Sustainability factors underlying traditional grazing in Mount Rinjani National Park, West Nusa Tenggara, Indonesia

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Ethnobotany Research and Applications 30:31 (2025) - http://dx.doi.org/10.32859/era.30.31.1-14
Manuscript received: 12/12/2024 - Revised manuscript received: 27/03/2025 - Published: 29/03/2025

Research

Abstract

Background: Traditional grazing in Mount Rinjani National Park (MRNP), West Nusa Tenggara, Indonesia, is a crucial livelihood practice for local communities. However, it poses ecological challenges such as overgrazing, habitat degradation, and an increased wildfire risk. Understanding the sustainability of grazing requires an integrated assessment of ecological, social, economic, and institutional factors.

Methods: This study employed the MICMAC method to analyze key sustainability variables and their interdependencies. Data collection included expert judgment, interviews with local farmers and stakeholders, field surveys, and secondary data analysis. A structured influence-dependence matrix was used to classify variables based on their role in the grazing system.

Results: The quadrant analysis identifies key factors influencing grass utilization in MRNP. Determinant variables such as vegetation cover (C1), land area (C4), grass use (C6), use frequency (C8), and use pattern (C7) play a major role in shaping grazing sustainability. Linkage variables, including institutional factors (C9) and demographics (C5), highlight the importance of governance and community dynamics. Other factors significantly influence the dependent variables, whereas autonomous variables, such as wildlife habitat (C2) and carrying capacity (C3), have minimal interaction with the system. These findings emphasize the need for an integrated approach to balancing grazing activities and conservation efforts in MRNP.

Conclusions: Sustainable grazing management in MRNP requires a collaborative approach that integrates community participation, institutional support, and conservation strategies. Fire prevention, controlled livestock management, and the rehabilitation of degraded grasslands are necessary interventions. Future policies should balance ecological conservation with local economic needs to ensure long-term sustainability.

Keywords: Grazing, MICMAC, Mount Rinjani National Park, Natural resources, Sustainability

Abstrak

Background: Penggembalaan tradisional di Taman Nasional Gunung Rinjani (TNGR), Nusa Tenggara Barat, Indonesia, merupakan praktik mata pencaharian penting bagi masyarakat lokal. Namun, praktik ini menimbulkan tantangan ekologis seperti penggembalaan berlebihan (*overgrazing*), degradasi habitat, dan peningkatan risiko kebakaran hutan. Untuk memahami keberlanjutan penggembalaan, diperlukan penilaian yang terintegrasi dari aspek ekologi, sosial, ekonomi, dan kelembagaan.

Methods: Penelitian ini menggunakan metode MICMAC untuk menganalisis variabel-variabel utama yang mempengaruhi keberlanjutan penggembalaan serta keterkaitannya. Pengumpulan data dilakukan melalui penilaian ahli, wawancara dengan petani dan pemangku kepentingan, survei lapangan, serta analisis data sekunder. Matriks pengaruh-ketergantungan yang terstruktur digunakan untuk mengklasifikasikan variabel berdasarkan perannya dalam sistem penggembalaan.

Results: Analisis kuadran mengidentifikasi faktor utama yang mempengaruhi pemanfaatan padang rumput di TNGR. Variabel determinan seperti tutupan vegetasi (C1), luas lahan (C4), penggunaan rumput (C6), frekuensi pemanfaatan (C8), dan pola penggunaan (C7) memiliki peran utama dalam keberlanjutan penggembalaan. Variabel penghubung seperti faktor kelembagaan (C9) dan demografi (C5) menunjukkan pentingnya tata kelola dan dinamika komunitas. Variabel dependen sangat dipengaruhi oleh faktor lain, sedangkan variabel otonom, seperti habitat satwa liar (C2) dan daya dukung habitat (C3), memiliki interaksi minimal dengan sistem. Temuan ini menekankan perlunya pendekatan terpadu untuk menyeimbangkan aktivitas penggembalaan dan upaya konservasi di TNGR.

Conclusions: Pengelolaan penggembalaan berkelanjutan di TNGR memerlukan pendekatan kolaboratif yang mengintegrasikan partisipasi masyarakat, dukungan kelembagaan, dan strategi konservasi. Upaya pencegahan kebakaran, pengelolaan ternak yang terkendali, serta rehabilitasi padang rumput yang terdegradasi menjadi langkah penting. Kebijakan ke depan harus berfokus pada keseimbangan antara konservasi ekologi dan kebutuhan ekonomi lokal untuk memastikan keberlanjutan jangka panjang.

Keywords: Penggembalaan, MICMAC, Taman Nasional Gunung Rinjani, Sumber daya alam, Keberlanjutan

Background

The Mount Rinjani National Park (MRNP), as designated by the Decree of the Minister of Forestry Number 280/Kpts-VI/1997 dated May 23, 1997, covers a definitive area of 41,330 ha. MRNP serves multiple functions for the surrounding communities, including water source conservation, ecotourism, income generation, education, research, and scientific development. The park's natural beauty is mesmerizing, particularly the volcanic lake at the summit, which offers breath-taking views (Nurcholish *et al.* 2016). Beyond its aesthetic appeal, MRNP plays a crucial ecological role in maintaining the health and stability of the surrounding ecosystem.

The communities in the villages surrounding the national park depend on forest resources for their livelihoods (Wen *et al*. 2017, Lepcha *et al*. 2019, Rahman *et al*. 2021). Smallholder farmers rely on the forest for construction materials, fuelwood, food, medicinal plants, and other forest products, either for subsistence and economic purposes (Nerfa *et al*. 2020). Additionally, they engage in livestock grazing within the national park area (Yu *et al*. 2021). The potential for grass resources in the MRNP area is significant, with its distribution spanning all zones of the national park, including utilization, traditional, rehabilitation, wilderness, and core zones. Grass within the national park plays a crucial role, as it serves as a primary source of animal feed for the local farming and ranching communities, who depend heavily on it for their livestock (Siburian *et al*. 2024). However, during the dry season, these grasslands become highly susceptible to wildfires, posing a serious environmental risk (Sutomo *et al*. 2021).

While the grazing system benefits the livelihoods of local communities, it also presents challenges for park management, particularly in maintaining ecosystem productivity and controlling overgrazing (Mekonen 2020). Overgrazing can degrade soil quality and reduce fodder availability, threatening both ecosystem sustainability and the livelihoods of villagers who depend on the land, as observed in Central Hungary (Varga *et al*. 2021). In Baluran National Park, domestic livestock grazing has led to the degradation of savanna habitats, increased the risk of illegal hunting, and facilitated the spread of invasive acacia species, which, in turn restricts the range and population growth of the black-winged myna (Squires *et al*. 2022).

Similarly, in the Nowa Mountain rangeland, overgrazing has been reported to negatively impact plant species diversity (Mahmoudi *et al*. 2021).

Comprehensive conservation efforts for protected areas should shift the paradigm from a solely protection-focused approach to one that emphasizes sustainable utilization and collaboration (Iswandono *et al*. 2016). Positioning local communities as key stakeholders in management efforts is essential (Helida *et al*. 2015). Indigenous communities play a significant role in utilizing natural ecosystems while ensuring their sustainability (Garnett *et al*. 2018, Fa *et al*. 2020). For instance, in the MRNP, indigenous communities enforce customary rules that must adhere to by their members. Any violations are met with social or customary sanctions in accordance with local traditions (Rudiah *et al*. 2023).

Currently, the management of conservation areas must ensure the sustainable use of resources and ecosystems to support the livelihoods of communities around natural ecosystems (Ward *et al*. 2018). A strict prohibition-based approach for managing national parks and other conservation areas often proves counterproductive, leading to inevitable resource conflicts, especially with local communities (Zuhud *et al*. 2020). Effective conservation strategies should integrate community-based management, traditional ecological knowledge, and participatory decision-making to balance ecological preservation with local economic needs (Rampheri & Dube 2021).

Given the complexity of dynamics within traditional grazing systems, a structured analytical framework is essential to understand the interdependencies among ecological, economic, social, and institutional factors. Analytical methods such as MICMAC have become essential tools for understanding these intricate connections. This method offers a structured and systematic framework for analyzing the complex interrelationships among various sustainability factors (Firdaus *et al*. 2023). MICMAC takes the analysis a step further by mapping these relationships and differentiating between driving factors and dependent variables within the system (Latif *et al*. 2023). This approach is instrumental in identifying the primary drivers that have a significant impact on sustainability (Bakrie *et al*. 2023). This insight is crucial for developing strategic plans and implementing effective interventions within the system (Primadasa *et al*. 2024).

This study aims to assess the sustainability of traditional grazing practices among local communities in MRNP by examining ecological, social, institutional, and economic aspects. Evaluating these four dimensions of sustainability serves as a foundation for comprehensive management and policy development in the area (Afrianto *et al*. 2024). Additionally, the study seeks to identify the intersection between local knowledge and regional management to promote collaborative and sustainable resource utilization (Afrianto & Metananda 2023).

Materials and Methods

Study area

Geographically, MRNP is located between 116°17'30" - 116°33'30" East Longitude and 8°17'30" - 8°33'00" South Latitude (Figure 1). Administratively, the park spans three districts: North Lombok Regency, covering 12,357.67 ha (29.9%) across two sub-districts and 16 villages; Central Lombok Regency, covering 6,819.45 ha (16.5%) across two sub-districts and five villages; and East Lombok Regency, covering 22,152.88 ha (53.6%) across ten sub-districts and 17 villages. The MRNP area is part of the Mount Rinjani Forest Group, as determined by the Minister of Forestry through Decree Number SK.3065/Menhut-VII/KUH/2014, dated April 23, 2014. This decree designates the Mount Rinjani Forest Group as a protected area spanning 125,200 ha across West Lombok Regency, North Lombok Regency, East Lombok Regency, and Central Lombok Regency.

Data Collection and Analysis

The analysis aimed to determine, organize, and map key factors while examining their relationships to provide critical insights for system enhancements. The MICMAC method was conducted with three steps: (i) pinpointing key factors, (ii) mapping the association between influence (Y) and dependence (X) variables, and (iii) demonstrating their significance and causal links within the system. This approach can be used to understand and simplify system complexity (Fauzi 2019). The MICMAC method identifies influential and dependent variables by analyzing interconnections among elements, illustrating system evolution through a structured matrix-based approach (Godet 2000).

This analysis examined and classified the indicators influencing the sustainability factors underlying traditional grazing in MRNP, West Nusa Tenggara, Indonesia. Factor determination was conducted through a literature review and expert judgment. In the MICMAC analysis, experts should come from diverse practitioner and academic backgrounds to comprehensively understand the issues. Furthermore, expert panels can range from three to five individuals with diverse expertise (Delgado *et al*. 2020).

In this study, the expert team consisted of eight individuals with diverse backgrounds and specialized expertise, collectively contributing to a comprehensive well-rounded skill set (Table 1). The team included five academics specializing in biology, ethnobotany, agriculture, and animal husbandry. Additionally, expert practitioners were from academia, the conservation sector (NGOs), and MRNP staff. All experts had more than ten years of professional experience in their respective fields. The combination of practical experience and academic insight enhanced the team's capabilities in addressing the social, economic, ecological, and land management aspects of traditional grazing in MRNP, West Nusa Tenggara, Indonesia.

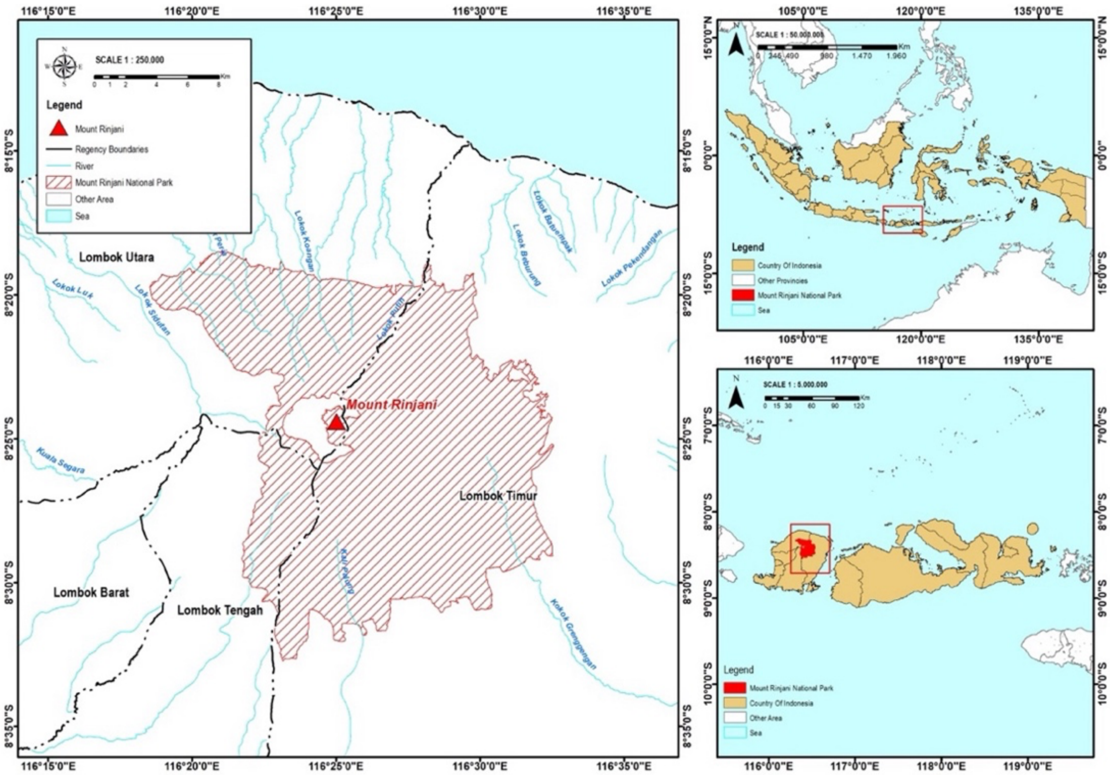

Figure 1. Map of study sites in the MRNP

Table 1. Expert's team

Expert	Status	Position	Expertise
E1	Academics	Professor	Tropical Rangeland and Grazing Animal Production
E2	Academics	Professor	Animal Husbandry Socio-Economics
E3	Academics	Senior lecture	Biology
E4	Academics	Lecture	Ethnobotany
E5	Academics	Lecture	Agricultural Technology
E6	Practitioner	Staff MRNP	Conservation
E7	Practitioner	Staff MRNP	Conservation
E8	Practitioner	Researcher NGO	Ethnobotany

The data used in this study consisted of both primary and secondary sources. Primary data were collected through interviews and surveys to identify significant variables. The interviews conducted in this research followed a semi-structured approach. This technique involved providing answer choices for some questions while leaving others open-ended, allowing respondents to express diverse opinions or respond based on their knowledge. The sample size determination in this study was divided into two groups: respondents providing community data on the traditional grazing system and those supplying socio-economic data. The selection of respondents for socio-economic data collection followed the snowball sampling method (reference). This approach involved identifying key informants knowledgeable about the grazing system, such as sub-district heads, village heads, or local community leaders. Initially, one or two key figures were selected, and additional informants were included based on recommendations from these initial key figures. Additionally, secondary data were obtained from the MRNP database and unpublished previous studies. These sources provided information on the area's carrying capacity, vegetation diversity, MRNP's total area, demographics, and existing management practices.

Afterward, the collected data were carefully curated to identify key variables influencing traditional grazing practices in MRNP. The approach employed a systematic process that combined multiple sources of information, including the final judgments of experts through structured assessments, an in-depth literature review of relevant studies, and the analysis of secondary data from official reports, research publications, and local records. This comprehensive evaluation led to the identification of nine critical factors distributed across four main aspects: social, economic, ecological, and land management. These findings are summarized in Table 2, offering a structured framework for understanding the complexities of traditional grazing in MRNP.

This study used the MICMAC method to analyze the strategic variables that had been identified (Fauzi 2019). The analysis was carried out systematically in several key stages. The first stage involved constructing the direct influence matrix, where the relationships between variables were assessed based on their level of influence on one another. A rating scale was used to evaluate these relationships, consisting of P (Potential), 0 (no influence), 1 (weak influence), 2 (moderate influence), and 3 (strong influence). This matrix was developed based on expert assessments to understand the direct interconnections between variables within the traditional grazing system in MRNP.

Indirect influences were calculated by applying the MICMAC algorithm to identify secondary and tertiary relationships between variables. This step was crucial in uncovering hidden impacts that might not be evident in the direct analysis. By considering indirect influences, the mapping of variable relationships became more precise, offering a deeper understanding of the system structure under analysis.

Following this, influence and dependence scores were determined for each variable. The influence score was obtained by summing the impact total exerted by a variable on all other variables. In contrast, the dependence score was calculated based on the extent to which a variable was affected by others in the system. This step helped classify the variables according to their roles and significance in the dynamics of traditional grazing in MRNP.

Table 2. Variables used as the determinant utilization of grass in MRNP

Category	Code	Indicator	Description	References
Ecological	C1	Vegetation cover	The characteristics of grass vegetation conditions	Dossa *et al*. 2013, Metandanda *et al*. 2025, Sutomo *et al.* 2021
	C2	Wildlife habitat	Utilization of MRNP areas for herbivorous wildlife	Gandiwa *et al*. 2013, Muir *et al*. 2015, Yang *et al*. 2018
	C3	Habitat carrying capacity	Habitat carrying capacity estimation determines the amount of green fodder or feed productivity that wildlife can utilize	Christensen *et al*. 2003, Abdullah *et al*. 2017, Ren *et al*. 2021
	C4	Land area	The area used by the community for grazing	Azizah *et al*. 2021a, Alamanda *et al*. 2022, Pudyatmoko *et al*. 2018
Socio-Economic	C5	Demographic	Description of residents engaged in grazing around the MRNP area	Azizah *et al*. 2021b, Siburian *et al*. 2024
	C6	Grass use	the amount of grass utilized by farming and cattle-raising households around the MRNP area	Siburian *et al*. 2024
	C7	Use pattern	Grass utilization patterns in the MRNP area	Siburian *et al*. 2024
	C8	Use frequency	Grass frequency in the MRNP area	Siburian *et al*. 2024
Institutional	C9	Institutional	Institutions encompass the foundational structures that shape community social behavior, including norms, regulations, and law enforcement systems.	Pudyatmoko *et al*. 2018, Ichsan *et al*. 2019, Siburian *et al*. 2024

Subsequently, the influence and dependence score calculations were refined by incorporating indirect effects. Some variables that initially seemed less significant gained strategic importance once indirect effects were taken into account. This adjustment facilitated the development of a more representative variable relationship map, more accurately reflecting the reality of the system under study.

The final stage involved classifying the variables using the influence-dependence matrix. The calculated scores were plotted on a quadrant diagram to determine the strategic roles of each variable. This diagram was divided into four main quadrants:

- Quadrant I (determinant variables) - Variables with high influence but low dependence, acting as key factors shaping the system.
- Quadrant II (linkage variables) - Variables with both high influence and high dependence, representing highly sensitive variables that are closely interconnected with others.
- Quadrant III (dependent variables) - Variables with low influence but high dependence, meaning they are more affected by other factors rather than influencing the system themselves.
- Quadrant IV (autonomous variables) - Variables with both low influence and low dependence, playing a marginal role in the system with limited significance in the analyzed dynamics.

This study presents a variable mapping that illustrates the degrees of influence and dependence using the Matrix of Direct Influence (MDI). Additionally, it includes a displacement map that highlights shifts in variable positions due to indirect relationships, as well as a hierarchical structure of variables derived from both matrices of direct and indirect influence (MDII). The variables are categorized and ranked based on their direct influence, dependence levels, and indirect influence factors.

Results

Table 3 presents the MDI used in MICMAC analysis, which evaluates the interactions and dependencies among nine variables (C1-C9). Each row and column represent a specific variable, including vegetation cover (C1), wildlife habitat (C2), habitat carrying capacity (C3), land area (C4), demographic factors (C5), grass use (C6), use patterns (C7), use frequency (C8), and institutional factors (C9). The matrix values indicate the strength of direct influence between variables, ranging from 0 (no influence) to 3 (strong influence).

Table 3. The MDI for MICMAC analysis

Indicator	C1	C2	C3	C4	C5	C6	C7	C8	C9
C1: Vegetation cover	0	3	3	3	1	3	3	3	1
C2: Wildlife habitat	2	0	3	1	0	0	0	0	2
C3: Habitat carrying capacity	3	3	0	0	0	0	0	0	2
C4: Land area	3	2	3	0	0	3	3	3	1
C5: Demographic	0	0	3	3	0	3	3	3	0
C6: Grass use	3	1	P	3	0	0	3	3	3
C7: Use pattern	3	1	2	3	0	3	0	3	0
C8: Use frequency	3	2	2	3	0	3	3	0	0
C9: Institutional	3	3	3	3	0	3	1	3	0

A quadrant analysis graph categorizing different indicators (C1-C9) into four quadrants representstheir influence on grass utilization in MRNP (Figure 2A). Quadrant I includes vegetation cover (C1), land area (C4), grass use (C6), use frequency (C8), and use pattern (C7), indicating strong positive influences on grass utilization. Quadrant II contains institutional factors (C9), highlighting the regulatory or governance role in resource utilization, and demographic factors (C5), suggesting that population dynamics have a relatively lower impact on grass utilization. Quadrant IV consists of wildlife habitat (C2) and habitat carrying capacity (C3), likely representing ecological factors with distinct patterns of influence. The distribution of these variables across the quadrants helps illustrate their significance and interactions in shaping the sustainable use of grass in MRNP. This analysis covers the distribution of land use zones in MRNP, as shown in Figure 2B, highlighting the extent of areas designated for traditional grazing, conservation, and rehabilitation efforts, while Figure 2C illustrates the number of households involved in grass utilization across different regions, indicating the socioeconomic dependence on grazing practices.

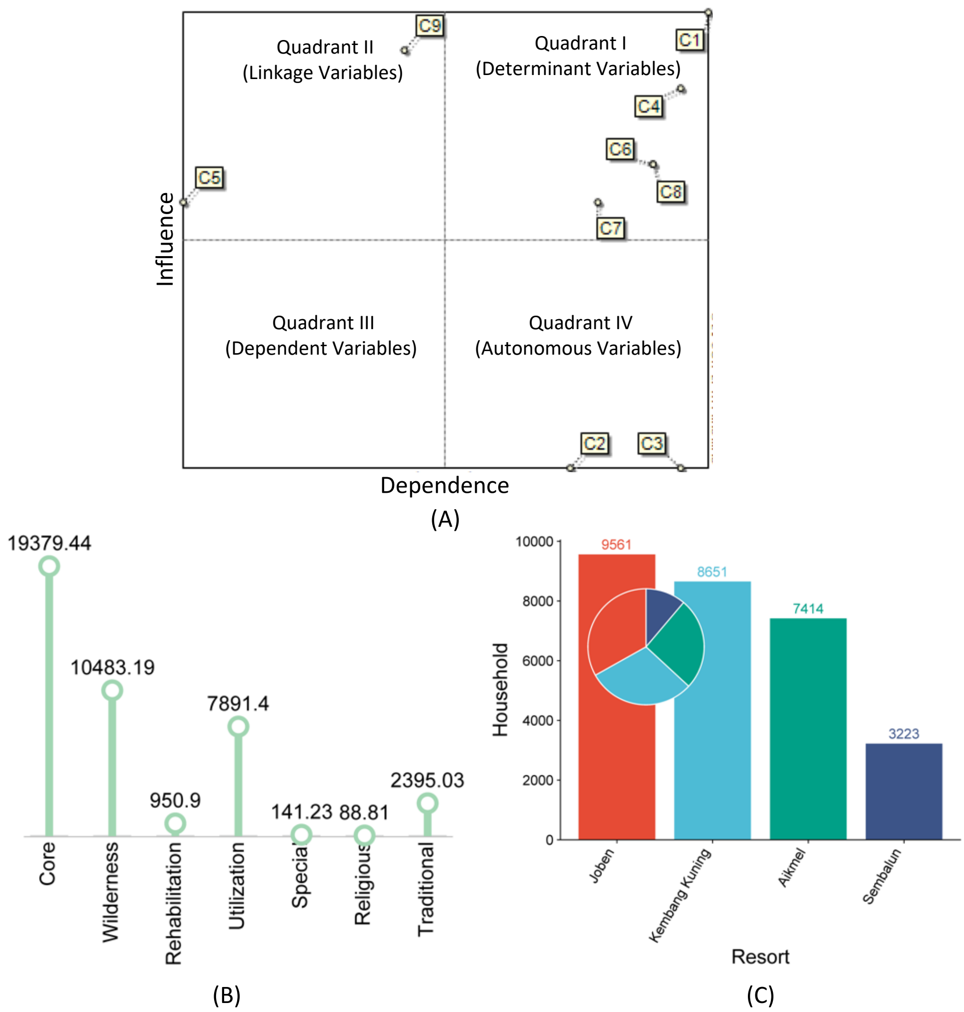

Figure 2. (A) Influence-Dependence Map for sustainability traditional grazing in MRNP, (B) area size (ha) of the zone, and (C) number of households utilizing grass in the MNRP in MRNP (MRNP 2022),

As illustrated in Figure 3a, most factors exhibit strong mutual influence, while others have a more moderate impact on various elements. The strongest influences are depicted in red, highlighting key relationships such as the effect of habitat carrying capacity (C3) on use frequency (C8), use pattern (C7), and institutional factors (C9). Additionally, wildlife habitat (C2) strongly influences vegetation cover (C1), land area (C4), use frequency (C8), and institutional factors (C9). Meanwhile, Figure 3b, meanwhile, presents the indirect relationships between variables. The numerical values on each arrow indicate the degree of influence, calculated iteratively using the Boolean matrix. The blue arrows represent weaker indirect influences, while the red arrows indicate relatively strong indirect influences. The analysis reveals that land area (C4), grass use (C6), and institutional factors (C9) exert the strongest indirect effects, particularly on vegetation cover (C1). This visualization highlights how both direct and indirect relationships contribute to overall system dynamics, with certain variables playing a crucial role in shaping the sustainability of grazing practices in MRNP.

Figure 4 presents a comparative ranking of variables related to grass utilization in MRNP, with connections between different rankings indicated by red and green lines. The green lines represent a positive or upward change in ranking, while the red lines indicate a decline or downward shift in position. In Figure 4a, the rankings of variables shift across different categories. Notably, land area (C4), demographic factors (C5), and wildlife habitat (C2) are linked by red lines, indicating a decline in ranking. Meanwhile, grass use (C6), use pattern (C7), and institutional factors (C9) are connected by green lines, suggesting an improvement in ranking. A different trend emerges when comparing ranking dependencies in Figure 4b. grass use (C6), use pattern (C7), and use frequency (C8) appear with red lines, signifying a drop in ranking. In contrast, wildlife habitat (C2) and institutional factors (C9) are associated with green lines, showing an upward movement in ranking.

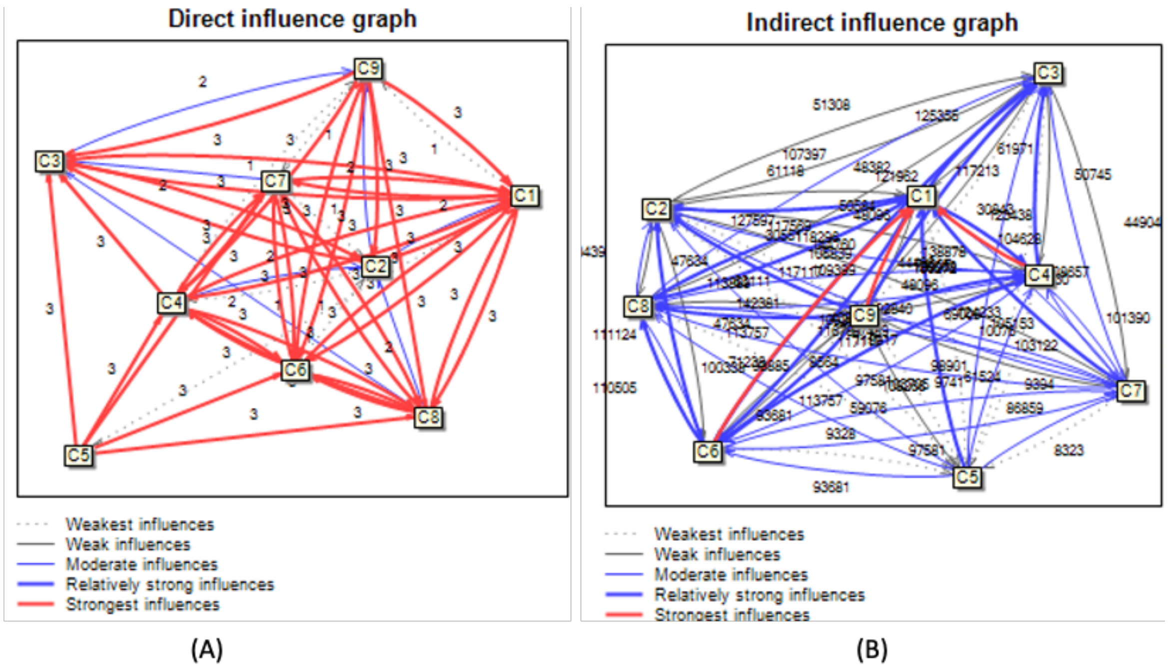

Figure 3. Map of (a) direct and (b) indirect influence among variables

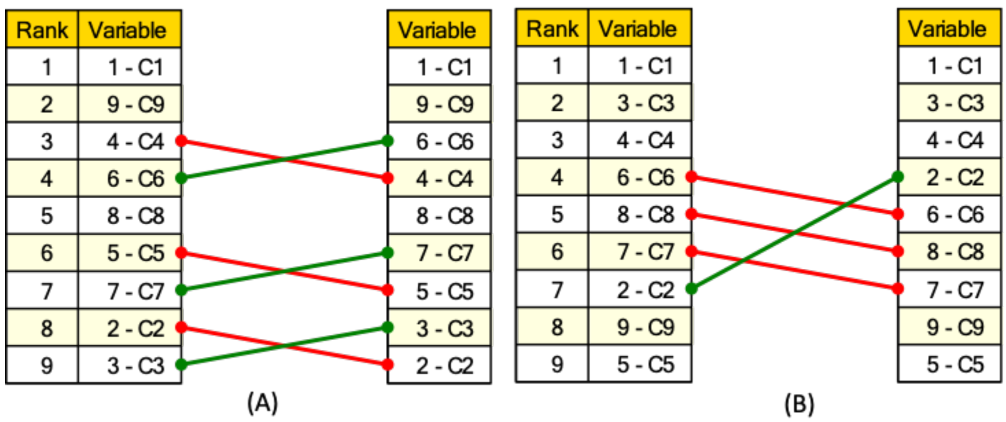

Figure 4. Rank comparison between all variables based on (a) influences and (b) dependence

Discussion

The MDI identified nine elements or variables representing ecological, economic, social, and institutional dimensions (Table 3). It is calculated in a 10 × 10 matrix. These variables illustrate the circumstances of society and local management concerning traditional livelihood sustainability in the study area (Marpaung *et al*. 2023). The MDI describes the relationship in the procedure. It was employed to estimate per variable in the MICMAC analysis with numbers between 0 and 3 (possible/0, mild/1, moderate/2, and strong/3 effects) (Ilhami *et al*. 2024).

Quadrant 1 exhibits high influence and low dependence, making it a significant factor with the potential to serve as a fundamental determinant in the system (Figure 3A) (Ardiansyah *et al.* 2022). This quadrant includes vegetation cover (C1), land area (C4), grass use (C6), use pattern (C7), and use frequency (C8). Vegetation cover (C1) is commonly referred to as savanna or grassland, with most grasslands dominated by plant species belonging to the Poaceae family (MRNP 2022). In some areas, species from the Cyperaceae and Asteraceae families also prevail. According to the MRNP plant diversity database, *Themeda triandra* is the dominant understory plant species in MRNP. Fires in MRNP naturally influence savanna vegetation, stimulating the growth of grasses on the ground surface (Metananda *et al.* 2025). The species composition in the transition zone between forest and savanna includes *Rytidosperma penicillatum*, *Ficus septica*, *Engelhardia spicata*, *Macaranga tanarius*, *Athyrium sp*., *Saurauria sp.*, and *Lindera sp*. (Sutomo *et al.* 2021). Plant species diversity in MRNP decreases with increasing elevation, with environmental factors exerting a stronger influence on the phylogenetic structure of communities at higher elevations (Dossa *et al.* 2013).

Land area (C4) in MRNP consists of seven zones such as the core zone, wilderness zone, rehabilitation zone, utilization zone, special zone, religious zone, and traditional zone (MRNP 2022) (Figure 2B). Among these, the zones that the community can utilize are the traditional zone, rehabilitation zone, and utilization zone, covering a total area of 11,237.33 ha. These zones provide opportunities for local communities to engage in sustainable land use practices (Blouch 2010). Nurrochmat *et al*. (2019) argue that the community forestry approach is an effective strategy for making grazing more sustainable by integrating local knowledge and traditional land management practices. This approach promotes responsible land stewardship while ensuring that natural resources are utilized in a way that minimizes environmental degradation. Furthermore, sustainable grazing practices within these designated zones can help maintain ecosystem balance, reduce the risk of overgrazing, and support biodiversity conservation efforts (Yao *et al*. 2025).

Based on interviews with local farmers, grass use (C6) in MRNP varies: households with many cattle (15 or more) generally adopt continuous grazing, while those with fewer than 15 tend to use the pick-up-and-drop-off method. On average, cattle owners who use the cut-and-carry system own 3.4 cattle. Owners with 1-4 cattle collect grass once a day, whereas those with more than four typically collect grass twice daily. Only about 20% of owners have more than four cattle. The amount of grass collected from the TNGR area ranges from a minimum of 60 kg to a maximum of 100 kg per trip, with an average of 80 kg. According to Siburian *et al*. (2024), a cow requires approximately one full wheelbarrow of grass (35 kg), which costs around IDR 25,000 per wheelbarrow.

Grassland utilization followed two main patterns (C7): the cut-and-carry system and grazing. Grazing was further divided into continuous grazing (free-range) and the pick-up-and-drop-off system. In the continuous grazing system, cattle roamed freely without being brought home in the afternoon. Owners only retrieved them when necessary, such as for sale, making this method nearly cost-free, except for the occasional fee to capture the cattle. In contrast, the pick-up-and-drop-off system involved herding cattle to designated grazing areas within the MRNP in the morning and bringing them back home in the evening, requiring more active management. Free-range livestock adversely affects wild mammals without proper management in national park by decreasing species richness, reducing occupancy probability, and disrupting activity patterns (Pudyatmoko *et al*. 2017).

The frequency of grass collection (C8) varies between seasons. During the rainy season, owners need only 1-2 hours per trip to collect grass, as the forage availability is higher. However, during the dry season (July-October), the process takes longer —approximately 2-3 hours — due to the reduced availability of grass. During the dry season, most stands were heavily grazed, whereas in the wet season, the majority were moderately grazed (Abdullah *et al*. 2017). Almost all owners rely on motorcycles to transport the harvested grass, ensuring efficiency in collection and transportation. This is because local farmers search for grass far from their homes (Siburian *et al*. 2024).

Quadrant II indicates that 3,678 farmer-cattle households utilize grass in the MRNP (C5). These households are distributed across various resorts, with 1,878 in the Kembang Kuning Resort, 675 in the Aikmel Resort, 275 in the Sembalun Resort, and 850 in the Joben Resort (Figure 2C). The demographic aspects that can influence the cattle population are private livestock ownership, age, and education level. Local communities have traditionally developed systems to regulate the use of natural resources. However, these systems have become less effective due to increasing pressures from modern development, leading to more exploitative resource use (Moukrim *et al*. 2018). Despite this, local communities remain aware of ongoing environmental degradation and recognize the need to participate in managing communal grazing lands, contributing both labor and financial resources (Amare *et al*. 2017).

Based on interviews with MRNP staff, various efforts have been made to prevent illegal grazing within the park. These efforts include educational outreach, providing access to grass collection for animal feed through a cut-and-carry system, and assisting with communal enclosures. However, the results have not been satisfactory. Although the impact of illegal grazing is not yet highly visible, if it continues, it could gradually alter the function of the national park. According to Ichsan *et al*. (2017), one of the community empowerment programs, the Conservation Village Model in MRNP, has yet to operate optimally. This situation is due to several factors, including the lack of a clear mechanism for community access to the national park, inconsistencies between program interventions and community preferences, and the absence of well-defined mechanisms for benefit-sharing and dispute resolution at the operational level (Ichsan *et al*. 2021).

Quadrant IV includes wildlife habitat (C2) and habitat carrying capacity (C3). *Bos sondaicus* and *Rusa timorensis* are the primary herbivores inhabiting the area, consuming grass and other vegetation (MRNP 2022). According to interviews with MRNP staff, although *B. sondaicus* has been domesticated as livestock, it can quickly revert to its wild state if left to roam freely. Meanwhile, *R. timorensis* spends most of its time feeding, with no significant differences in feeding behavior across age or sex (Pairah *et al.* 2014). Regular direct monitoring indicates that *B. sondaicus* exists in both wild and domesticated forms, with more than 70% living as wild animals, while the remainder are kept as livestock (MRNP 2022). According to respondents, *B. sondaicus* owners periodically visit their animals for monitoring and management.

According to internal MRNP data, the 13,778.29-ha savanna area can support forage for large herbivorous ruminants (equivalent to cattle) up to 11,676 livestock units or small herbivorous ruminants (comparable to *R. timorensis*) up to 58,379 livestock units (MRNP 2022). Assuming that the herbivorous ruminant population in MRNP consists of 70% cattle and 30% *R. timorensis* living freely side by side, the total carrying capacity under current conditions is estimated at 25,687 livestock units. However, the MRNP savanna remains insufficient to fully sustain herbivorous ruminants or other grass-eating species, such as grasshoppers. Additionally, livestock populations remain concentrated in specific areas, particularly the Sembalun Resort, while the calculated carrying capacity applies to the entire national park. Balancing wild herbivore populations with forage-livestock resources can help reduce grazing pressure and prevent grassland degradation (Yang *et al*. 2018).

Furthermore, Figure 3 shows that the strongest influences include the effects of vegetation condition (C1) and habitat carrying capacity (C3) on the land area (C4), grass use (C6), use pattern (C7), and use frequency (C8), and institutional factors(C9). Considering these data, it is evident that the grassland's carrying capacity in TNGR is insufficient to fully meet the needs of wildlife. This is because the capacity accounts for the entire national park, whereas the forage demand in just one resort is already considerably high. This situation will undoubtedly impact the grass use (C4, C 6-8). To manage this condition institutionally (C9), the strategy for grasslands management in TNGR should align with the broader concepts of environmental conservation and optimizing the utilization of the national park area. Vegetation disturbances, whether caused via fire or livestock activity, can be mitigated through fire prevention efforts and rehabilitation by planting vegetation (Afrianto *et al*. 2020).

Vegetation condition (C1) remains a variable that does not shift in the order of variables based on influence (Figure 4a) and dependence (Figure 4b) after accounting for indirect relationships. In addition to overgrazing, the risk for wildfires in grasslands also poses a threat. The biomass potential of grassland vegetation in MRNP reaches 5.7 Mg ha^{-1}, with a grass thickness of approximately 10 cm over two years (Metanda *et al*. 2025). These visualizations effectively highlight the dynamic nature of grass utilization variables, emphasizing how their relative importance fluctuates based on different analytical perspectives. The shifting rankings underscore the interconnected influence of ecological, socio-economic, and institutional factors in shaping grass utilization within MRNP.

Conclusion

The study underscores the complex interplay between ecological, social, economic, and institutional factors in sustaining traditional grazing in MRNP. Overgrazing and the increasing dependence on natural grasslands pose significant challenges to conservation efforts. The MICMAC analysis reveals the crucial factors for sustainable grass utilization in MRNP. Determinant variables significantly influence grazing practices, including vegetation cover, land area, grass use, use frequency, and use pattern. Linkage variables, such as institutional factors and demographics, highlight the importance of governance and community participation. On the other hand, autonomous variables like wildlife habitat and carrying capacity have limited interaction within the system. Effective strategies should involve community engagement, fire prevention, rehabilitation of grasslands, and controlled livestock management. A shift towards collaborative and adaptive conservation policies is essential for balancing ecological preservation with local economic needs, ensuring the long-term sustainability of grazing practices within the national park.

Declarations

List of abbreviations: MRNP-Mount Rinjani National Park; MICMAC- Matrix of Cross Impact Multiplications Applied to Classification (MICMAC), MDI-Matrix of Direct Influences; MDII- Matrices of Direct and Indirect

Ethics approval and consent to participate: This study was conducted according to the ethics guidelines of the International Society for Ethnobiology Code of Ethics All the participants provided prior informed consent before the interviews.

Consent for publication: Not applicable

Availability of data and materials: Not applicable

Competing interests: Not applicable
Funding: Not applicable
Author contributions: A.A.M., S., I.G.M., S., conducted the research idea, data collection, analysed and interpreted the data, drafted the initial manuscript. W.F.A. and N.H.A. analysed, interpreted the data, revised and improved the manuscript. All the authors read, reviewed, and approved the final version of the manuscript.

Acknowledgements
We would like to thank all the local farmers and MRNP staff who contributed to this research and shared their knowledge.

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