THE EFFECTIVENESS OF CONTROLLING METHODS FOR INVASIVE SPECIES MERREMIA PELTATA (L.) MERR. IN BUKIT BARISAN SELATAN NATIONAL PARK, LAMPUNG

Efektivitas Metode Penanganan Spesies Invasif Mantangan (Merremia peltata (L.) Merr.) di Taman Nasional Bukit Barisan Selatan, Lampung

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ABSTRACT. *Deforestation and degradation in Bukit Barisan Selatan National Park (BBSNP) have facilitated the aggressive invasion of Merremia peltata. By 2020, reports indicated that the species had infested over 8,000 hectares, significantly disrupting ecosystem dynamics. Despite various management interventions, control efforts have yielded limited success, necessitating a comprehensive evaluation of current methods. This study assesses the effectiveness of M. peltata control methods using the Analytical Hierarchy Process (AHP) and identifies strategic alternatives through A'WOT analysis. Results indicate effectiveness ratings for mechanical (46.67%), chemical (44.88%), biological (34.92%), and social (55.22%) methods. Although the social approach achieved the highest value, it remains classified as "less effective" according to the study's criteria. These findings suggest that current standalone efforts are insufficient. The analysis identifies the integration of control strategies as the primary priority, with an acquisition value of 59.7%. Consequently, optimizing control activities in BBSNP requires a multi-faceted, integrated management framework to improve ecological outcomes.*

Keywords: *Analytical hierarchy process; effectiveness; invasive species management; Merremia peltata*

ABSTRAK. Deforestasi dan degradasi di kawasan Taman Nasional Bukit Barisan Selatan (TNBBS) telah memicu invasi agresif spesies *Merremia peltata*. Hingga tahun 2020, spesies ini tercatat telah menginvasi lebih dari 8.000 hektare, yang secara signifikan mengganggu dinamika ekosistem. Meskipun berbagai intervensi manajemen telah dilakukan, upaya pengendalian tersebut belum memberikan hasil yang signifikan, sehingga diperlukan evaluasi komprehensif terhadap metode yang diterapkan. Penelitian ini bertujuan mengevaluasi efektivitas metode pengendalian *M. peltata* menggunakan Analytical Hierarchy Process (AHP) dan merumuskan alternatif strategi melalui analisis A'WOT. Hasil analisis menunjukan tingkat efektivitas metode mekanis (46,67%), kimia (44,88%), biologi (34,92%), dan sosial (55,22%). Meskipun metode sosial memperoleh nilai tertinggi, persentase tersebut masih tergolong dalam kategori "kurang efektif" berdasarkan kriteria klasifikasi dalam penelitian. Temuan ini mengindikasikan bahwa upaya parsial saat ini masih belum optimal. Prioritas utama dalam strategi pengendalian *M. peltata* yang dihasilkan adalah integrasi strategi pengendalian dengan nilai perolehan sebesar 59,7%. Dengan demikian, optimalisasi pengendalian di TNBBS memerlukan kerangka manajemen terpadu yang bersifat multifaset untuk meningkatkan kualitas pemulihan ekosistem.

Kata kunci: Analytical hierarchy process; efektivitas; pengelolaan spesies invasif; Merremia peltata

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INTRODUCTION

Bukit Barisan Selatan National Park (BBSNP), covering an area of 313,572.48 ha, possesses unique ecosystem, high biodiversity, and natural beauty. It serves as a vital habitat for protected species, notably the Sumatran Tiger (*Panthera tigris sumatrae*), Sumatran Elephant (*Elephas maximus sumatranus*), and Sumatran Rhinoceros (*Dicerorhinus sumatrensis*). Therefore, BBSNP's existence is crucial for the survival of these endangered species. In addition, in 2004, BBSNP, Kerinci Seblat National Park, and Gunung Leuser National Park were collectively designated by UNESCO as Tropical Rainforest Heritage of Sumatran World Heritage Sites. Currently, the BBSNP area's sustainability is threatened by deforestation and habitat degradation. This habitat loss has led to extensive open areas, creating another serious management

challenge “the invasion of mantangan (*Merremia peltata* (L.) Merr.)”. This native plant has become invasive due to the disturbed and damage ecosystem. Currently, *M. peltata* has invaded 2% of total BBSNP area (Master et al., 2013).

M. peltata has a considerable influence on the management of BBSNP. Its ability to grow and spread rapidly, coupled with a broad tolerance for diverse environmental conditions, allows it to quickly colonize and dominated ecosystems. *M. peltata*’s expansion is significant, having already dominated approximately 7,000 ha of the BBSNP area (Master et al., 2013). This rapid spread potentially exacerbates human-wildlife conflict. Furthermore, the uncontrolled proliferation of *M. peltata* can have several adverse ecological effects. These include modification of existing vegetation structure and species community composition, intense competition with native flora for essential resource, alternation of food chains, ecosystem functions, and the ecological interactions among local and non-local species.

Management strategies for *M. peltata* aim to mitigate its spread, thereby preventing disruption to the sustainability of ecosystem dynamics within the affected area. BBSNP has implemented several control methods for *M. peltata*. These efforts include mechanical control, which utilizes both simple tools (e.g., machetes) and heavy equipment, and chemical control, involving the application of herbicides. Furthermore, the park employs controlled utilization, repurposing the invasive species as compost, using its stems for crafts, and its leaves for animal feed. Despite these varied control efforts, the progress report on *M. peltata* management in BBSNP indicates as significant and escalating invasion. As of 2019, *M. peltata* has covered an area of 8,322 ha within the park. This spread is compounded by the species aggressive annual growth rate, estimated at approximately 20% (calculated based on the area covered in 2000). This data demonstrates the massive scale and intensity of the *M. peltata* invasion within BBSNP, highlighting the ongoing challenge faced by park authorities.

Evaluation is essential for determining whether the objectives of a program or activity have been achieved (Maksum, 2005). Controlling *M. peltata* is a complex undertaking due to its involvement of multiple stakeholders, its prolonged duration, and its substantial resource requirements. To ascertain the success rate of *M. peltata* control efforts, mitigate the risk of failure, and enhance overall success, various management action processes are necessary. One critical process is evaluating the effectiveness of *M. peltata* control methods within the BBSNP.

To date, no in-depth study or systematic evaluation of the effectiveness of *M. peltata* control methods implemented in BBSNP has been conducted. Therefore, this study evaluates the effectiveness of these control methods to determine whether the applied treatments have successfully reduced the distribution rate and suppressed the *M. peltata* population, thereby mitigating ecological disturbance within BBSNP. Furthermore, this study aims to identify the challenges and contributing factors that hinder the achievement of *M. peltata* control objectives within the park. The findings are expected to serve as a reference for developing alternative strategies to improve the management of invasive species in the area.

METHODS

Time and Location

The research was conducted from August to December 2022 in Bukit Barisan Selatan National Park, Tanggamus Regency, Lampung Province. Based on data and evaluation reports from the BBSNP management, *M. peltata* had invaded more than 8,000 hectares of the BBSNP area by 2020 (BBSNP, 2020). This invasion is distributed across several resorts, including Pemerihan, Way Haru, and Way Nipah, with the highest concentration found in the Tampang resort. A detailed visualization of the spatial distribution of *M. peltata* is presented in Figure 2. This invasion is predicted to exacerbate in the future due to climate change, a trend further compounded by a lack of serious attention and sustainable management strategies.

M. peltata suppresses the growth of underlying tree saplings by blocking sunlight from reaching the forest floor, while its aggressive vines can reach and strangle canopy trees to death. Consequently, the *M. peltata* invasion serves as a significant factor driving changes in ecosystem dynamics within the BBSNP area (BBSNP, 2013). This

finding aligns with Genovesi et al. (2015), who stated that invasive species are a primary driver of population declines in native and rare plants. In fact, in several countries, invasive species pose the second greatest threat to biodiversity, surpassed only by habitat conversion and destruction.

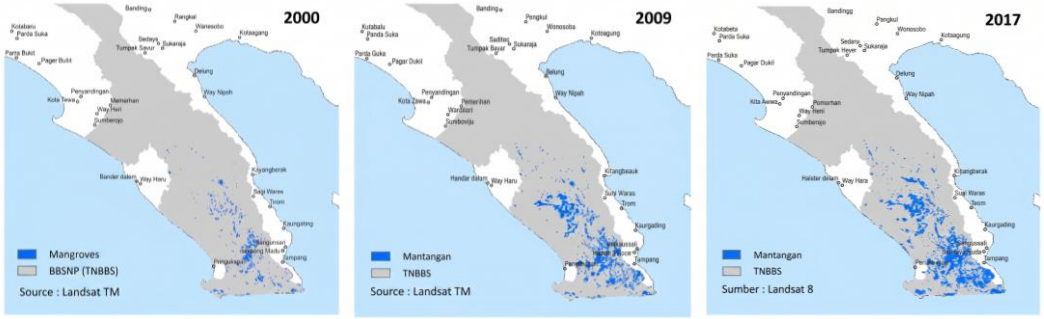

Figure 1. Spatial distribution and area expansion of *M. peltata* in BBSNP across three periods: 2000 (1,735 ha), 2009 (4,706 ha), and 2017 (7,384 ha) (Source: BBSNP, 2019b).

Based on the zoning of the National Park, the distribution of *M. peltata* spans the jungle, utilization, and rehabilitation zones. Specifically, *M. peltata* has massively invaded the Tampang, Way Haru, and Way Nipah resorts, while spreading sporadically within the Pemerihan resort. Secondary forests are widely distributed across the southern region of the National Park. A secondary forest is defined as a forest that regenerates and develops naturally following disturbances caused by natural disasters or anthropogenic activities, as well as alterations to the primary forest (Setiadi & Tjondronegoro, 1989). Chronologically, the southern region of BBSNP suffered degradation due to natural disasters, forest fires, and deforestation. These disturbances triggered the invasive behavior of *M. peltata*, allowing it to dominate the area and subsequently expand into surrounding ecosystems. If left unmanaged, the rapid growth rate of *M. peltata* poses a severe threat, potentially restricting wildlife corridors, disrupting natural habitats, and encroaching into the National Park's core zone.

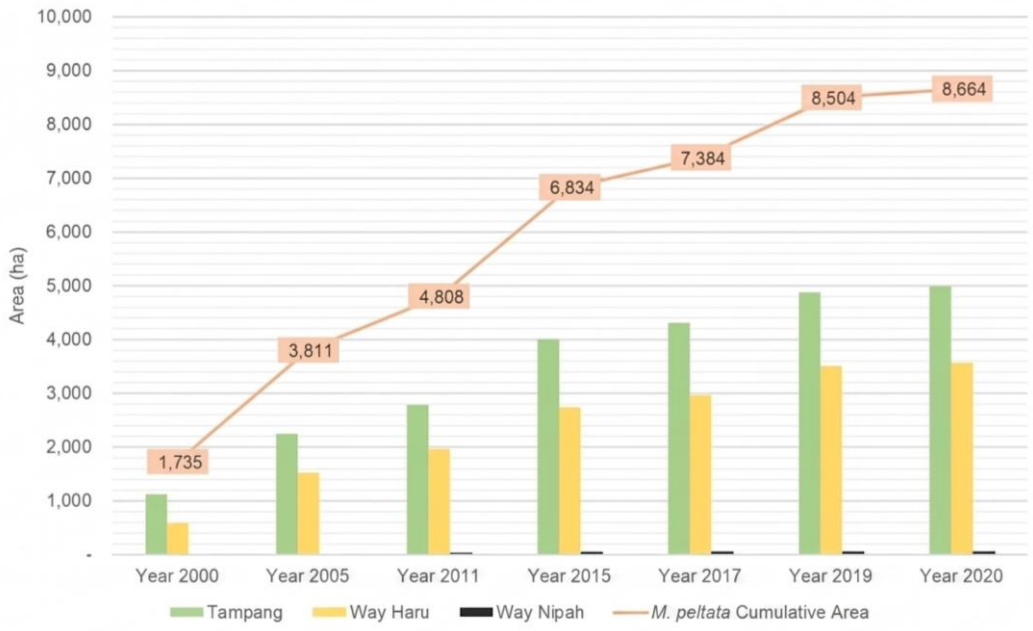

Figure 2. Graphical representation of the *M. peltata* spread rate across the Bukit Barisan Selatan National Park, specifically within the Tampang, Way Haru, and Way Nipah resorts (Source: BBSNP, 2020).

Type and Data Source

1. Primary Data

   Primary data for this study were collected directly from data source. This data primarily includes information and perceptions obtained from respondents, expert, members of the community involved in the management of *M. peltata*, and relevant stakeholders concerning *M. peltata* control within BBSNP. Additional primary data pertinent to the research topic ware also acquired.

2. Secondary Data

   Secondary data are obtained indirectly by researchers, such as from existing documents. The required secondary data include information on the research site's condition, geographical condition and rainfall, biophysical conditions, historical records of *M. peltata* control activities, and the design of future control activities.

Data Collection Methods

1. Literature Review

   A literature review was conducted to gather information on the current conditions of *M. peltata* control, the management measures that have been implemented and are planned for implementation, as well as findings from biophysical research and eradication methods previously applied to *M. peltata*. The data and information were sourced from books, peer-reviewed journals, research reports, and activity reports produced by site managers, in addition to other relevant references utilized as primary and secondary literature.

2. Interviews and Qustionnaires

   Interviews were conducted to obtain the necessary information from respondents to determine the set of criteria and indicators for the Analytical Hierarchy Process (AHP). Concurrently, questionnaires were utilized as data collection instruments, distributed to respondents to gather specific insights. In this study, the distributed AHP questionnaires evaluated the success of *M. peltata* management. These were administered to experts or key informants capable of providing comprehensive explanations regarding the issues under investigation. The informants included one academician, three managers from the BBSNP, two representatives from relevant NGOs (WCS-IP Lampung), two non-academic researchers from the National Research and Innovation Agency (BRIN), and two field assistants/local community members (members of the Forest Police Partner Community/MMP and Forest Farmer Groups/KTH) involved in *M. peltata* management within the area. The selected informants were representative and deeply knowledgeable about the research problem, thereby ensuring the accuracy and objectivity of the interview data.

3. Observation

   Observation is a data collection method involving the direct examination of the subject under study at the designated field or research site. This approach was employed to obtain data that could not be acquired through interviews or questionnaire administration.

Data Analysis Methods

Data analysis methods are adapted to the research objectives. These methods include; AHP (Analytical Hierarchy Process) and A'WOT (SWOT and AHP integration). More detailed data analysis methods are presented in Table 1.

Table 1. Data Analysis Methods

Objective	Variable	Analysis method	Output of analysis
Evaluation of the effectiveness of *M. peltata* control	Objectives, criteria, sub criteria, verifier	AHP	The level of effectiveness
The direction of the control strategy *M. peltata*	Objectives, criteria, sub-criteria, alternatives	A'WOT	Alternative strategies

1. AHP (Analytical Hierarchy Process)

AHP is a decision support model developed by Thomas L. Saaty. This model will describe complex multi-factor or multi-criteria problems into a hierarchy. According to Saaty (1988), hierarchy is defined as a representation of a complex problem in a multi-level structure where the first level is the goal/focus, followed by the level of factors, criteria, sub criteria, indicators and so on down to the last level.

According to (Marimin, 2004), the assessment scale of criteria and indicators is based on expert assessment using the pairwise comparison method developed by Thomas L. Saaty. The pairwise comparison rating scale is as presented in Table 2. The stages of data analysis using AHP are as follows:

a. Hierarchical arrangement
Arrange hierarchy according to the purpose/focus of controlling *M. peltata*, then describe in criteria and indicators as and verifiers.
b. Establishment of criteria and indicators
Establish criteria and indicators with several considerations, such as simple to understand, accountability, ease of obtaining data and adequate data quality.
c. Validation of set of criteria and indicators
The set of criteria and indicators that have been established are verified and validated by experts, so that they become the right tools for evaluating.
d. Pairwise comparisons
Pairwise comparisons were carried out by distributing AHP questionnaires to informants, namely experts and stakeholders. The pairwise comparison rating scale can be seen in Table 2.

Table 2. Pairwise comparison rating scale

Scale	Description
1	Both elements are equally important
3	One element is slightly more important than the other elements
5	One element is more important than the other elements
7	One element is clearly more important than the other elements
9	One element is absolutely important than the other elements
2,4,6,8	The value between two adjacent consideration values
Reciprocal	If one of the numbers above belongs to the element *i* when compared to elements *j,* then element *j* will have the opposite When compared to elements *i*

e. Synthesis
Processing the data obtained from pairwise comparisons, so that the weights of the criteria and indicator sets are obtained.
f. Consistency index calculation
Calculate the Consistency Index (CI) by using the following formula:

$$\mathrm{CI} = \frac{(\lambda \max - \mathrm{n})}{(\mathrm{n} - 1)}$$

Information: n = the number of elements
The weights obtained from the results of pairwise comparisons must be consistent, indicated by a CI <10% (Mendoza & Macoun, 1999).
g. Scoring for each indicator and calculation of total score evaluation of the effectiveness of *M. peltata* controlling methods
The scoring process is carried out in stages starting from calculating the score of each indicator, criterion, to the total score of the research object (Jatmiko et al., 2014) with the following formula:

$$\mathbf{R} = \sum_{i=1}^{n} (X_i . B_i) \dots\dots\dots\dots\dots\dots\dots (1)$$

Information:
R : Score on each indicator
X_i : Score on gauge i
B_i : Measuring weight i

$$V_i = \left[\sum_{i=1}^{n} (X_i . B_i)\right] \times BV_i \dots\dots\dots\dots\dots\dots\dots (2)$$

Information:
Vi : Score on each criterion
BV_i : Indicator weight

$$\mathbf{K} = \sum_{i=1}^{n} V_i \dots\dots\dots\dots\dots\dots\dots (3)$$

Information: K: Score on the criteria

h. Convert AHP scores into percentages

The total score for the effectiveness of the *M. peltata* controlling method is then

converted into a percentage by comparing the value of the score vector of the assessment results with the maximum score vector value that can be achieved, then multiplied by one hundred percent and given a predicate according to the percentage value. The percentage classes and predicates of the effectiveness of controlling *M. peltata* in more detail are presented in Table 3.

Table 3. Percentage class and predicate of effectiveness of controlling *M. peltata*

Class percentage	Predicate
< 33%	Inadequate (ineffective) management
33% – 67 %	Management is inadequate (less effective)
> 67%	Fairly good management (effective)

2. A'WOT (SWOT and AHP Integration)

AHP is one of the most widely used multi-criteria analysis methods and has been used successfully in conjunction with SWOT analysis. AHP requires decision-makers to perform a series of comparisons of factors and assign a rating representing each decision. This decision reflects the decision maker's perception of the relative importance of the factors. According to Margles et al. (2010), when AHP is used to compare factors resulting from a SWOT analysis, researchers can identify and quantitatively prioritize the most significant strengths, weaknesses, opportunities, and threats related to the action plan.

Filbert et al. (2018) stated that the systematic stages in using the A'WOT method are divided into the SWOT stage and the AHP stage. At the stage in the SWOT method, it is carried out:

a. Collect and analyze all data;
b. Analyze data by comparing internal factors (strengths and weaknesses) and external factors (opportunities and threats);
c. Formulate strategies that can be used to improve the effectiveness of controlling *M. peltata*.

After identifying internal and external factors with the SWOT method, Furthermore, it is necessary to identify priorities from various alternative strategies that can be used to improve the controlling of *M. peltata* with the AHP method. The steps taken are:

a. Preparation of hierarchies or alternatives of each internal and external factor;
b. The weighting of criteria (with the help of paired comparison rating scale tables);
c. Calculation of the weight of criteria and alternatives;
d. Priority strategy determination.

RESULT AND DISCUSSION

History of M. peltata Controlling in BBSNP

Control of *M. peltata* within BBSNP has primarily occurred in rehabilitation zones across the Tampang, Way Haru, Way Nipah, and Pemerihan resorts. Initial treatment commenced in 2005 at the Tampang Resort, which presented the largest invasion area. However, subsequent BBSNP report indicate that this area has since been re-invaded. According to Subiakto et al. (2016), managing widespread *M. peltata* invasions is notably challenging due the substantial resource investment and the requirement for consistent, long-term control measures. Consequently, current control effort is concentrated on newly invaded areas to prevent the further geographical expansion of *M. peltata*. Control methods implemented in BBSNP include mechanical, chemical, biological, and social methods.

Figure 3. (a) Invasion of *M. peltata* at Tampang Resort before July 2008; (b) Tampang Resort after mechanical eradication in July 2008; (c) Post-intervention evaluation results as of July 2009. (Source: BBSNP, 2012)

Mechanical control methods, including manual slashing with machetes and the deployment of heavy machinery such as bulldozers, were employed to manage *M. peltata* infestations in 2008 by PT. AKN (Adhiniaga Kreasinusa). However, these efforts achieved only 20% of the targeted clearance area (BBSNP, 2012). By 2009, all previously cleared areas had reportedly been re-invaded, a condition that has persisted to the present day (see Figure 3). Subsequent eradication and control measures have been primarily directed toward newly invaded areas in order to mitigate the further spread of *M. peltata* (Subiakto et al., 2016). Based on current methodologies, complete eradication of *M. peltata* from its existing range is projected to require until 2075; however, this estimate does not account for potential re-establishment or further dispersal into new territories.

The limitations of these methods arise from several key factors, most notably the rapid regenerative capacity of *M. peltata* and the propensity of stem cuttings to re-establish growth. Although mechanical eradication using heavy machinery such as bulldozers effectively removes the species down to the root system, this process causes considerable disruption to soil structure. Such disturbances frequently facilitate the establishment of other invasive species, including *Lantana camara*, *Clidemia hirta*, and *Imperata cylindrica* (BBSNP, 2013), and result in the inadvertent uprooting and mortality of native tree saplings. Consequently, the application of mechanical methods without concurrent reforestation efforts yields only temporary control, as *M. peltata* rapidly recolonizes and spreads across open, unshaded areas.

Chemical methods have been employed in BBSNP since 2005. Two herbicides have been used to control *M. peltata*. The systemic herbicides Lindomin 865 SL and Starlon 665 EC, both containing the active ingredient triclopyr BEE, which functions by inhibiting plant growth hormones, are applied by foliar spraying (BBSNP, 2019b). Another herbicide, Garlon 480 EC, diluted in diesel fuel, was applied topically to the stems and leaves of *M. peltata* (BBSNP, 2019b). Garlon 480 EC has demonstrated sufficient effectiveness in suppressing the growth rate of *M. peltata* (BBSNP, 2019c).

Although herbicide application has proven relatively effective, chemical control carries a significant drawback: it can contaminate the soil and, with prolonged use, may induce herbicide resistance in *M. peltata*. This concern aligns with the findings of Aditiya (2021), who reported that the prolonged use of chemical herbicides poses a substantial

threat to forest ecosystems. Given that *M. peltata* is a native species that has transitioned to an invasive status, the most ecologically appropriate management strategy would involve the identification of biological control agents; however, no such natural enemies have been identified to date.

Biological control measures implemented by the management team involved the introduction of plant species suspected to function as natural enemies of *M. peltata*. In 2013, park managers introduced tepusan (*Etlingera coccinea*) across a 2-ha invasion area with the aim of suppressing the spread of *M. peltata*. However, monitoring and evaluation data subsequently obtained by BBSNP revealed that approximately two years following the implementation of these biological control measures, nearly the entire treated area had been re-invaded (BBSNP, 2013). To date, research investigating the natural enemies of *M. peltata* remains scarce; consequently, biological control efforts have yet to be optimized.

Social management methods implemented at BBSNP include the establishment of KTH, which is expected to align with the conservation partnership policy. These methods are designed to achieve the goal of fostering active and independent community involvement in efforts to control *M. peltata*. Social management activities in the context of *M. peltata* management include eradication in invaded areas, accompanied by ecosystem restoration efforts. Various parts of the *M. peltata* plant are utilized as compost and animal feed, while the stems are used for handicrafts (BBSNP, 2019a).

The nutrient content of *M. peltata* compost includes nitrogen (N) ranging from 1.24% to 1.71%, phosphorus (P) from 76.45 to 231.94 mg/kg, potassium (K) from 2.00% to 2.38%, and organic carbon (C-organic) from 53.28% to 53.56% (Santori et al., 2021); these values are notably higher than those reported for conventional legume cover crops (LCC). Furthermore, *M. peltata* possesses a protein content of 9.70% and an energy content of 4,087 calories, surpassing the levels found in field grasses such as Paspalum conjugatum (8.85%) and Panicum repens (7.54%) (Garsetiasih et al., 2019). Consequently, *M. peltata* demonstrates significant potential as a source of organic fertilizer and as an alternative livestock feed.

Figure 4. Utilization *M. peltata* as crafts, compost and animal feed. (Source: BBSNP, 2019a)

Evaluating the Effectiveness of Management Methods for M. peltata in BBSNP

Defining Criteria and Indicators

The establishment of criteria and indicators was driven by the primary objectives of *M. peltata* management: mitigating its dispersal rate to prevent interference with ecosystem dynamics and maintaining or enhancing forest ecosystem functions. Consequently, several criteria and indicators were selected to align with these objectives, following the management cycle approach established by the World Commission on Protected Areas (WCPA) (Hockings et al., 2006).

This study limits the assessment of *M. peltata* management effectiveness to the output stage, as suggested by Hockings. Accordingly, the criteria considered include planning, inputs, processes, and outputs. These criteria were further operationalized into specific indicators, collectively referred to as the criteria and indicator set.

The development of these criteria and indicators was informed by a comprehensive literature review of scientific journals, planning documents, and activity reports. Furthermore, technical input was sought from invasive species experts and park managers. The complete set of criteria, indicators, and their respective verifiers for assessing management effectiveness is detailed in Table 4.

Table 4. A framework of criteria and indicators for evaluating the effectiveness of *M. peltata* management

C	Indicator	Verifier
1.	**Planning**	
a.	Action Plan for Mitigation	• Development of action plans aligned with management objectives. • Engagement of multiple stakeholders, including local governments, universities, communities, and NGOs. • Inclusion of diverse programs concerning pollution control, ecosystem restoration, monitoring, and evaluation. • Dissemination of information to all relevant parties.
b.	Operational Mitigation Plan	• Implementation of *M. peltata* management activities in strict accordance with the established action plan. • Alignment and strategic coordination with all relevant stakeholders. • Comprehensive documentation of operational details, including geographical location, chronological framework, implementation protocols, funding sources, and designated executing parties.
c.	Preliminary Mitigation Design	The primary design for managing *M. peltata* has met its objectives and possesses the requisite foundational documentation (including location, distribution area, and other relevant data)
2.	**Input**	
a.	Human Resources	• The availability and structural composition of specialized personnel are adequate to meet institutional requirements • Stakeholders and personnel possess a comprehensive understanding of their respective roles, responsibilities, and functions. • The capacity and professional quality of skilled personnel align with the requisite institutional qualifications.
b.	Budgetary Allocation	• Budgetary certainty: Dedicated funding streams, both from state (APBN) and non-state (non-APBN) sources, are routinely allocated for *M. peltata* management. • Diversified funding: Financial resilience is bolstered by external partnerships, such as CSR initiatives, grants, and donor-funded programs. • Operational sustainability: Long-term financial provisions are adequate to maintain consistent and stable eradication and control efforts.
c.	Infrastructure and Facilities	• Procurement of Infrastructure: The acquisition of both mobile and fixed infrastructure was conducted to facilitate the management of *M. peltata*. • Operational Requirements: All logistical requirements for the management of *M. peltata* were fulfilled in accordance with the specific methodologies employed. • Maintenance Protocols: Routine and periodic maintenance of the infrastructure used for *M. peltata* management was performed to ensure continued operational efficiency.
d.	Management Data	• Integrated Data Management: All data and information pertaining to the management of *M. peltata* are documented within a centralized and integrated database system (e.g., spreadsheet-based, web-based, or formal reports). • Comprehensive Informational Support: Comprehensive data regarding regional conditions and ecological processes including ecological, socioeconomic, and biophysical metrics of invaded areas, alongside sociocultural data, distribution maps, activity evaluations, infrastructure inventories, and invasion history are sufficient to support all strategic planning and decision-making processes for *M. peltata* management.

		• Systematic Data Synchronization: Data updates are conducted systematically and periodically, informed by surveys, identification, inventories, and routine consultations, as well as comprehensive, integrated research findings tailored to management requirements.
3.	**Process**	
	a. Stakeholders, Budgetary Allocation, and Data Management	• The management team conducts routine coordination for the mitigation of *M. peltata* through monthly meetings, informal communication channels, and other collaborative platforms. • Budgetary allocations are aligned with the priorities outlined in the action plan. For instance, while the initial plan designated approximately 200 hectares in the Pemerihan resort for *M. peltata* management, the budget for the current fiscal year prioritized an initial phase of 20 hectares. • Data are readily accessible, structured, and integrated within a centralized database. Furthermore, these data have been processed into actionable information to support management interventions.
	b. Control Mechanisms	• Standardization and Compliance: The implementation of control methods was conducted in accordance with field conditions and established Standard Operating Procedures (SOPs). • Stakeholder Engagement: Control measures were executed through a collaborative framework involving local communities as primary actors, management as supervisors and coordinators, and external partners as providers of necessary facilities and infrastructure. • Inter-organizational Communication: Active and effective communication channels were maintained among management, community members, and partners throughout the execution of control activities. • Operational Consistency: The control of *M. peltata* was carried out through a combination of routine, scheduled, and incidental interventions to ensure long-term sustainability.
	c. Monitoring and Evaluation (M&E)	Systematic monitoring and evaluation are ensured through routine management audits, spanning the entire operational phase and subsequent environmental follow-ups.
	d. Ecosystem Restoration	• Ecological Restoration: The management of *M. peltata* encompasses ecosystem recovery efforts, specifically through the planting or enrichment of indigenous species and their subsequent maintenance. • Stakeholder Engagement: Restoration initiatives involve the strategic collaboration of relevant government agencies, local communities, and institutional partners. • Operational Framework: The restoration program is defined by a detailed operational plan, comprising routine, scheduled, and incident-based (ad hoc) activities.
4.	**Output**	
	a. Ecological	• The eradication of *M. peltata* within the designated target areas was successfully achieved. • Management interventions effectively suppressed the regeneration rate of *M. peltata* across the specified sites. • No regrowth of *M. peltata* was observed within the ecosystem recovery zones during the monitoring period. • Ecosystem health improved significantly, evidenced by increased floral diversity within the restored sites previously invaded by *M. peltata.*

	b. Social	• Enhanced public awareness regarding the importance of habitat conservation (specifically the prevention of deforestation) serves to mitigate the expansion rate of *M. peltata.* • There is a growing communal awareness concerning site preservation and the identification of anthropogenic triggers for *M. peltata* dispersal, leading to active voluntary participation in control initiatives. • The cultivation of public trust and the spirit of communal cooperation have been instrumental in the successful implementation of these activities.
	c. Economic	Participants involved in the management of *M. peltata* receive formal remuneration, which includes wages and economic development through community empowerment and mentoring programs, ultimately leading to an increase in household income.

Information: C = Criteria

Results of the Effectiveness Assessment of M. peltata Control Methods in BBSNP

The effectiveness of *M. peltata* control methods was evaluated by establishing criteria and indicators aligned with the primary objective of controlling *M. peltata* in BBSNP namely, reducing its rate of spread. To achieve this objective, four criteria were considered: planning, input, process, and output. Each criterion was subsequently operationalized into specific indicators, collectively referred to as the criteria and indicator framework. This framework was then applied to assess the effectiveness of each control method employed in BBSNP. The methods evaluated in this study include mechanical, chemical, biological, and social control approaches.

Table 5. Weighting criteria and indicators of control effectiveness of *M. Peltata*

C	Indicator	Weight
1.	Planning	**0.094**
	a. Action Plan for Mitigation	0.405
	b. Operational Mitigation Plan	0.150
	c. Preliminary Mitigation Design	0.445
2.	Input	**0.340**
	a. Human Resources	0.251
	b. Budgetary Allocation	0.550
	c. Infrastructure and Facilities	0.120
	d. Management Data	0.080
3.	Process	**0.420**
	a. Stakeholders, Budgetary Allocation, and Data Management	0.320
	b. Control Mechanisms	0.486
	c. Monitoring and Evaluation	0.107
	d. Ecosystem Restoration	0.088
4.	Output	**0.146**
	a. Ecological	0.714
	b. Social	0.188
	c. Economic	0.098

C: Criteria

The criteria and indicators used as measurement tools in assessing the effectiveness of *M. peltata* control vary in their relative importance, as reflected by the assigned weights of each criterion and indicator. Based on calculations performed using the Analytic Hierarchy Process (AHP) method, the weight of each criterion is presented in Table 5.

As shown in Table 5, the process criterion received the highest weight (0.420), followed by the input, output, and planning criteria, respectively. These weight values indicate that the process and input criteria contribute most substantially to the overall assessment of *M. peltata* control effectiveness in BBSNP.

The process criterion carries the highest weight because it represents the operational phase where all resources (human, financial, and infrastructural) are actively deployed through specific control methods, rigorous monitoring, and intensive ecosystem restoration. The success or failure of *M. peltata* management in BBSNP is largely determined by the execution quality of this phase. Substantively, the process criterion acts as the primary linkage transforming planning and resources into tangible ecological outputs. Because *M. peltata* is characterized by rapid growth and high regenerative capacity, it demands consistent, routine, and sustained control mechanisms. Under this criterion, management effectiveness is measured by the precision of field methods, the integration of databases in decision-making, and seamless communication among stakeholders. Furthermore, indicators for ecosystem recovery and post-control monitoring ensure that cleared areas are not re-invaded, but rather directed toward natural ecological succession within the BBSNP area. Consequently, the process criterion is heavily weighted because it serves as the critical stage for directly testing, evaluating, and adapting intervention strategies to maintain forest ecosystem stability.

Table 6. Scoring results of each indicator of *M. peltata* controlling methods

C	Indicator	Score			
		Mechanical	Chemical	Biological	Social
1.	Planning				
	a. Action Plan for Mitigation	4	4	3	4
	b. Operational Mitigation Plan	4	3	3	4
	c. Preliminary Mitigation Design	2	2	2	3
2.	Input				
	a. Human Resources	3	3	2	3
	b. Budgetary Allocation	2	2	2	2
	c. Infrastructure and Facilities	2	2	2	2
	d. Management Data	2	2	2	2
3.	Process				
	a. Stakeholders, Budgetary Allocation, and Data Management	2	2	2	2
	b. Control Mechanisms	3	3	2	3
	c. Monitoring and Evaluation	2	2	2	3
	d. Ecosystem Restoration	3	2	3	3
4.	Output				
	a. Ecological	1	1	1	2
	b. Social	3	3	3	4
	c. Economic	2	2	1	3

C: Criteria

The analysis of effectiveness levels using the Analytic Hierarchy Process (AHP) across four control methods for *M. peltata* revealed that the social method achieved the highest score of 55.22%. Nevertheless, based on the classification percentage and predicate criteria adopted in this study, all four methods mechanical, chemical, biological, and social were categorized as less effective in controlling *M. peltata* within BBSNP. These findings are presented graphically in Figure 5.

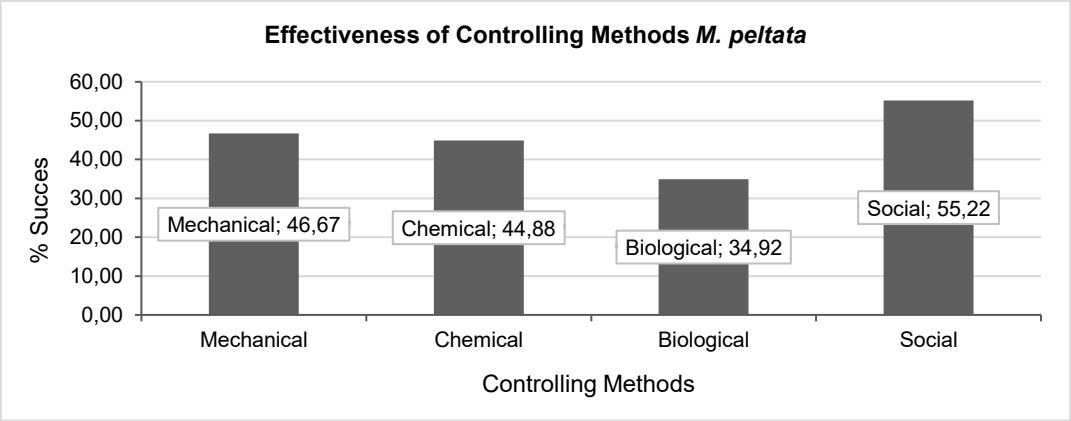

Figure 5. Diagram of the results of assessing the effectiveness of *M. peltata* controlling methods in BBSNP

These conditions indicate that controlling *M. peltata* using these methods is not optimal; therefore, further efforts are needed to improve or optimize the control of *M. peltata*. Future efforts to optimize the control of *M. peltata* that can be implemented for each criterion are as follows:

1. Planning

Planning is a criterion that can be fulfilled through various methods of controlling *M. peltata* in BBSNP. However, the primary challenge remains the absence of fundamental documents required to develop a comprehensive plan for *M. peltata* control activities. To address this issue, evaluative data from these activities must be updated and integrated into a centralized database, ensuring streamlined access for the management and control of *M. peltata*.

2. Input

Input refers to all resources required to execute planned activities. Based on a review of input criteria, the primary challenge identified relates to budgetary constraints, particularly the annual changes in the budgeting mechanism, which disrupt planning at the UPT level and result in insufficient funds to conduct routine and sustainable control activities. Considering current conditions, there remains a possibility that the long-term objective of controlling *M. peltata* specifically, suppressing its population growth and reducing its rate of spread within BBSNP may be achieved, provided that adequate funding is secured and control efforts are implemented consistently over a minimum of five consecutive years.

Beyond budgetary constraints, there is a critical need to address the limited availability of skilled human resources with adequate competency in identifying, understanding, and managing *M. peltata* in field settings. Capacity-building efforts, particularly through structured training programs, are essential to develop competent personnel equipped with strong managerial skills and the ability to assess field conditions effectively, especially in the context of *M. peltata* control and management operations.

3. Process

Regarding process criteria, the implementation of control mechanisms warrants particular attention. The findings revealed that control mechanisms including eradication efforts, post-eradication monitoring and evaluation had not been conducted routinely or sustainably. Furthermore, ecosystem restoration activities in post-eradication areas had not been implemented optimally. To enhance the effectiveness of control activities, several measures are recommended: allocating adequate resources, developing comprehensive and systematically structured activity plans, and maintaining institutional commitment to executing the full range of control processes in an optimal manner.

The use of heavy machinery for land clearing through mechanical eradication poses significant negative impacts on soil structure and the surrounding environment; therefore, the deployment of heavy equipment for controlling *M. peltata* within BBSNP is not advisable. Similarly, the use of machetes in mechanical control methods proves insufficient for complete eradication, as it fails to eliminate the root system of *M. peltata*. An alternative approach to address these limitations involves integrating mechanical and chemical methods:

selectively removing *M. peltata* vines through manual cutting, followed by targeted herbicide application to the remaining stumps to prevent regeneration.

4. Output

The output criteria for the management of *M. peltata* were assessed based on three primary indicators: ecological, social, and economic conditions. The ecological condition represents a critical dimension of these management activities, aligning with the fundamental management objective of controlling *M. peltata* populations to maintain regional ecosystem dynamics. Consequently, ecological indicators serve as the primary benchmark for evaluating intervention effectiveness. Evaluations based on these indicators reveal that socially-based management interventions successfully suppressed regeneration rates and eradicated *M. peltata* within designated target sites. However, these methods did not achieve total extirpation of the population. The species persisted within the target areas even following ecosystem restoration efforts involving the planting of pioneer and climax species.

Based on social indicators, the social method achieved the maximum score (3), outperforming alternative approaches. This score indicates that the implementation of social interventions significantly enhanced community knowledge, awareness, and trust regarding the importance of regional conservation, particularly concerning the drivers of *M. peltata* dispersal. Furthermore, this method successfully fostered active community participation and collective action, establishing local residents as primary actors directly involved in management activities. In contrast, while mechanical, chemical, and biological methods increased public awareness of the threats posed by *M. peltata*, the level of conscious community participation in these interventions remained suboptimal.

From the perspective of economic indicators, the social method achieved the maximum score, suggesting a significant contribution to local economic welfare. This contribution is realized through direct labor wages for community members involved in mitigation activities such as clearing and spraying as well as through income enhancement via business development assistance, mentoring, and conservation-based partnership empowerment. Furthermore, the implementation of the social method catalyzed the formation of Forest Farmer Groups (KTH). These groups do not only function to control *M. peltata* within the target areas but also valorize the cleared biomass into economically viable products, including compost and handicrafts. Consequently, *M. peltata*, initially an invasive and detrimental species, has been successfully transformed into a resource that augments community income.

The output criteria for managing *M. peltata* in BBSNP across various implemented control methods have not yet demonstrated adequate effectiveness in suppressing its spread rate. This inefficiency stems from two primary factors: first, management activities have not been conducted routinely or sustainably; and second, current control capacities remain insufficient to offset the rapid regeneration rate of *M. peltata*. Empirical evidence of this condition is reflected in the annually recorded expansion of its distribution. Consequently, it can be concluded that existing control measures are inadequate, and this invasive species continues to proliferate within the BBSNP area.

Alternative Strategies in Controlling M. peltata in BBSNP

The Management Status and Institutional Framework for M. peltata Control in BBSNP

Currently, *M. peltata* has invaded approximately 8,000 hectares within the BBSNP (BBSNP, 2019e). The highest distribution density is concentrated in the Tampang, Way Haru, and Way Nipah resorts. In these areas, the infestation is considered massive, leading to the formation of homogeneous landscapes. While *M. peltata* has also spread to other locations, such as the Pemerihan resort, its occurrence there remains limited or sporadic.

Based on the zoning within BBSNP, *M. peltata* infestations are distributed across the wilderness, utilization, and rehabilitation zones in the Tampang, Way Nipah, Way Haru, and Pemerihan resorts. Given that this expansion has reached the wilderness zone, the management of *M. peltata* requires urgent attention. Failure to implement rigorous control measures may allow the invasion to extend into the National Park's core zone. Such an escalation would significantly jeopardize ecosystem dynamics

and disrupt the habitats of key and protected species within the area.

Currently, management efforts for *M. peltata* are conducted within rehabilitation zones, focusing on new areas where its distribution remains sporadic. This strategic containment aims to prevent further expansion into unaffected regions. Furthermore, managing *M. peltata* in newly invaded sites requires significantly fewer resources than addressing massive infestations. This approach aligns with Subiakto et al. (2016), who assert that controlling *M. peltata* is most effective when initiated in newly invaded areas to impede the expansion of the invasion front. Several management strategies have been implemented, including mechanical methods: manual clearing using machetes and the deployment of heavy equipment, chemical methods: Herbicide application via spraying, biological methods: the introduction of suspected natural enemies, though it should be noted that these biological controls are currently limited to pilot projects, social methods: research-based utilization and social management frameworks.

Experts argue that existing control efforts have been insufficient in reducing the distribution of *M. peltata* within the region due to systemic management weaknesses. These deficiencies include:

1. Resource Constraints: There is a significant lack of human resources, infrastructure, and dedicated funding for *M. peltata* management. Currently, there is no routine allocation within the State Budget (APBN), resulting in sporadic control efforts that are entirely dependent on incidental budget availability.
2. Insufficient Research: There is a dearth of empirical studies to serve as a benchmark for achieving management effectiveness or for exploring potential utilization opportunities of the species.
3. Low Stakeholder Engagement: Participation and awareness among relevant stakeholders regarding the urgency of *M. peltata* containment remain inadequate.
4. Restrictive Regulatory Frameworks: Existing policies and legislation do not sufficiently support management initiatives, particularly concerning "controlled utilization" as a strategy to reduce population density.
5. Information Gaps: There is a lack of publically accessible data and information regarding *M. peltata*, compounded by the absence of a centralized database to track management progress and outcomes.

Based on the evaluation of several management methods for *M. peltata*, social methods demonstrate significant potential for implementation in BBSNP. This potential is driven by the intrinsic utility of *M. peltata* and the role of local communities as primary actors. Regarding its utilitarian value, extensive research has examined the chemical constituents of *M. peltata* for medicinal applications. Specifically, the species shows potential as a treatment for alopecia (Abdurrahman et al., 2023; 2022) and cancer particularly breast cancer (Alen et al., 2016), while also serving as a topical treatment for wounds, skin diseases (Mulatasih & Ardini, 2024), diabetes mellitus (Afidah et al., 2021), and diarrhea (Ilham, 2019). Furthermore, studies indicate that *M. peltata* possesses high nutrient content relative to leguminous cover crops (Amalia et al., 2024)(Santori et al., 2021), suggesting its viability as a source of organic fertilizer. The species also contains substantial protein (9.70%) and energy (4,087 calories), making it a potential alternative for livestock feed (Garsetiasih et al., 2019), while its stems can be utilized in handicrafts such as basket weaving (BBSNP, 2019d). These findings suggest that *M. peltata* offers diverse economic opportunities if managed effectively. Consequently, given these significant benefits, controlling *M. peltata* through socio-economic methods is a promising strategy. Management activities are more likely to succeed when local communities derive tangible benefits, leading to conscious and active participation. Therefore, a management strategy based on research-driven utilization and social governance should be developed in collaboration with mechanical and chemical methods. Such an integrated approach requires strong commitment from managers and stakeholders to optimize the control of *M. peltata* in BBSNP.

Given the status of the area as a National Park, utilizing plant resources sourced directly from within the region is challenging. The extraction of flora from forest areas, particularly conservation zones, is subject to

stringent licensing and regulatory frameworks. This challenge is further compounded by the status of *M. peltata* as an invasive species; there are significant concerns that its utilization could inadvertently accelerate its dispersal. However, should utilization proceed, it must be implemented under strict control measures aligned with management objectives specifically, population suppression. Consequently, as the managing authority, BBSNP is obligated to oversee and monitor any utilization of *M. peltata* originating from within the park boundaries.

The management of *M. peltata* in BBSNP involves a diverse range of stakeholders, including WCS-IP, WWF Indonesia, the Indonesian Rhino Foundation (YABI), the Indonesian Environmental Information Center (PILI), PT. Adiniaga Kreasinusa, Repong Indonesia, the GEF-UNDP Sumatran Tiger Project, and local community groups. Each entity plays a distinct role in these control efforts. Given the current status of *M. peltata* within the park, the rate of dispersal is accelerating and is projected to worsen in the absence of a unified management framework. Consequently, it is imperative for the BBSNP Authority to strengthen its leadership in coordinating control initiatives and their implementation, particularly regarding the strategic allocation of budgetary resources.

Strategic Policy Priorities for the Management of M. Peltata

The hierarchical structure for controlling *M. peltata* in BBSNP comprises four levels: objectives, criteria, sub-criteria, and alternatives. The objective is defined as reducing the rate of spread of *M. peltata*. The criteria are evaluated through a SWOT framework encompassing strengths, weaknesses, opportunities, and threats. The sub-criteria include the importance value of the area, the existence value of BBSNP, resource allocation, coordination of management institutions, community awareness in surrounding areas, the potential utilization of *M. peltata*, research attention from universities and non-governmental organizations (NGOs), potential corporate social responsibility (CSR) funds to support management, damage to forest ecosystems, and land use needs. Finally, the proposed alternatives consist of the integration of control strategies, strengthening of management institutions, and enhanced cooperation and coordination among relevant stakeholders. Further details are presented in Figure 6.

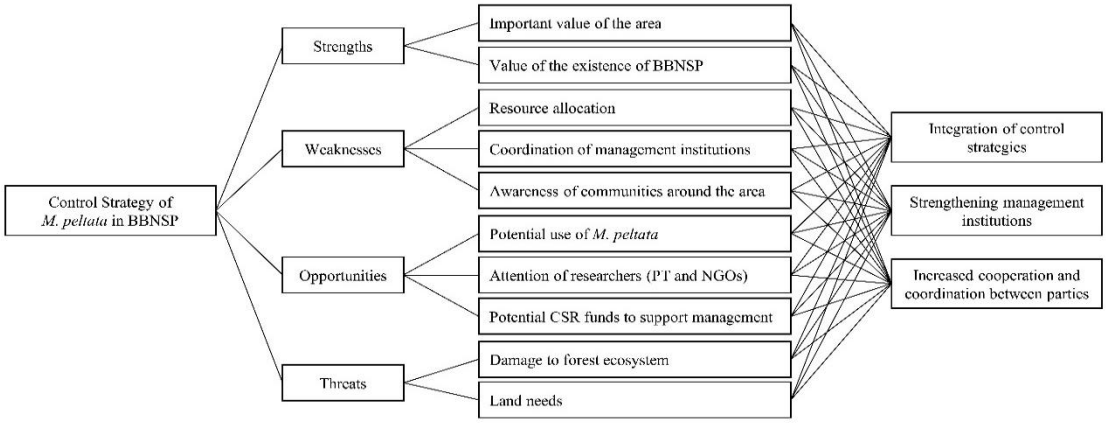

Figure 6. The hierarchical structure of *M. peltata* controlling strategy in BBSNP

Table 7. Alternative controlling policies *M. peltata* sustainable in BBSNP

Policy Alternative	Value	Decision Value
Integration of Control Strategy	0,597	
Strengthening Management Institutions	0,281	
Increasing Cooperation and Coordination Between Parties	0,122	
Consistency Rasio (CR)		0,03

Based on the A'WOT analysis results, three strategic alternatives were identified and ranked by priority: Alternative I, the integration of control strategies, received the highest weight (59.7%), followed by Alternative II, the strengthening of management institutions (28.1%), and Alternative III, the enhancement of cooperation and coordination among stakeholders (12.2%). The validity of the analysis is supported by a consistency ratio of 0.03, which falls below the acceptable threshold of 0.1 (10%). As established by Saaty (1988), a pairwise comparison matrix is considered acceptable when the consistency ratio is less than 0.1. The detailed results are presented in Table 7.

The primary policy alternative proposed is the integration of control strategies. The second policy alternative involves strengthening management institutions, which would provide clarity in the management and control of *M. peltata*, ensure the effective implementation of various program activities, and establish rules and policies that are mutually harmonized to prevent overlapping interests and programs. Enhancing cooperation and coordination among relevant stakeholders serves as a supporting policy for achieving the sustainable control of *M. peltata* in BBSNP.

The integration of control strategies represents an approach to managing *M. peltata* by combining multiple control methods, thereby allowing the limitations of any single method to be offset by the strengths of others. Furthermore, integration in this context encompasses the coordinated involvement of managers, surrounding communities, and relevant stakeholders in the holistic management of *M. peltata*, with the overarching goal of reducing its rate of spread and preventing its adverse effects on the sustainability of ecosystem dynamics within the affected area.

An integrated control strategy may be implemented through the following measures: (1) updating ecological, social, and economic data through routine monitoring; (2) developing detailed work plans based on updated data, particularly to address pressures and threats arising from the presence of *M. peltata*; (3) establishing comprehensive technical and operational guidelines for management activities, including mechanisms for control, monitoring, evaluation, and ecosystem recovery; (4) coordinating efforts among managers, relevant parties, local governments, and communities to implement control measures and restore ecosystems invaded by *M. peltata*; (5) engaging surrounding communities as primary actors through empowerment initiatives in areas affected by *M. peltata* invasion; (6) conducting outreach programs and educational guidance for local communities; (7) strengthening existing institutions and fostering community organization; and (8) integrating or combining multiple control methods (mechanical, chemical, biological, and social) within a unified management activity. As an illustration, social control strategies for *M. peltata*, comprising research-driven utilization and community-based management, can be synthesized with mechanical and chemical methods. Furthermore, achieving optimal control of *M. peltata* in BBSNP requires a strong commitment from both managers and stakeholders in these eradication efforts.

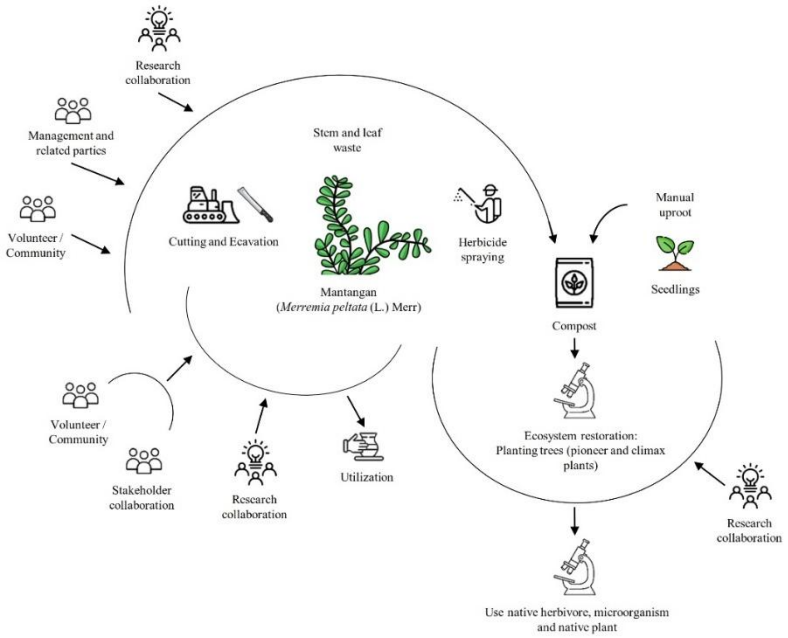

Figure 7. Integration scheme of *M. peltata* control strategy in BBSNP

CONCLUSION

The effectiveness rates of *M. peltata* control in BBSNP using mechanical, chemical, and biological methods were 46.67%, 44.88%, and 34.92%, respectively, while the combined approach yielded 55.22%. All values were classified as ineffective, indicating that further efforts are required to optimize *M. peltata* management within BBSNP.

Three alternative strategies were identified for *M. peltata* control in BBSNP: Alternative I, the integration of control strategies, received the highest priority weight (59.7%); Alternative II, strengthening management institutions, accounted for 28.1%; and Alternative III, enhancing cooperation and coordination among stakeholders, contributed 12.2%.

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