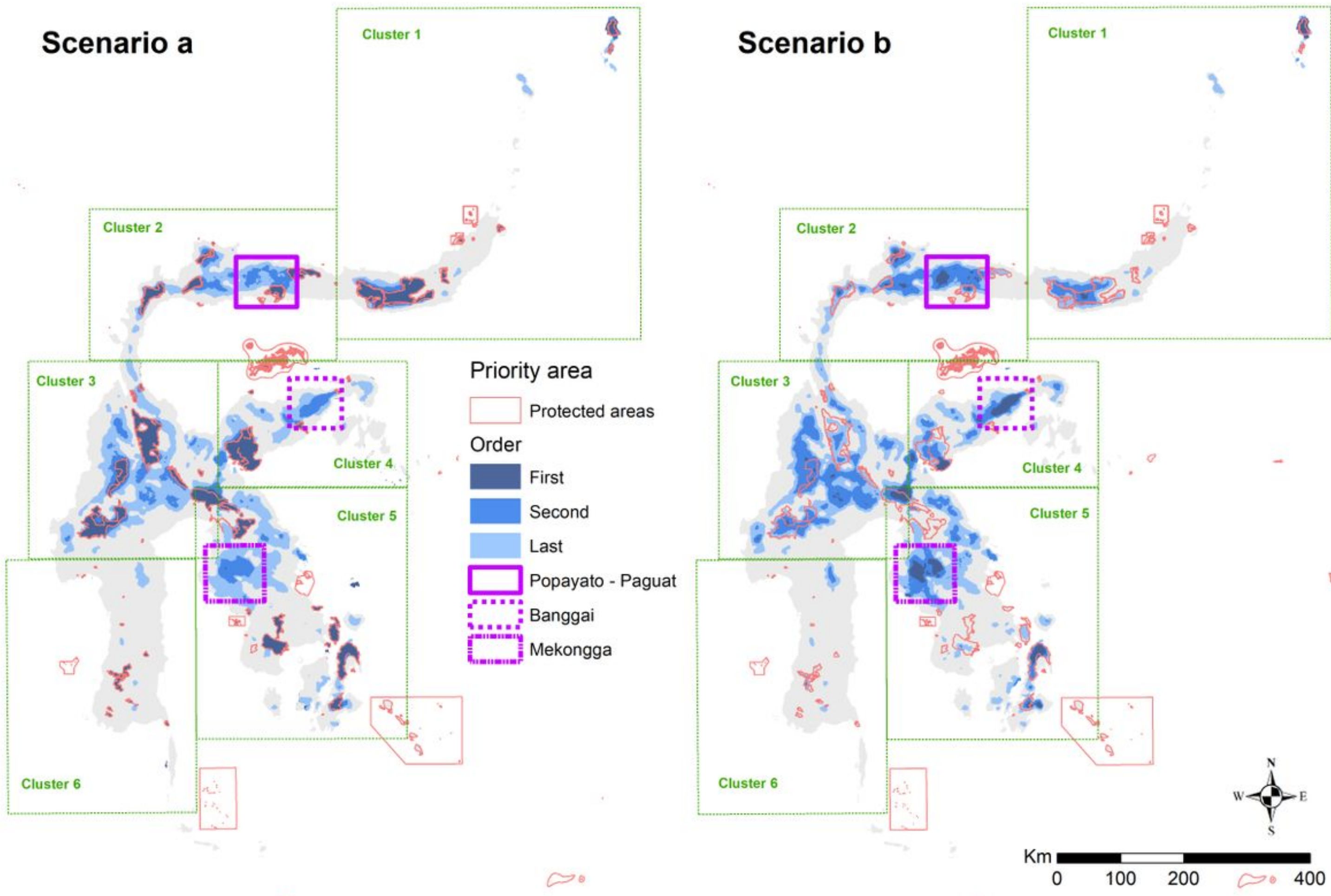

Figure 5

Priority areas in Sulawesi based on scenarios ‘a’ (in which the current PA network had to be included in the selection) and ‘b’ (in which any area could be selected), as well as the proposed order of selection (from light to dark blue) for protecting these areas.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- SupplementaryMaterialv10.pdf