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Research article

Biophysical-based sustainable management of KHDTK Mungku Baru: Mapping conservation, research and utilization blocks

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Abstract

Importance of the work: Sustainable management of Special Purpose Forest Area (KHDTK) Mungku Baru, requires area planning based on mapping and determining management blocks that are in accordance with biophysical conditions.

Objectives: To create management plots based on watershed boundaries and group them into management blocks based on biophysical conditions: vegetation density, land surface temperature, carbon stock and land cover type.

Materials and Methods: Management plots were designed by considering watershed boundaries using the Digital elevation model (DEM), normalized vegetation index (NDVI) analysis and land surface temperature (LST) analysis based on Landsat 9 imagery, carbon stock analysis and land cover analysis. Management blocks were created based on a weighted overlay of management plots with NDVI, LST, carbon stock and land cover.

Results: The overlay of management plots, NDVI, LST, land cover and carbon stocks produced 26 conservation blocks, with an additional 24 plots in the research and development block, 6 plots in the indigenous cultural block and utilization and 6 plots in the rehabilitation block. The minimum area limit for KHDTK utilization was no more than 10% of the area, in accordance with applicable regulations.

Main finding: The arrangement of the KHDTK Mungku Baru area was designed by creating management blocks according to biophysical conditions, with the aim being to ensure the sustainability of the KHDTK Mungku Baru.

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Introduction

KHDTK is a forest area designated by the Indonesian government for forestry research and development activities, forestry education and training, or religious and cultural activities (Peraturan Pemerintah Republik Indonesia, 2021). Universities are one of the parties that can apply to manage KHDTK, based on forestry research and development activities. Since 2014, the Palangka Raya City Government and the University of Muhammadiyah Palangkaraya have been appointed to manage KHDTK as an educational forest, located in Mungku Baru Village, Rakumpit District, Palangka Raya City, Central Kalimantan, Indonesia (known as KHDTK Mungku Baru).

The KHDTK Mungku Baru area is dominated by primary swamp forest, secondary dryland forest, secondary swamp forest and river riparian areas. The primary swamp forest to the south of KHDTK stores large amounts of carbon reserves in the form of peat. The peat in KHDTK Mungku Baru plays an important role in supporting fauna wealth, because the peat ecosystem provides a unique habitat and abundant resources for various animal species. For example, fauna diversity research (Buckley et al., 2018)(Buckley et al., 2018) identified 32 species of mammals (7 endemic species, 2 species classified by the IUCN as "critically endangered" and 4 species as "endangered"), 5 species of wild cats and 6 species of primates. In addition, the KHDTK Mungku Baru is important to some of the surrounding communities who use the KHDTK to meet some of their livelihood needs, such as land for farming and a source of non-timber forest products that have economic potential (Hanafi et al., 2017), as well as providing traditional medicine and local food sources (Rosawanti et al., 2021).

The ongoing existence of the Mungku Baru KHDTK faces several threats, including directly bordering the oil palm plantation area, illegal gold mining activities along the river and land ownership claims by the community. Consequently, efforts are needed to protect and manage the KHDTK to reduce these various threats. One of the components in KHDTK management is the arrangement of the area and the division of the KHDTK into blocks and plots to facilitate the implementation of activities and the supervision and evaluation of KHDTK management activities. The division of blocks and plots takes into account biophysical conditions, as well as the activity plans to be developed. The division of management plots is made based on the watershed, which allows for management that is more in accordance with ecosystem dynamics.

This study aimed to arrange the KHDTK Mungku Baru area by dividing it into small plots based on watershed boundaries and grouping plots based on biophysical conditions (carbon stocks, vegetation, temperature and land cover) into management blocks. Each block needs to be managed with different strategies to achieve the desired goals and to minimize conflicts (Chen and Cai, 2022). Through careful planning, the KHDTK area can be divided into small plots so that management is more focused, directed and sustainable and facilitates the implementation of activities, supervision and evaluation.

Materials and Methods

Study area

The research was conducted in KHDTK Mungku Baru, a forest area of approximately 4,970 ha located in Mungku Baru Village, Rakumpit District, Palangka Raya City, Central Kalimantan, Indonesia (Fig. 1).

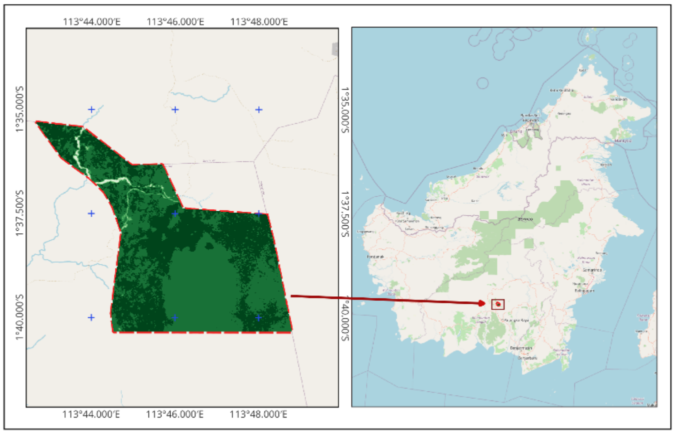

Fig. 1 Study area of KHDTK Mungku Baru, Palangka Raya City, Central Kalimantan Province, Indonesia.

Materials

Carbon stock data were processed into the KHDTK Mungku Baru carbon stock map. The Digital Elevation Model (DEM) was obtained from (Badan Informasi Geospasial, 2024), and the Landsat 9 Imagery in GeoTiff (.TIF) format was accessed through the United States Geological Survey (USGS) for the KHDTK Mungku Baru area (September 2023, path 118, row 061, with a cloud cover of less than 5%). The land cover map of KHDTK Mungku Baru was based on land cover data issued by the Directorate of Forest Resources Inventory and Monitoring, Directorate General of Forestry Planning and Environmental Management, Ministry of Environment and Forestry of Indonesia in 2023.

Research Methods

Processing of satellite data:

The management plots were designed by following the watershed micro boundaries. DEM data was integrated with watershed micro data using the QGIS software version 3.28.9 (Dawson et al., 2023) using r.watershed in the GRASS tool (Barranco Sanz & Álvarez Rodríguez, 2009).

Landsat 9 imagery was subjected to radiometric and atmospheric correction, using the Semi-Automatic Classification Plugin (SCP; Congedo et al., 2024). SCP is used for supervised classification of remote sensing images and for preprocessing and image processing. The normalized vegetation index (NDVI) was used to determine vegetation density. The surface temperature was determined based on a land surface temperature algorithm from the radiation value in the thermal band (bands 10 and 11).

Land cover map validation:

Validation of the land cover classification was based on field observation and field photos to carry out field classification validation, overall accuracy and kappa accuracy.

Carbon stock validation:

Validation of carbon stocks in KHDTK was based on the coefficient of determination (R^2), the adjusted R^2, the p test level and the root mean square error (RMSE).

Design of block arrangement for KHDTK Mungku Baru area:

The plots were combined into management blocks, by conducting a weighted overlay of several biophysical parameters (NDVI, LST, carbon stocks and land cover). The result was a collection of plots grouped into conservation blocks: 1) research and development, indigenous culture and utilization and rehabilitation. The research flow chart is provided in Fig. 2.

Results and Discussion

Management plots analysis

In 2014, KHDTK Mungku Batu was established as an educational forest in Palangka Raya City, Central Kalimantan. Muhammadiyah University of Palangkaraya (as the manager of KHDTK) coordinates and collaborates with the Palangka Raya City Environmental Service and the Borneo Nature Foundation (BNF) in managing KHDTK Mungku Baru. In accordance with its designation, activities carried out in KHDTK include education and research for the academic community of Muhammadiyah University of Palangkaraya and other parties interested in forest conservation activities. The establishment of boundaries for these activities was carried out in 2021–2022.

In accordance with the regulations, the manager is responsible for preparing a management plan for KHDTK Mungku Baru and is required to obtain approval from the Human Resource Extension and Development Agency (BP2SDM) of the Ministry of Environment and Forestry of the Republic of Indonesia. One of the activities in preparing the management plan is the division of blocks and management plots based on biophysical conditions. Based on processing of watershed-based plot boundaries using the DEM data and the r.watershed tool, with a minimum polygon size of 45 ha. The results of image analysis to obtain management plots are presented in Fig. 3.

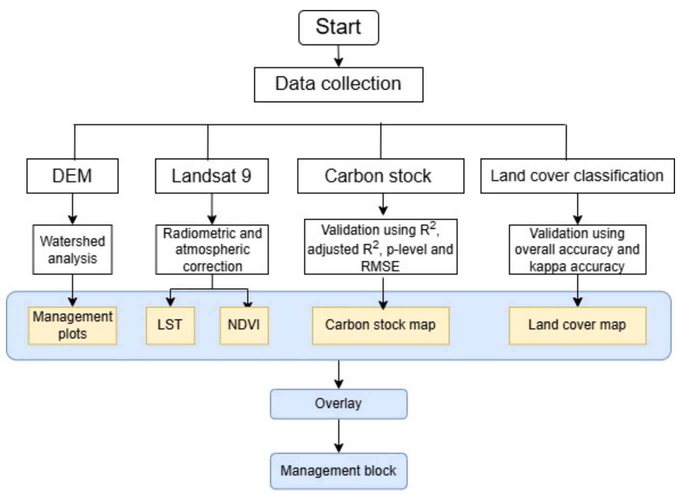

Fig. 2 Flowchart of research on KHDTK area planning based on weighted overlay of biophysical parameters (normalized vegetation index (NDVI), land surface temperature (LST), carbon stock and land cover) for formation of management blocks, where R^2 = coefficient of determination and RMSE = root mean square error.

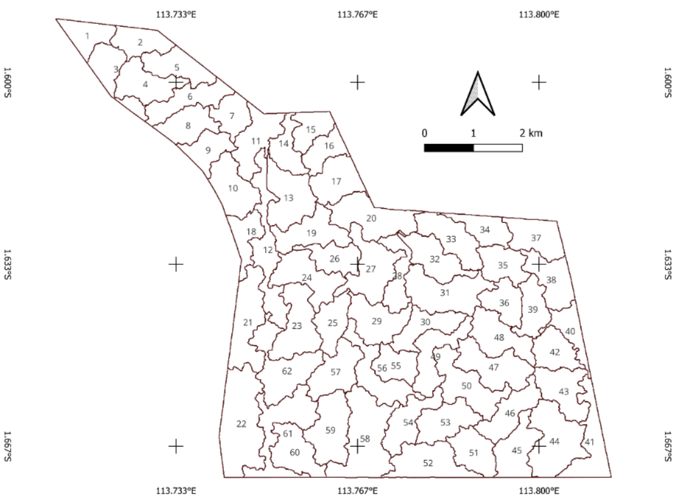

Fig. 3 KHDTK Mungku Baru management plots based on r.watershed analysis

The results of the image analysis produced 62 polygons, (area range 47.24–165.9 ha). These polygons can be used as boundaries of KHDTK management plots. The next stage was the assignment of plot numbers, to facilitate the grouping process in management blocks. The use of watershed boundaries as management plots reflected topographic conditions, water flow patterns and landscapes. The use of these boundaries allowed for management that was more in line with ecosystem dynamics, compared to square plots.

Normal difference vegetation index analysis

Healthy plants reflect more near-infrared light and absorb more red light, resulting in a high NDVI value; conversely, a low NDVI value indicates stressed and unhealthy vegetation, that reflects less near-infrared light (Pamuji et al., 2023). NDVI values can be used to determine land cover conditions (Gandhi et al., 2015; Liu et al., 2022), greenness levels and canopy structures (Wang et al., 2023) and to predict the amount of biomass in an ecosystem (Wang et al., 2016; Malik et al., 2022).

NDVI values are in the ranges from -1 to +1 with the higher the value, the higher the vegetation density. The NDVI and density classifications was based on Aldoski et al. (2013). The results of the NDVI analysis of KHDTK Mungku Baru are presented in Table 1 and Fig. 4.

Table 1 Normal difference vegetation index (NDVI) analysis of KHDTK Mungku Baru

NDVI value	Density type	Area (ha)
-1–<0.2	Non-vegetation	4.50
0.2–<0.4	Sparse vegetation	30.001
0.4–0.6	Moderate vegetation	33.404
0.6–≤ 1	Dense vegetation	4,910.160

Different densities of vegetation will have different NDVI values. Thus, the high dense vegetation value (4,910.160 ha) indicated that KHDTK Mungku Baru had healthy vegetation and stable environmental conditions, while the moderate vegetation value (33.404 ha) indicated there was minimal risk of ecosystem disturbance, though this area required regular monitoring. The sparse vegetation value (30.001 ha) indicated land that was vulnerable to disturbances such as climate change and required conservation measures. Overall, high NDVI values indicate fertile and growing vegetation, which is useful for assessing forest health and monitoring environmental changes (Pompa-García et al., 2022).

Land surface temperature analysis

LST is a measurement of the earth's surface temperature (Tang et al., 2024), which can be used to monitor plant health (Heinemann et al., 2020) and extreme heat events (Gouveia et al., 2022). LST is not only used to detect changes in soil surface temperature, but also can detect the beginning of forest and other land-based fires (Stoyanova et al., 2022). This can help area managers to understand how the microclimate can affect the plant species growing in the forest. The results of the LST analysis at KHDTK Mungku Baru are presented in Table 2 and Fig. 5.

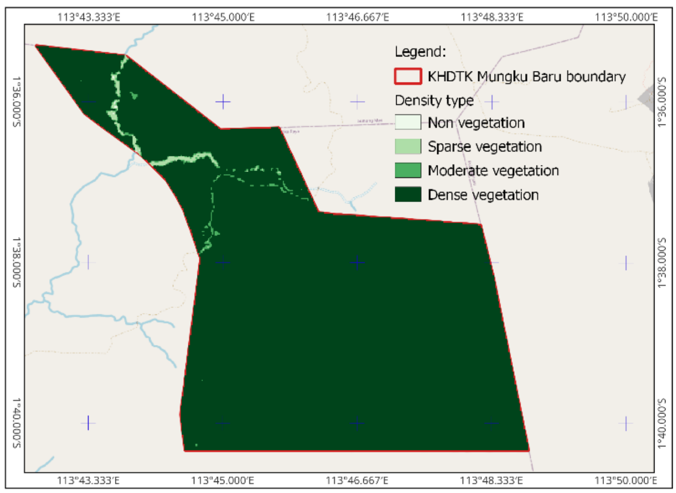

Fig. 4 Vegetation density typing in KHDTK Mungku Baru based on normal difference vegetation index analysis

Table 2 Land surface temperature (LST) classes in KHDTK Mungku Baru

LST value	LST class	Area (ha)
20-23	Very low	785.302
23-26	Low	4,181.073
26-29	Moderate	11.685

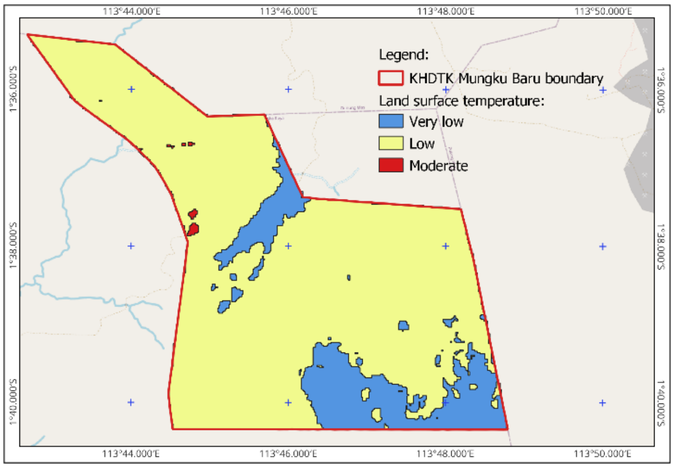

Fig. 5 Land surface temperature class in KHDTK Mungku Baru

The surface temperature in KHDTK Mungku Baru was in the range 21–28°C (based on Landsat 9 images from 9 September 2023). The Palangka Raya City region in Central Kalimantan Province, up to August 2023, had experienced the most forest and land-based fires, besides the Kotawaringin Barat and Pulang Pisau Regencies. This was due to a long drought and the El-Nino phenomenon in 2023 that was moderate compared to El-Nino in 2019 (Baskoro and Rizki, 2023). The existence of dense vegetation created a microclimate around the forest, so that the ground surface temperature remains stable and reduces the risk of forest fires.

Land cover analysis

Land cover plays an important role in forest management planning, since good land cover conditions affect the forest ecosystem which is important for the survival of flora and fauna. There was a very good correlation between the land cover analysis and actual field conditions, with differences likely due to the presence of clouds causing land cover classification errors. The land cover analysis in KHDTK Mungku Baru is presented in Table 3 and Fig. 6.

Table 3 Land cover types in KHDTK Mungku Baru

Land cover type	Symbol	Area (Ha)
Primary swamp forest	Hrp	2,098.309
Secondary dryland forest	Hs	1,072.818
Shrubs	B	1.461
Secondary swamp forest	Hrs	970.448
Dry Land agriculture mixed with bushes	Pc	171.691
Swamp bush	Br	663.342

Primary swamp forests dominate the land cover (2,092.609 ha), acting as a terrestrial carbon sink and reducing the impact of climate change (Kanokratana et al., 2011; Halimanjaya et al., 2018), supporting ecosystem services such as agricultural water supply, fisheries and biodiversity conservation (Hamdani et al., 2022). The diversity of tree species in primary swamp forests contributes to carbon storage (Mensah et al., 2020), with low harvesting and the low occurrence of forest fires (Lu et al., 2022). Other functions include slowing down the occurrence of floods in the rainy season and maintaining water flow in the dry season (Yule, 2010).

Secondary swamp forest covered 968.448 ha of KHDTK, with a sandy soil and a thin layer of peat originating from the organic litter of the vegetation. These forests also have the ability to absorb and store water during the rainy season (Bruijnzeel, 2004) and reduce the risk of flooding in downstream areas, as well as being able to absorb and store carbon (Hergoualc'h and Verchot, 2011).

Secondary dryland forests are forest ecosystems that are disturbed and have regenerated; they can store carbon, support biodiversity and play an important role in ecosystem balance (Rusdiana et al., 2012). Changes in land cover, the presence of vegetation, climatic factors and terrain characteristics can affect the LST value (Adeyeri et al., 2024). Research in Kedah, Malaysia (Wan Mohd Jaafar et al., 2020) reported that the decline in vegetation due to deforestation increased the soil surface temperature.

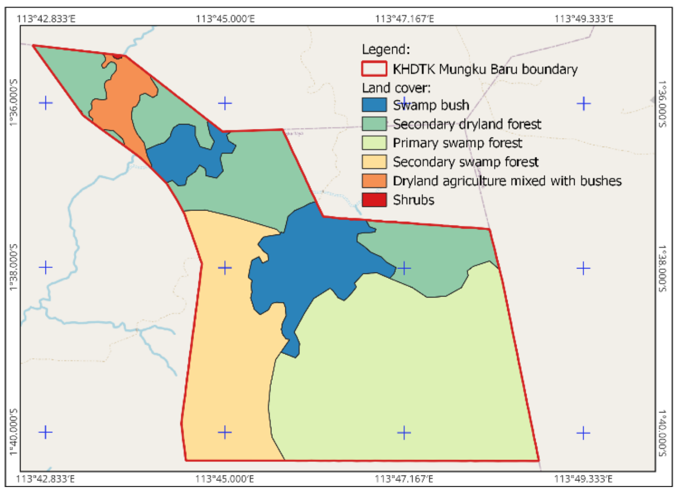

Fig. 6 Land cover types in KHDTK Mungku Baru

Carbon stock analysis

The vegetation density in KHDTK Mungku Baru affects the areas potential for carbon storage, with the denser the vegetation, the greater the carbon reserve value. The diversity of vegetation types also plays an important role in the ability of the land to absorb carbon dioxide from the atmosphere, storing it in the form of tree biomass (Sahoo et al., 2021). The carbon stock analysis in KHDTK Mungku Baru is presented in Table 4 and Fig. 7.

High carbon stocks were estimated for 3,421.54 ha in KHDTK Mungku Baru, which need to be protected and monitored for biodiversity to be maintained. Moderate carbon stocks were estimated for 1,422.52 ha, where attention is needed to prevent deforestation that would reduce carbon stocks. For the low carbon stock area (32.89 ha), rehabilitation and reforestation are needed to increase carbon stocks. Monitoring and evaluation activities are needed to measure changes in carbon stocks and the effectiveness of management actions.

Table 4 Carbon stock classification in KHDTK Mungku Baru

Carbon stock (t/ha)	Classification	Area (ha)
< 0	Water body, road	93.36
0–58.56	Low	32.89
58.57–108.13	Moderate	1,422.52
> 108.13	High	3,421.54

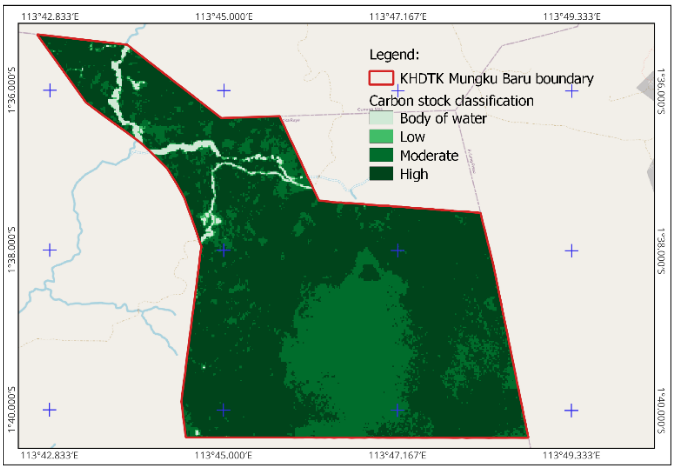

Fig. 7 Carbon stock mapping in KHDTK Mungku Baru

Overlay analysis

Overlay analysis based on management plots, NDVI, LST, land cover and carbon stocks was used to determine management blocks. The management design of KHDTK Mungku Baru was based on dividing the watershed-based management area into four blocks: conservation; research and development; indigenous culture and utilization; and rehabilitation. The results of this analysis are shown in Table 5 and Fig. 8.

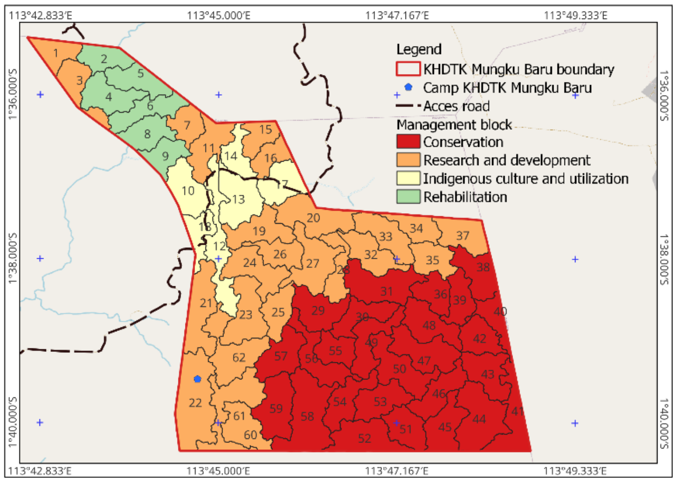

Fig. 8 Management blocks in KHDTK Mungku Baru based on overlay results using management plots, normal difference vegetation index, land surface temperature, land cover and carbon stock

Table 5 Overlay analysis of management blocks in KHDTK Mungku Baru

Plot number	NDVI	LST	Carbon stock	Land cover type	Area (ha)	Management block type
29, 30, 31, 36, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59	Dense vegetation	Very low-to-low	Moderate-to-high	Hrp, Hrs, Hs, Br	2,169.74	Conservation
1, 3, 7, 11, 15, 16, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 32, 33, 34, 35, 37, 60, 61, 62	Low-to-high density	Very low-to-moderate	Moderate-to-high	Hrp, Hrs, Br, Hs, Pc	1,937.44	Research and development
10, 12, 13, 14, 17, 18	Low-to-high density	Very low-to-moderate	Moderate-to-high	Hs, Hrs, Br	471.57	Indigenous culture and utilization
2, 4, 5, 6, 8, 9	Non-vegetation; low-to-high density	Low-to-moderate	Low-to-moderate	Hs, B, Pc, Br	399.26	Rehabilitation

NDVI = normal difference vegetation index; LST = land surface temperature; Hrp = primary swamp forest; Hrs = secondary swamp forest; Hs = secondary dryland forest; Br = swamp bush; Pc = dry land agriculture mixed with bushes; B = shrubs.

A conservation block contains dense vegetation with very low-to-low LST values, medium-high carbon stocks and is predominantly in primary swamp forests. The primary swamp forests have unique characteristics, with interconnected river flows being a very important area to preserve, as in addition to supporting the hydrological cycle, they provide habitat for flora and fauna species. For example, Buckley et al. (2018) noted that orangutans in KHDTK Mungku Baru are often seen along riverbanks and in mixed swamp areas.

The plots located in secondary swamp forest, swamp shrubland and secondary dryland forest were designated for forestry research and development blocks, with low-to-high density, very low-to-moderate LST and moderate-to-high carbon stocks, with aim of studying ecosystem dynamics and developing sustainable forest management practices. The natural regeneration process that occurs in secondary swamp forests is of interest for learning more about the development of dominant species and the time it takes for the ecosystem to recover and function as it had in its original condition. Borges et al. (2023) studied secondary succession in swamp forests and reported that species diversity recovered after 19 yr, while it took 90 yr to restore biomass conditions. The diversity of vegetation in secondary dryland forests is also of interest to study further, regarding how it stores carbon stocks. In KHDTK Mungku Baru, the northern secondary dryland forest is directly adjacent to oil palm plantations, impacting the microclimate and biodiversity. Secondary dryland forests are under serious threat from human activities and climate change (Siyum, 2020), so support is needed in sustainable management.

The Mungku Baru Village community utilizes roads to access the KHDTK Mungku Baru, with the development of agricultural fields on both sides of these roads. The agricultural system carried out by the Mungku Baru community, like the Dayak community in general, is to cultivate by moving from place to place, usually starting with clearing the forest by cutting, cutting and burning, without damaging the forest and the environment (Murhaini and Achmadi, 2021). Then, after 2–3 planting periods the area is left fallow and cultivation moves to opening other fields. The former fields are a potential source of conflict between the manager and the Mungku Baru Village community, requiring immediate action to avoid exacerbating the situation. Based on this approach, the former field area is being used as an indigenous culture and utilization block.

Rehabilitation is planned for the northern part of the area ("bird's head"), with land types of shrubs, secondary dry forests and secondary dry agriculture. In addition, the plot in the bird's head position is vulnerable to forest degradation from gold mining activities by the community along the riverbank. The desired outcome for the rehabilitation block is to change degraded land into productive land for absorbing and storing carbon.

This study produced a structured management block map, based on physical, ecological and social conditions to support sustainable forest area governance. In line with research in KHDTK Loa Haur, remote sensing was used to manage space use conflicts through management block mapping combined with analysis based on strengths, weaknesses, opportunities and threats and the implementation of collaborative strategies with the community (Rifadi et al., 2019). In addition, research in the Tangkoko Nature Reserve and Duasudara Nature Reserve in North Sulawesi compiled management blocks using thematic map overlay techniques, which included land cover, elevation, slope, wildlife distribution and population information of the community in the area (Effendi et al., 2014). The approaches used in mapping relevant management blocks could be applied usefully to other areas, depending on their physical, ecological and socio-cultural conditions. Notable, each management block should have its own tailored management plan.

Conflict of Interest

The authors declare that there are no conflicts of interest.

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