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Full Length Research Article

Identification of Key Actors in the Conservation of *Amorphophallus gigas* in North Sumatra Using the MACTOR Method

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ABSTRACT

Indonesia's tropical forests harbor exceptional plant diversity; however, rising global demand for forest-based commodities is intensifying extraction and increasing the risk of extinction. In North Sumatra, *Amorphophallus gigas* persists within community-managed agroforestry understorey systems, yet a surge in tuber demand since 2019 has accelerated harvesting and expanded trade networks from local collectors to export markets. These pressures threaten the species and highlight the need to identify and coordinate key actors in governing sustainable harvesting and habitat management. This study applies a prospective mixed qualitative–quantitative approach, combining in-depth interviews with farmers, village authorities, collectors, government agencies, academics, non-governmental organizations, industry representatives, and exporters. The MACTOR method was used to assess actor influence and dependence and to map convergence and divergence across three objectives: species conservation, agroforestry habitat protection, and income-oriented cultivation. Results indicate that the Center for Conservation of Natural Resources (BBKSDA) North Sumatra is the most influential and least dependent actor, while farmers remain highly dependent despite managing most habitats on private land. Habitat protection is the most mobilizing objective but shows substantial divergence, reflecting unresolved trade-offs between conservation and cultivation. These findings underscore governance imbalances and the need for inclusive, adaptive strategies, including farmer incentives, capacity building, formalized harvesting rules, and synergies between ex situ conservation and sustainable agroforestry.

1. Introduction

National parks (NPs) are essential components of global conservation strategies, serving as vital refuges for biodiversity and delivering indispensable ecosystem services. Besides their importance in conserving biodiversity, NPs deliver essential services for nature-based tourism, which is widely regarded as a sustainable means of integrating conservation with socio-economic development (Kim et al. 2019; Nugroho and Numata 2021, 2022) and as a source of local support for conservation (Salampessy et al. 2024). In Indonesia, NPs were vigorously promoted as prime tourist destinations (Wiratno et al. 2022), thereby highlighting their dual importance for environmental sustainability and community engagement. Studies have shown that NPs attract large numbers of tourists, thereby generating alternative livelihoods for local communities (Balmford et al. 2015). Furthermore, experience-based learning from nature-based tourism activities fosters a stronger relationship between tourists and the natural world, potentially increasing support for conservation efforts (Smit et al. 2017; Zhang et al. 2024). The two-fold benefits of economic empowerment and environmental concern further highlight the need to promote and support NPs.

The *Araceae* family, also known as aroids, is widespread across tropical regions worldwide, including Indonesia. The genus *Amorphophallus*, or elephant foot yam, is an important lineage of plants within this family. In Indonesia, at least 25 species of *Amorphophallus* have been recorded across diverse environmental gradients, ranging from low- to mid-elevation environments and from shaded understories to more open, light-rich environments (Mursyidin and Hernanda 2021; Yuzammi 2018). Several species of this genus are experiencing reduced populations due to (i) naturally low and patchy distributions, (ii) degradation or loss of relatively undisturbed secondary forests, which are key habitats for these species, and (iii) alteration of reproductive patterns due to loss of pollinators and seed dispersers, including specialized insects such as beetles, flies, and potentially birds of large size, which could be threatened by hunting and habitat fragmentation (Claudel 2021; Murrell et al. 2025; Yuzammi and Hadiah 2018). These pressures could be more critical for newly described or less-studied species for which little or no conservation assessments have been conducted.

Amorphophallus gigas Teijsm. & Binn. is a geographically restricted aroid endemic to northern Sumatra, which has been insufficiently studied but has seen increased utilization in recent years. It is known as *atturbung* in the field; it is largely affected by land management practices in working landscapes rather than by regulations in formally protected areas. Results from distribution surveys and habitat modeling showed that *A. gigas* is mainly found, or in some areas exclusively, in community agroforestry gardens, which are affected by land conversion and increased tuber extraction related to livelihood and market activities (Rambey et al. 2025). Since the early part of 2019, rising demand for *A. gigas* tubers has been observed, particularly in local community harvesting and in marketing activities by local collectors to provincial buyers and export markets. This demand, as well as that for other aroids, has been rising particularly in the North Tapanuli, South Tapanuli, and South Labuhanbatu districts (Rambey et al. 2021, 2022). Furthermore, *A. gigas* has not yet been assessed for inclusion in the IUCN Red List and is not listed as a protected species under the Regulation of the Ministry of Environment and Forestry of the Republic of Indonesia No. P.106/2018 on Protected Plant and Animal Species. This formal non-recognition has made *A. gigas* a ‘governance-sensitive’ species, with outcomes depending on how communities, government agencies, researchers, and market actors interact regarding land use, extraction, and incentives.

Interventions in conservation that fail to account for the distribution of power, dependence, and incentives among various actors are prone to poor implementation, non-compliance, and capture by powerful actors, especially in multi-level natural resource systems, where institutions and social relations mediate access to benefits (Gayo 2025). Hence, structured approaches for conducting stakeholder analyses have been developed that go beyond descriptions to model their influence, interdependence, and strategic alignment, thereby facilitating the development of credible policy options and coalitions (Masarira et al. 2024). MACTOR (Matrix of Alliances and Conflicts: Tactics, Objectives, and Recommendations) is a structured stakeholder analysis tool developed in futures research and strategic planning that enables quantification of direct and indirect influences, dependencies, and convergence or divergence in objectives (Davood 2025). MACTOR has been used in various sustainability domains in Indonesia, such as mangrove forest management and restoration planning (Mahardika et al. 2022; Tandio et al. 2023), marine tourism (Triyono et al. 2023), sustainable agriculture programs (Sartika et al. 2023), small-scale gold mining (Ismayanti et al. 2025), and in diagnosing implementation conflict in various complex socio-ecological systems (Komarolya 2025; Mukhlis et al. 2025).

Considering that many wild plant species are harvested and traded as non-timber forest products (NTFPs), conservation is affected not only by ecological constraints but also by accessibility, decision-making authority, and economic benefits along the multi-stage value chains of harvesters, intermediaries, processors, and regulators. Harvesting can change population trends and disrupt ecological interactions. Studies of value chains also show that we need to understand who is involved, who influences decisions, and how actors are connected to identify the real threats and design practical, enforceable interventions across the chain (Araujo-Santos et al. 2025). This study aims to identify the key actors involved in conserving *A. gigas* in North Sumatra. It uses MACTOR to examine their influence, dependence, and alignment with conservation goals, providing a basis for practical conservation strategies and forestry policy suited to local management.

2. Materials and Methods

This study was conducted in North Sumatra, from 2023−2024 (**Fig. 1**). The primary data obtained were processed using prospective analysis methods. Prospective analysis is a method employed to study a policy in the future. In this study, prospective analysis was carried out using MACTOR (Méthode Acteurs, Objectifs, Rapports de Force) software (Rees and MacDonell 2017).

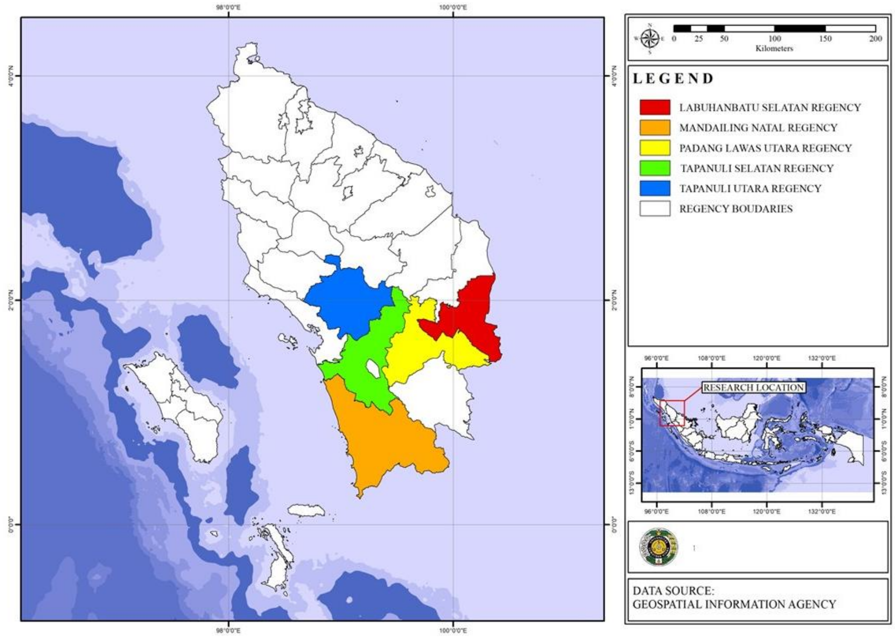

Fig. 1. Research location.

This method mapped the strength of relationships between actors and factors in the development of conservation for *Amorphophallus gigas* in North Sumatra. The analysis method considered position and intensity variables based on the influence, role, position, and attitude of actors towards the chosen policy, and their power in determining the maximum variables, based on preliminary results from in-depth interviews.

MACTOR works by filling in the position matrix, namely the *1MAO* (Actor-Objective Matrix) and the *2MAO* matrices. The next matrix to complete is the *MID* (Direct Influence Matrix), which describes the variables that influence one another. After filling in the *MID* and *1MAO* matrices, MACTOR will calculate the *2MAO* matrix via a computer program. The MACTOR system works as intended by Mafruhah et al. (2020), Rees and MacDonell (2017), and Villegas and Alejandro (2011). The calculation formula is presented in Equation 1.

$$MIDI_{A\rightarrow B} = MIDI_{A-B} + \sum_{C}[min(MID_{A\rightarrow C}, MID_{C\rightarrow B})] \quad (1)$$

To understand the balance of power among actors, it is necessary first to calculate each actor's direct and indirect impacts. If M_A is defined as the direct total influence of actor A on the others, then it can be expressed as shown in Equation 2.

$$M_A = \sum_{B} (MIDI_{A,B}) - MIDI_{A,A} \quad (2)$$

If D_A is defined as the total direct and indirect effects received by A from other actors, the calculation is given in Equation 3.

$$D_A = \sum_{B} (MIDI_{B,A}) - MIDI_{A,A} \quad (3)$$

Furthermore, the coefficient of the balance of the strength of the relationship is calculated by Equation 4.

$$r_A = \left[\left(\frac{M_{A-MIDI_{A,A}}}{\sum_A (M_A)}\right] x \left[\frac{M_A}{M_A + D_A}\right] \quad (4)$$

In the next step, MACTOR will calculate the *3MAO* matrix, namely the basis matrix that is important in the MACTOR discussion, as formulated in Equation 5.

$$3MAO_{A,i} = 2MAO_{A,i} \; x \; r_A \quad (5)$$

Using the *3MAO* matrix, various features can be generated, including the mobilization coefficient, indicating the different actors involved in a given situation, as shown in Equation 6.

$$MOB_A = \sum |3MAO| \quad (6)$$

Approval and disagreement over a goal are then overlaid using Equations 7 and 8.

$$Ag_A = \sum_A \left(3MAO_{A,i}(3MAO > 0)\right) \quad (7)$$

$$DisAg_A = \sum_A \left(3MAO_{A,i}(3MAO < 0)\right) \quad (8)$$

Another feature that can be derived from the *3MAO* matrix is the convergence matrix (*3CAA*), which describes how much the actors agree on an issue, and the divergence matrix (*3DAA*), which describes the opposite or disagreement. The convergence matrix (approval) is generated through Equation 9.

$$3CAA = \frac{1}{2}\sum \left(\left(\lceil 3MAO_{Ai}\rceil + \lceil 3MAO_{B,i}\rceil\right)\left(3MAO_{A,i} X 3MAO_{B,i} > 0\right)\right) \quad (9)$$

The divergence (disagreement) matrix is written in Equation 10.

$$3DAA = \frac{1}{2}\sum\left(\left(\lceil 3MAO_{Ai}\rceil + \lceil 3MAO_{B,i}\rceil\right)\left(3MAO_{A,i}X3MAO_{B,i} < 0\right)\right) \tag{10}$$

Furthermore, calculating the convergence and divergence between these actors yields the final actor from MACTOR, namely the ambivalent coefficient for each actor, as calculated by Equation 11.

$$3EQ_i = 1 - \left[\frac{\left(\sum_k \left\|3CAA_{i,k} - 3DAA_{i,k}\right\|\right)}{\left(\sum_k \left\|3CAA_{i,k} + 3DAA_{i,k}\right\|\right)}\right] \tag{11}$$

where, *A*, *B*, and *C* are indices for actors (stakeholders), *MIDI* or *MID* is matrix of direct and indirect influences, $\sum_C$ is the summation of all possible intermediate actors *C*, M_A is the total influence (driving power), $\sum_B$ is the sum across all actors *B*, D_A is the total direct and indirect influence received by *A* (dependence), r_A is the relative strength coefficient of actor *A*, and *i* is an index for objectives or issues.

In addition to employing a prospective analysis approach, this study also formulated the results of stakeholder interviews directly related to *A. gigas* conservation in North Sumatra. It mapped the roles and attitudes of key actors in *A. gigas* conservation. The key actors involved in the interviews included farmers, village-level collectors, village heads, representatives of the

Center for Conservation of Natural Resources or *Balai Besar Konservasi Sumber Daya Alam* (BBKSDA) Sumatra Utara, academics, provincial-level collectors, companies, and exporters. The complete research method scheme is shown in **Fig. 2**.

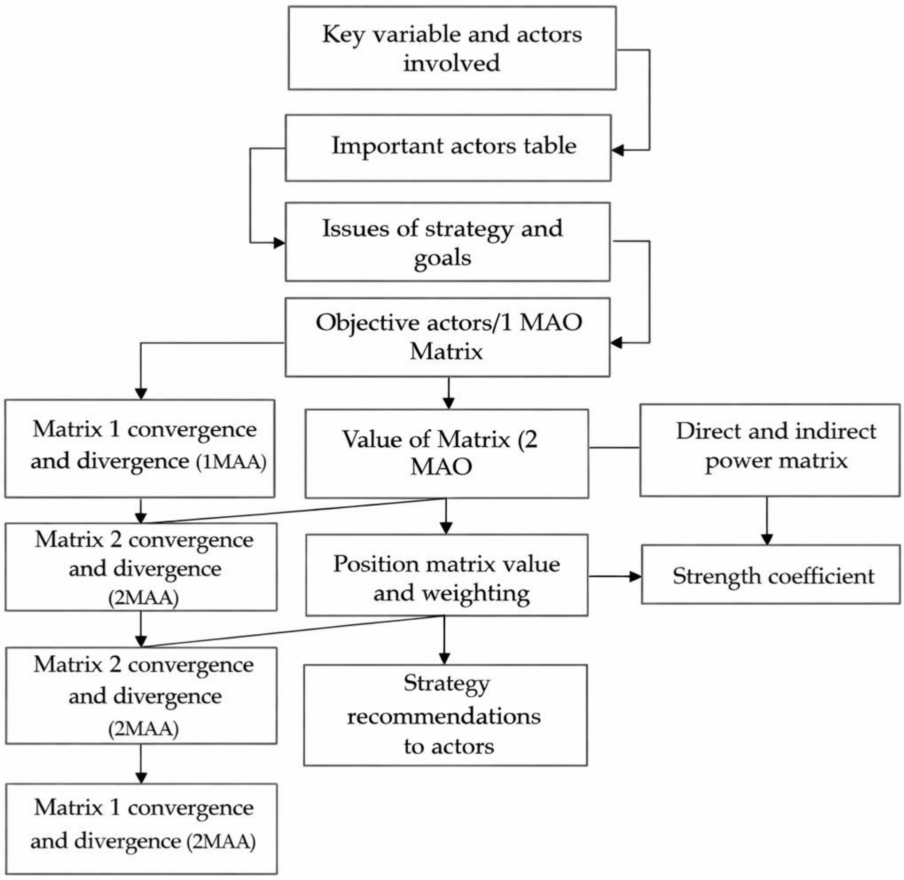

Fig 2. Research stages in identifying key actors in the conservation of *A. gigas* in North Sumatra.

The process began with the identification of key variables and relevant actors involved in the system under analysis, followed by the construction of an actors table to screen and prioritize stakeholders. The strategic issues and objectives were identified and defined, forming the basis of the actors' objectives matrix (*1MAO*), which indicates each actor's position. From this matrix, the value matrix (*2MAO*) was developed to quantify the actor-objective relationships. Simultaneously, the direct and indirect power matrices were created to determine the levels of influence and dependence among actors. From this matrix, the strength coefficients were calculated. Convergence and divergence matrices (*1MAA* and *2MAA*) were generated to assess the level of convergence or divergence between actors using weighted position values. The integration of the above matrices served as the basis for developing strategy recommendations for the different actors involved in the scenario.

3. Results and Discussion

In-depth interviews were initially conducted with individuals (actors) involved in *A. gigas* conservation activities who were aware of the importance and occurrence of this species in nature. A list of actors was then compiled, followed by MACTOR analysis. The results showed that ten key actors were involved in North Sumatra. These actors included local resource users, government institutions, civil society organizations, knowledge producers, and market-chain actors (**Table 1**). The local users, farmers ("Farmer"), are the primary users as the species occurs mainly in agroforestry landscapes. They are directly involved in harvesting wild tubers that are plentiful and rolling into the market supply. The next group closely related to farmers is farmer groups ("Farmgroup"), as this actor could influence the intensity of harvesting, as well as information sharing and participation in government or development programs.

Table 1. List of actors involved in the conservation of *A. gigas* in North Sumatra

No	Long Label	Short Label	Description
1	Farmer	Farmer	Farmers who collect the *A. gigas* tuber
2	Government of Village	GovVillage	Government of a village in the area of North Sumatra that takes the *A. gigas* tuber
3	Farmer Group	Farmgroup	A farmer group in North Sumatra that takes the *A. gigas* tuber
4	Collector of Village Level	Colectvill	Collector *A. gigas* tuber at the village level in North Sumatra
5	Natural Resources Conservation Center	ConservCenter	Center for Conservation of Natural Resources
6	Non-Government Organization	NGO	Non-Government Organizations that concentrate on natural resources
7	Academics	Academics	Academics' research on *A. gigas*
8	Collector of Province Level	Collectprov	Provincial-level collectors collect tubers from their regions
9	Factory	Factory	A factory that processes tubers into chips in dry form
10	Exporter	Exportir	Exporters play a role in sending tubers abroad

Village governments ("GovVillage") serve as local-level authorities that influence resource utilization through local regulations and coordination with higher-level institutions. The commodity chain, village-("Colectvill") and provincial-level collectors ("Collectprov") act as key intermediate actors who transmit demand from markets to producers and local users to regional or international markets, often without involvement in conservation management. The role of factories ("Factory") is to add value to tubers through processing and drying. However, their influence on conservation management is limited and indirect, often channeled by supply. The role of exporters ("Exportir") is to drive demand from markets. However, their influence on conservation is limited by their geographical and institutional remoteness from resources. Institutional and knowledge-based actors play complementary roles, for example the Natural Resources Conservation Center ("ConservCenter"), which acts as the state authority for conservation policy; Non-government organizations ("NGO"), play an important role in advocacy and community engagement; and Academics ("Academics") which contribute to the scientific basis of *A. gigas* in terms of ecology and conservation.

The results from the direct influence matrix (MDII) indicate that power is highly unevenly distributed among actors (**Table 2**). The Center for Conservation of Natural Resources or *Balai Besar Konservasi Sumber Daya Alam* (BBKSDA) was found to be the most influential actor, with L_i = 42, as it exerts considerable influence on farmers, farmer groups, village governments, NGOs, and academics, while having low dependence on these actors. On the contrary, farmers and farmer groups were found to have relatively high dependence and low influence, reflecting their structural vulnerability, despite being the key landholders and habitat managers for *A. gigas*. Market-chain actors, such as exporters, factories, and provincial collectors, were found to have low influence and low dependence in the network, suggesting that, although they are key drivers of economic demand, their participation in formal decision-making for conservation is limited.

Table 2. Direct influence–dependence matrix (MDII) among actors

MDII	Farmer	GovVillage	Farmgroup	ColectVill	ConservCenter	NGO	Academics	CollectProv	Factory	Exportir	L_i
Farmer	3	3	3	2	0	2	2	1	0	0	13
GovVillage	8	4	6	3	0	3	4	0	0	0	24
Farmgroup	9	5	8	3	0	4	4	2	0	0	27
ColectVill	6	3	5	4	0	2	4	2	2	0	24
ConservCenter	11	7	10	3	0	5	6	0	0	0	42
NGO	6	4	5	3	0	2	4	0	0	0	22
Academics	7	5	7	3	0	4	4	0	0	0	26
CollectProv	1	1	1	1	0	0	0	3	3	3	10
Factory	0	0	0	1	0	0	0	2	5	3	6
Exportir	0	0	0	0	0	0	0	2	3	3	5
D_i	48	28	37	19	0	20	24	9	8	6	19

Notes: D_i = total direct dependence, L_i = total direct influence.

The influence-dependence (**Fig. 3**) and competitiveness histogram (**Fig. 4**) indicate that the system is polarized, with regulatory and knowledge actors dominant and local users exerting low upward influence. This polarization has serious implications for the sustainability, legitimacy and effectiveness of conservation interventions, as farmers' views and incentives are not sufficiently integrated into decision-making.

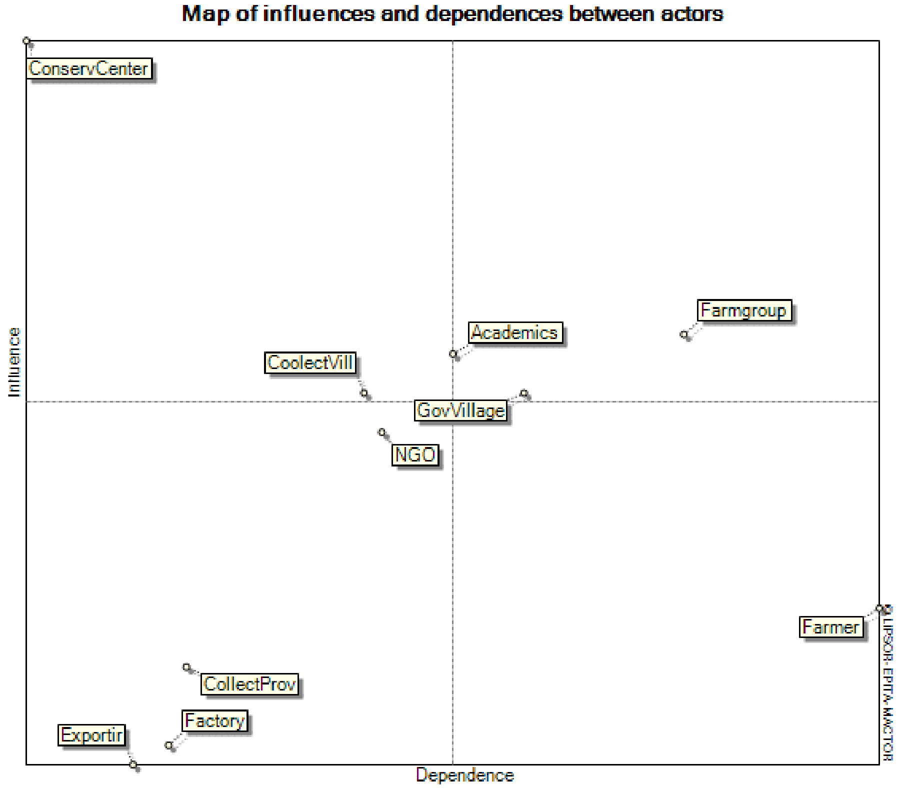

Fig 3. Matrix of influences and dependencies between actors.

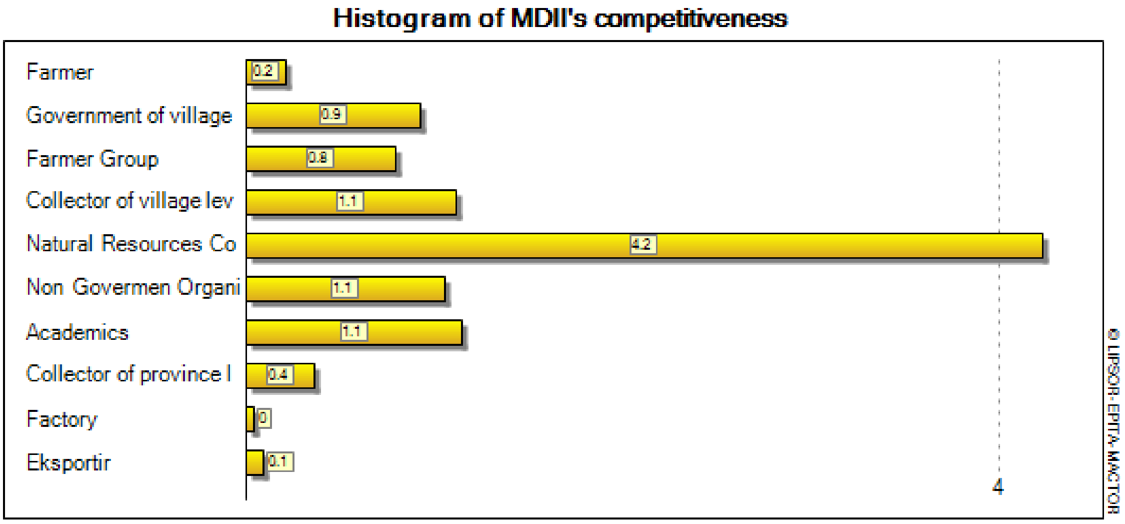

Fig 4. Histogram of MDII's competitiveness.

BBKSDA is in Quadrant 1 (top left). All actors in this quadrant have a large influence and low dependence on the conservation of *A. gigas*. In contrast, in Quadrant 3 (bottom right), only farmers are affected by the *A. gigas* conservation scenario in North Sumatra. In Quadrant 2, academics and farmer groups are relay actors. Relay actors depend on actors influenced by driven actors, but they also have a significant influence on actors in Quadrant 3. Meanwhile, NGOs, factories, exporters, and the provincial level are in Quadrant 4 as autonomous actors who have no impact but are also not affected by the conservation of *A. gigas*. Three objectives were assessed: conservation (preventing extinction), protection (maintaining agroforestry habitats), and cultivation (income generation) of *A. gigas* in the study region (**Table 3**).

Table 3. List of objectives in the conservation of *A. gigas* in North Sumatra

No	Long label	Short Label	Stake
1	Protecting *A. gigas* from the threat of extinction in the future	Conservation	Conservation Center
2	Maintaining agroforestry patterns as a suitable habitat for *A. gigas*	Protection	General
3	Cultivation of *A. gigas* as an effort to increase community income	Cultivation	Farmer

The degree of mobilization analysis (**Table 4**) indicates that protection achieved the highest overall mobilization score (34.9), followed closely by cultivation (33.8) and conservation (31.5). This pattern indicates that agroforestry maintenance receives the broadest support, largely because it protects habitat while still allowing households to sustain their livelihoods. BBKSDA Sumatra Utara, or "ConservCenter," was found to have high mobilization across all objectives, at 50.7, reinforcing the notion that it plays a key role in shaping the conservation discourse and setting priorities. Other actors, such as academics and NGOs, were also found to have relatively high levels of mobilization, suggesting that they share norms with the conservation and protection objectives. On the contrary, village and provincial collectors were found to have negative mobilization values for all objectives, indicating low agreement with the conservation objectives, particularly protection and cultivation. This finding is not surprising, as it has been widely recognized that there are trade-offs between resource regulation and short-term economic returns, particularly in the context of NTFP management.

Table 4. The degree of mobilization between stakeholders with objective goals

3MAO	Conservation	Protection	Cultivation	Mobilization
Farmer	0.6	0.6	0.6	1.9
GovVillage	0.9	0.9	0.9	2.8
Farmgroup	1.6	1.6	1.6	4.8
ColectVill	-1.1	-4.5	-3.4	-9.0
ConservCenter	16.9	16.9	16.9	50.7
NGO	4.2	4.2	4.2	12.6
Academics	4.6	4.6	4.6	13.8
CollectProv	-1.1	-1.1	-1.1	-3.3
Factory	0.0	0.0	0.0	0.1
Exportir	-0.4	-0.4	-0.4	-1.1
Number of agreements	28.9	28.9	28.9	
Number of disagreements	-2.6	-6.0	-4.9	
Degree of mobilization	31.5	34.9	33.8	

The presence of both agreements and disagreements over objectives suggests that conservation of A. gigas is not without conflict, but rather involves a negotiated balance between sustainability, habitat management, and income generation, as expected in multifunctional agroforestry systems. The pattern of convergence in the matrix (**Table 5**) and in the network visualizations (**Figs. 5−7**) indicates that BBKSDA Sumatra Utara, academics, NGOs, and farmers form a block with a high degree of convergence. In the convergence map, the direction and degree of divergence between actors are indicated. In addition, the map shows the distance between actors, which is an indicator of potential collaboration (Hasyim et al. 2022). In practice, the pattern of actors in the network suggests an epistemic–institutional configuration in which scientific actors and civil society organizations serve as bridging agents, translating the ideals of conservation into practice and facilitating the creation of practical rules and agreements. These bridging agents are recognized as facilitating conditions in adaptive co-management arrangements (Lakshmisha and Thiel 2022).

Table 5. Convergence matrix among actors, showing the degree of alignment in objectives

3CAA	Farmer	GovVillage	Farmgroup	ColectVill	ConservCenter	NGO	Academics	CollectProv	Factory	Exportir
Farmer	0.0	2.4	3.4	0.0	26.3	7.3	7.9	0.0	0.0	0.0
GovVillage	2.4	0.0	3.8	0.0	26.7	7.7	8.3	0.0	0.0	0.0
Farmgroup	3.4	3.8	0.0	0.0	27.7	8.7	9.3	0.0	0.0	0.0
ColectVill	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.2	4.6	5.0
ConservCenter	26.3	26.7	27.7	0.0	0.0	31.7	32.2	0.0	0.0	0.0
NGO	7.3	7.7	8.7	0.0	31.7	0.0	13.2	0.0	0.0	0.0
Academics	7.9	8.3	9.3	0.0	32.2	13.2	0.0	0.0	0.0	0.0
CollectProv	0.0	0.0	0.0	6.2	0.0	0.0	0.0	0.0	1.7	2.2
Factory	0.0	0.0	0.0	4.6	0.0	0.0	0.0	1.7	0.0	0.6
Exportir	0.0	0.0	0.0	5.0	0.0	0.0	0.0	2.2	0.6	0.0
Number of convergences	4.2	48.9	53.0	15.7	144.7	68.6	70.9	10.1	6.9	7.9
Degree of convergence (%)	0.0									

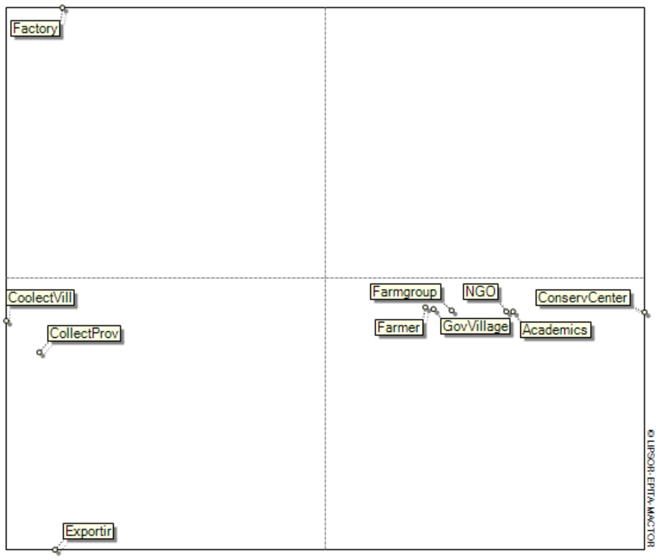

Fig. 5. Convergence map illustrating the relative alignment and potential alliances among actors.

The pattern of convergence in the network and the matrix, however, must be recognized as not necessarily leading to equitable forms of collaboration. In Indonesia's forestry sector, evidence suggests that stakeholder influence in forums is not necessarily equitable, even with broad stakeholder participation. In an analysis of the multiple stakeholder forums in the Indonesian National Forestry Council established by the government, stakeholder interactions were constrained by unequal resources and state-centric dynamics (Muttaqin et al. 2023). In an analysis of social forestry expansion in Indonesia, evidence shows that the transfer of responsibility to local user groups often occurs before capacity-building and support, leading to implementation tensions that undermine conservation success (Erbaugh 2019; Rakatama and Pandit 2020).

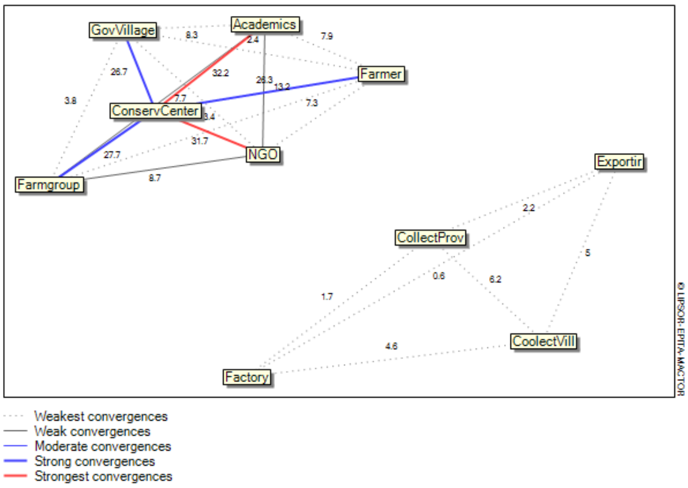

Fig. 6. Ordered convergence graph showing the relative strength of convergence among actors.

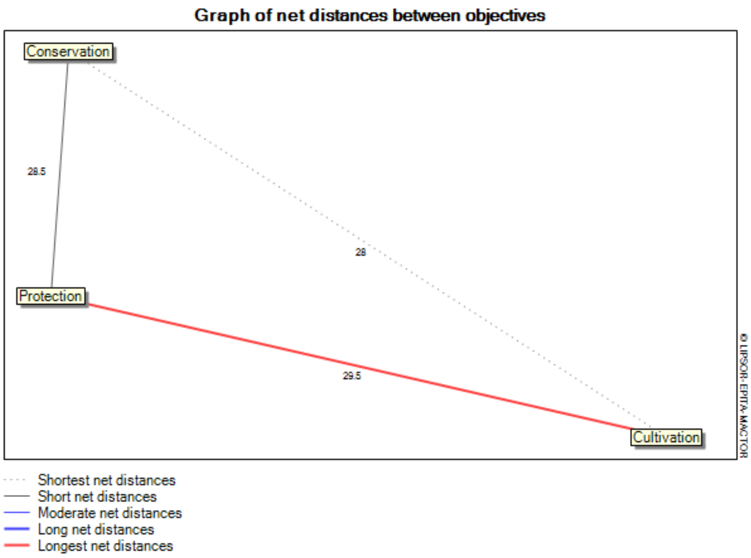

Fig. 7. Actor role map depicting the strategic positions of stakeholders based on their influence, dependence, and convergence in the conservation of *A. gigas* in North Sumatra.

In contrast, collectors, factories, and exporters constitute another cluster with limited connectivity to conservation actors. Exporters, provincial collectors, village collectors, and factories tend to possess divergent interests (Rees and MacDonell 2017). Nevertheless, all actors within this chain contribute to value-chain coordination by facilitating the flow of products, information, and finances that add value to the product (Handayani et al. 2022). The separation of these actors is characteristic of a common governance structure within NTFP and wildlife plant value chains, in which downstream actors influence incentives for extraction activities but remain poorly linked to conservation actors. The commercialization process does not always yield conservation dividends; rather, it increases ecological risks as market demand outstrips governance capabilities (Dempsey and Suarez 2016). Value chain studies of specific cases also reveal that poorly aligned regulations and weak enforcement capabilities can increase transaction costs, foster unofficial charges and promote unsustainable harvesting activities, as highlighted in NTFP trade governance in Cameroon (Tieguhong et al. 2015). In Indonesia, bridging strategies within livelihood-conservation value chains remain feasible but require specific institutional arrangements, including local regulations and market mechanisms that reward low-impact activities rather than promoting expansion of extraction activities (Harbi et al. 2023). In the case of *A. gigas*, its chain could heighten harvesting activities despite low levels of integration of downstream actors into conservation management. This outcome is consistent with global findings indicating that commodity chain initiatives can exacerbate habitat loss despite localized management and monitoring. Supply chain initiatives were only effective in lessening deforestation risks when actors were aligned and had credible enforcement (Lambin et al. 2018). Zero-deforestation initiatives were also ineffective, with limited coverage and insufficient monitoring (Garrett et al. 2019). Such poorly monitored initiatives also risk further marginalizing low-capacity actors who lack specific support (Grabs et al. 2021). Based on these experiences, it could be explained why collectors, factories, and exporters, despite weak alignment with conservation coalitions, can still intensify extraction through demand transmission under fragmented governance.

Farmers are actors who have direct contact with *A. gigas*, but their role in decision-making is very limited (Tandio 2023). In addition, the level of dependency-influence, being decisive, bridging, dominated, or autonomous, the role of actors that bridge or link interactions in the intermediary network, and the level of actors (key actors) and connections are also key to successful conservation (Venegas et al. 2022). In this study, the multi-problem actor model was applied to situations in which multiple actors faced several problems whose future evolution was uncertain and difficult to predict. For example, a situation like this may arise in multiparty negotiations, where various actors have different objectives regarding the issues under discussion. Another relevant application is participatory scenario planning, which enables actors to shape the evolution of complex situations by influencing multiple key variables or challenges (Thorn et al. 2020). Some of the knowledge-based elements that were expected to help actors solve problems include: a) democratization of organizational knowledge and human resources; b) creation of interdisciplinary collective learning institutional processes and the organization of essential knowledge; c) creation of continuous communication between actors, stakeholders, and resources; and d) strategic planning, organization, and facilitation of necessary knowledge-based activities (Qelichi et al. 2023).

Protection and cultivation were the most divergent objectives, as our findings showed, whereas protection was closer to conservation. This finding is consistent with existing research indicating that farmers grow *Amorphophallus* species in response to market demand and improve tuber quality, which could be counterproductive to habitat conservation if harvesting activities increase (Riptanti et al. 2022). By contrast, cultivation can also serve as a conservation tool when implemented to safeguard species, as shown by *ex situ* cultivation of *A. gigas* and *A. titanum* at the Bogor Botanical Garden (Yuzammi 2018). In Indonesia, conservation management (as defined in Law No. 5/1990) encompasses conservation, preservation, and utilization. Balancing these management objectives and actor interactions is essential for decision-making (Kusmana 2015). For *Amorphophallus*, effective strategies are generally considered to combine *in situ* maintenance in natural habitats, *ex situ* safeguards, utilization, and continuous research, with support from participatory approaches and extension by conservation authorities (Melo et al. 2019; Šijačić-Nikolić and Milovanović 2021). Three key priorities for the conservation of *A. gigas* in North Sumatra are synthesized in this study. First, coordination between key regulatory actors and heavily dependent land managers should be improved through negotiated, enforceable co-management arrangements that recognize power imbalances and the costs to farmers. Second, such arrangements need to be feasible within Indonesia's forestry governance system, where devolving tasks to local actors can be unsuccessful without continued technical, administrative, and financial support. Third, the outcomes of such conservation are likely to be short-lived unless market actors are engaged in developing conservation-compatible activities through traceability requirements, purchase conditions, locally negotiated rules governing tuber extraction, and incentive schemes that align trade with sustainability. Therefore, the output of convergence is not just the actor alliances but also the possible locus of action and the governance gaps revealed as necessary to be bridged through direct involvement of market linkages, which is the essence of the actor analysis framework.

4. Conclusions

This study shows that conserving *A. gigas* in North Sumatra is primarily a matter of governance and coordination, not solely ecology. The MACTOR analysis revealed a clear imbalance among actors: the BBKSDA Sumatra Utara exerts the greatest influence and depends little on others, whereas farmers, who manage much of the species' habitat within agroforestry gardens, remain highly dependent and have a limited voice in decision-making. The influence-dependence map also suggests that farmers are the most affected group, with academics and farmer groups acting as intermediaries. At the same time, several market-related actors operate more independently from the governance system. Among the three objectives, protecting agroforestry habitat generated the highest overall mobilization but also elicited the strongest disagreement, pointing to persistent tension between habitat protection and income-oriented use. This tension aligns with the more negative positions expressed by some trade intermediaries, suggesting that protection measures will be difficult to sustain unless the incentives driving harvesting and trade are addressed. Finally, the convergence analysis indicates a realistic pathway for coordination: the BBKSDA Sumatra Utara sits at the center of a high-alignment cluster that includes academics, NGOs, farmers, farmer groups, and village authorities, suggesting that negotiated collaboration and locally workable rules are achievable. At the same time, weak alignment between conservation-oriented actors and downstream market actors implies that demand could continue to drive extraction even when local conservation commitments exist, unless governance instruments extend to market interfaces. Our findings support conservation strategies that (i) strengthen farmer capacity and incentives for *in situ* stewardship within agroforestry, (ii) clarify and operationalize harvesting norms through locally enforceable agreements supported by the BBKSDA Sumatra Utara and village institutions, and (iii) link conservation to feasible cultivation pathways that reduce reliance on wild extraction while maintaining livelihood benefits. These priorities were synthesized directly by following the actor structure revealed by MACTOR, which identified where cooperation was most plausible and where governance gaps were most likely to persist.

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Author Contributions

R.R.: Conceptualization, Writing – Original Draft Preparation, Writing – Review and Editing, Data Curation, Methodology, Software, Validation; R.: Formal Analysis, Investigation, Resources, Writing – Review and Editing; A.R.: Writing – Review and Editing, Visualization; E.S.M.N.: Supervision, Project Administration, Funding Acquisition; M.H.I: Writing – Review and Editing, Visualization; M.N.S: Formal Analysis, Investigation, Resources, Writing – Review and Editing.

Conflict of Interest

The authors declare no conflict of interest.

Declaration of Generative AI and AI-Assisted Technologies in the Manuscript Preparation

During the preparation of this manuscript, the authors used AI-assisted tools to support literature search and language refinement. Scholar Labs and Scopus AI were used to help identify relevant publications and organize reference searches. QuillBot was used for English polishing and paraphrasing to improve clarity and readability. The authors take full responsibility for the integrity and accuracy of the manuscript.

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