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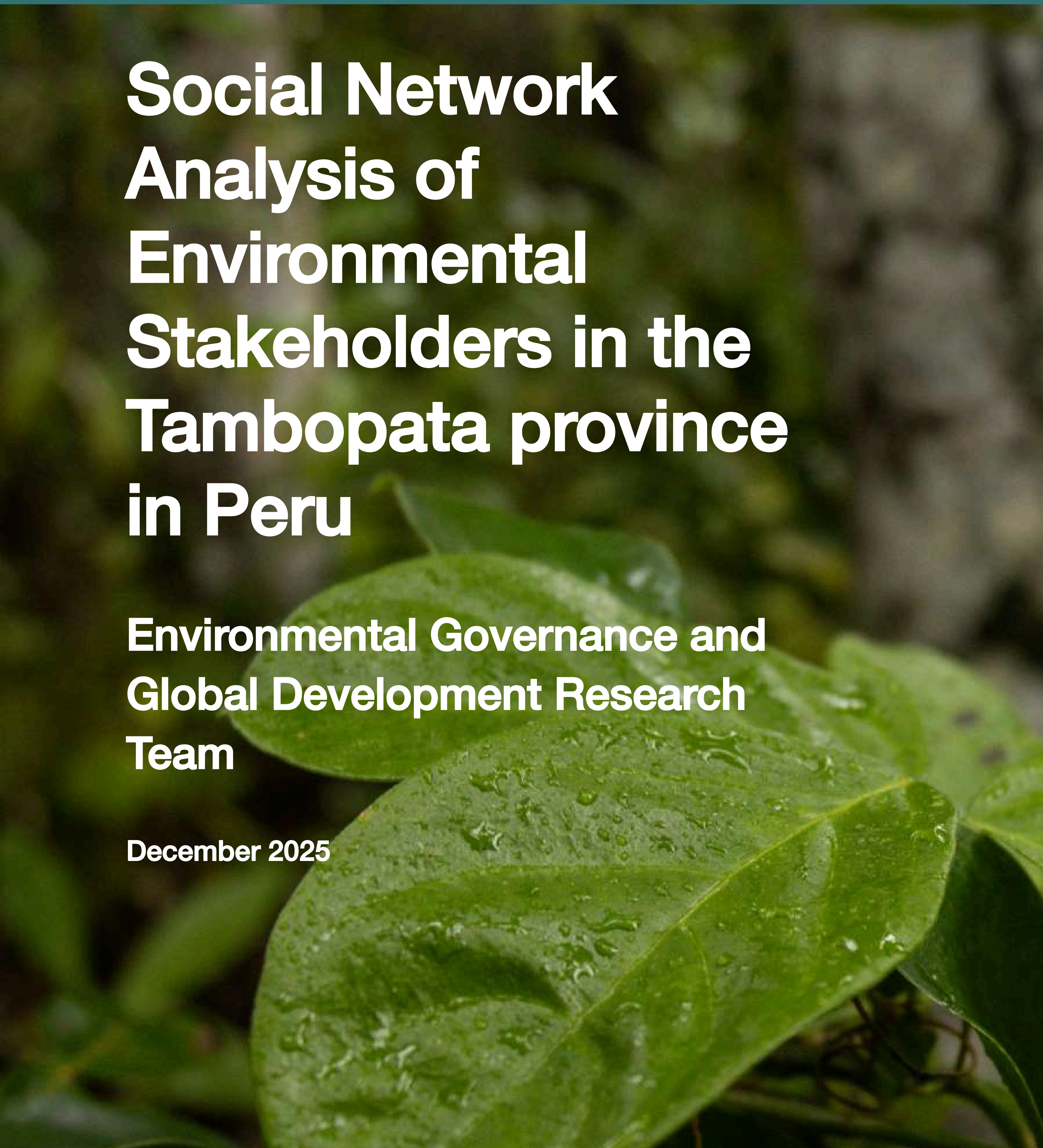

Social Network Analysis of Environmental Stakeholders in the Tambopata province in Peru

Environmental Governance and Global Development Research Team

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Executive Summary

This report presents a social network analysis of environment-related stakeholders in the Tambopata province in Madre de Dios, Peru, conducted by the Environmental Governance and Global Development Research Team at the Wyss Academy for Nature (WA) and the WA Hub South America. The analysis aims to improve our understanding of the relationships between diverse stakeholder groups and the environment, in order to identify entry points for more effective and inclusive governance interventions that promote co-benefits for nature and people.

The analysis draws on data from 49 semi-structured interviews conducted between November 2024 and February 2025 with representatives of 18 distinct stakeholder groups, including farmers, indigenous peoples, non-governmental organizations (NGOs), traders, government, and service providers, among others. The data were analyzed using descriptive and inferential social network analysis techniques, including network modeling. The standardized data were also compared to previously collected data about the network in 2023.

The findings reveal several important structural patterns and observable changes in the Tambopata social network since 2023:

- The network has become denser, with more connections between diverse stakeholder groups, suggesting increased interaction and information flow.
- NGOs, tourism, and finance-related stakeholders became the most central stakeholder groups, replacing government and public service providers.
- Indigenous peoples, farmers, and non-timber forest product collectors are better integrated into the network than before, signaling improved inclusion of stakeholders traditionally at the margins.
- Loggers, traders, and gold miners remain weakly connected to central stakeholders, even though they interact closely with different land covers and exert high environmental impact.
- Central stakeholders such as NGOs and government receive connections from many others but do not necessarily reciprocate them.

These findings point to opportunities to strengthen connectivity between certain stakeholder groups in the network, as well as support for more inclusive and reciprocal stakeholder engagement. Doing so is essential since some of the stakeholders weakly connected to the network share multiple connections to various land covers and can be, in practice, the ones that have the biggest impact on the environment.

Introduction

The Tambopata province is located in the department of Madre de Dios, in the Peruvian Amazon bordering Bolivia and Brazil. The area is considered a biodiversity hotspot, but the expansion of the agricultural frontiers and unsustainable extractive activities (e.g., gold mining and logging), together with the construction of the Interoceanic highway, transformed the landscape and accelerated environmental degradation in the past decades. [1]

The WA works in Madre de Dios to find a more sustainable and just development pathway that accounts for nature conservation and the well-being of local populations. The WA collaborates with a diverse range of stakeholders from indigenous groups to local cooperatives, universities, the private sector, and government authorities to promote a better future for both nature and people in Madre de Dios. [2]

Mapping how different stakeholders manage and interact with a landscape helps reveal both the formal and informal structures of the network, as well as the social links connecting people and the environment. [3] An improved understanding of the relationships between stakeholders can enhance engagement, help identify potential entry points, and better grasp the potential impact of future interventions on the network. When planning interventions targeting a land cover type (e.g., mining sites or primary forests), it is essential to consider the critical feedback loops that arise from collaborating with specific stakeholders. This requires a clear understanding of how these stakeholders interact among themselves and with ecosystems.

Social network analysis can be applied to analyze the relationships between social and ecological components. Social-ecological systems are complex and adaptive, small changes can have (de)stabilizing effects for biodiversity and resource management. [4]

[1] For more information on the historical changes and environmental consequences in Madre de Dios, please refer to Moore (2019).

[2] For an overview of the work of the Wyss Academy in Madre de Dios, please refer to Torre-Marin Rando et al. (2021).

[3] More detailed information about the methods, questionnaires, metrics, and other research steps can be found in the "Stakeholder Network Analysis Handbook"; please contact Henrique Sposito (henrique.sposito@wyssacademy.org) to request access. A previous report by the WA details the stakeholder network in Laos; for more information please refer to Kommadam et al. (2025).

[4] For more on the complex dynamics present in social-ecological systems and the challenges in studying them, please refer to Levin et al. (2013).

Identifying these dynamics helps us understand the consequences of changes in those networks and to recognize opportunities for transformation towards more sustainable human-nature coexistence. This is especially relevant for the development of planning strategies that align with the WA's impact visions for Madre de Dios. [5]

The objectives of this report are threefold. First, we provide an initial overview of the changes over time in the Tambopata social network since 2023. Second, we map how stakeholders in the network connect among themselves and to ecosystems they use or manage. Finally, we explore how network effects and attributes help characterize the structure of the network.

This report is divided into three parts. The first part describes the study area, outlines the data collection, and introduces social network methods. In the second part, we provide a descriptive analysis of the changes in the stakeholder network over time, examine how different stakeholders connect with diverse land covers, and model structural patterns in the network. The report concludes with the recommendations gathered from this study for the work of the WA in Madre de Dios.

[5] For an overview of how to analyze diverse social-ecological interactions and their effects on environmental outcomes, please refer to Ostrom and Cox (2010).

Study area, data, and methods

The Tambopata province in Madre de Dios

The department of Madre de Dios is the third largest in Peru (85,301 km2) and is home to over 140,000 inhabitants. Located in the southeast of Peru, bordering Bolivia and Brazil, the department's capital is Puerto Maldonado. Madre de Dios is home to several indigenous ethnic groups and extensive forests, largely undisturbed, boasting some of the world's highest levels of terrestrial species diversity. [6] As a result, around half of the territory is legally under some level of protection.

Historically, Madre de Dios was an isolated territory difficult to access due to its landlocked position within the Amazonian biome. The construction of roads along with government support for relocation in the area between the 1960s and 1970s, contributed to population growth and improved access to the department. The economic slowdown in Peru following the 2008 economic recession, combined with the historical increase in gold prices in the mid-2000s and the construction of the Interoceanic Highway connecting Madre de Dios to the Pacific Ocean and Brazil in 2011, drove the expansion of the agricultural frontier and other activities such as logging and mining. This, in turn, led to widespread landscape transformations and environmental degradation. [7] In response to the intensification of unsustainable extractive activities, particularly mining, the regional government promoted formalization through the establishment of a mining corridor that concentrates mining concessions. [8] The need to promote the sustainable use of natural resources while improving the

[6] Please refer to Sánchez-Cuervo et al. (2020) for an overview of the biodiversity in Madre de Dios and how the development of the region impacts land use dynamics and local conservation efforts.

[7] For more information on the expansion and impacts of legal and illegal small-scale and artisanal gold mining in Madre de Dios, please refer to Cortés-McPherson (2019).

[8] The Formalization and Restructuring Plan for Madre de Dios confines mining along the mining corridor and pushes for commitments to follow certain processes and guidelines. For more information on mining in Madre de Dios, please refer to Salo et al. (2016).

people's livelihoods brought many environmental and development-related NGOs and research institutions to the region. [9]

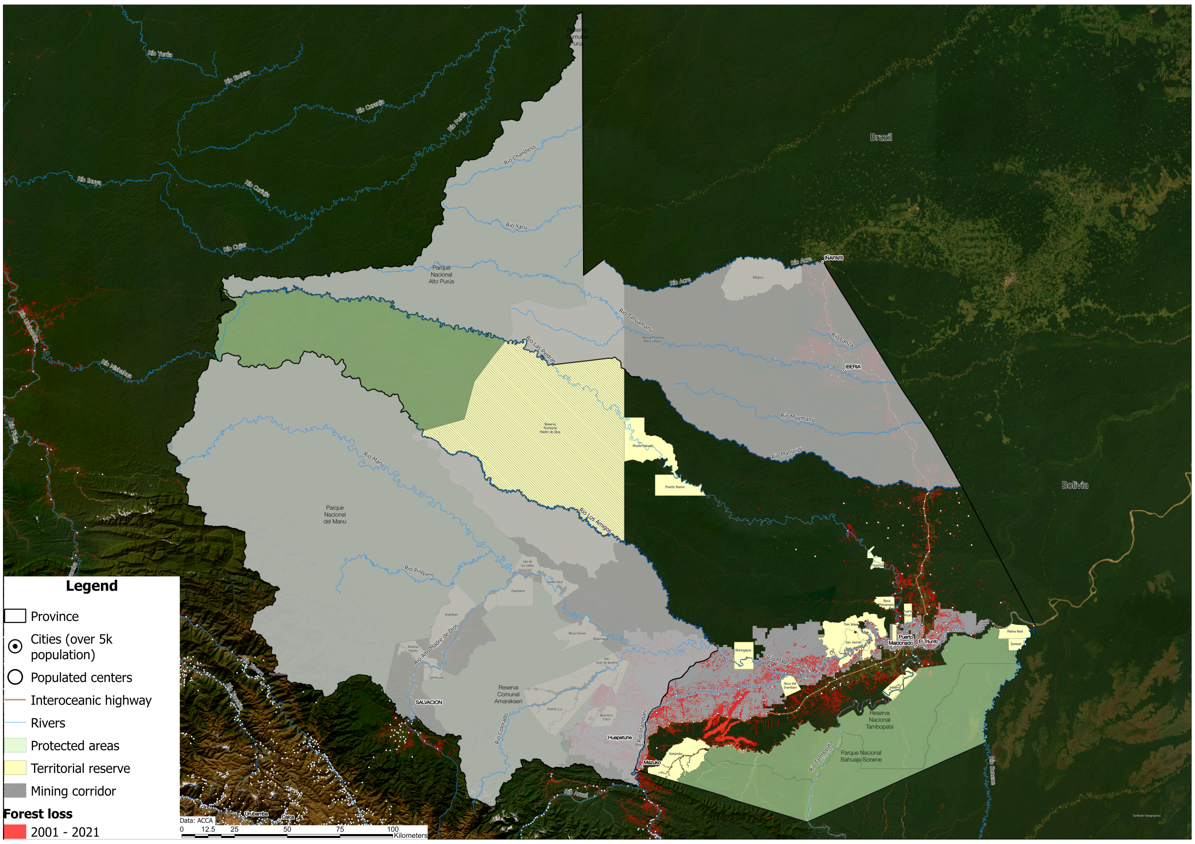
Tambopata is the largest of the three provinces in Madre de Dios. The province's capital, Puerto Maldonado, is the largest city in the department with over 80,000 inhabitants. Protected areas take most of the province's territory, particularly the Tambopata National Reserve. However, large areas around these reserves have been increasingly affected by both legal and illegal mining activities, especially when they are close to the Interoceanic highway. At the same time, ecotourism has become increasingly popular with local and international tourists and relevant for the province's economy. [10] Figure 1 illustrates different land uses in the province, highlighting how forest loss concentrates along the mining corridor and the highway.[11]

[9] For more information about how the WA works with various local stakeholders to establish science-policy-society collaborations to ensure biodiversity conservation and human well-being in Madre de Dios, please refer to Mathez-Stiefel et al. (2020).

[10] Please refer to Ocanas and Thomsen (2023) for an overview of the opportunities and challenges related to sustainable tourism in Madre de Dios.

[11] We would like to thank Lorenz Zeller for producing the map.

Figure 1: Land use change and forest loss in Tambopata, Madre de Dios



Data collection

The data collection underlying this report took place in three steps. We detail them below.

- Step 1: Stakeholder selection

We rely on a study previously conducted by the WA in Madre de Dios in 2023 aimed at gaining an initial understanding of the network dynamics and to identify "difficult to reach" stakeholders. [12] This study produced a comprehensive list of stakeholders and an initial overview of their relations. This list of stakeholders was used to establish 19 stakeholder groups of interest. Representatives from each stakeholder group were then pre-selected to make up the interview sample. The heterogeneity and size of

[12]For more information about the previous study conducted in 2023 titled "Mapeo de actores en Madre de Dios", please contact Elena Borasino (elena.borasino@wyssacademy.org) to request access.

stakeholder groups were considered in the selection. For example, representatives of diverse stakeholder groups with a large presence in the area (e.g., farmers) appear more often in the pre-selected sample than representatives of homogeneous groups (e.g., a specific government institution). [13] Typically, between 1 and 4 representatives per stakeholder group were contacted for an interview. [14]

- Step 2: Questionnaire development

We collected social network data via in-person semi-structured interviews. The interview questionnaire included network-related questions (e.g., common contacts and frequency of their contacts) and open-ended questions related to perceptions about the environment. [15] We also included questions about the social-ecological links between stakeholders and different land cover types, to grasp how stakeholders manage services provided by the ecological systems in the landscape, such as forests, rivers, and agricultural lands.

- Step 3: Interview logistics and training

We recruited several local facilitators to support the data collection process. [16] The local facilitators underwent a comprehensive training on how to build trust with respondents, accurately formulate questions, and capture responses. The training also

[13] Please note that heterogeneity is defined in terms of the stakeholder group. For example, for a specific organization, we assume less representation is necessary to understand with their connections than for more diverse and larger groups such as farmers. For government stakeholders, we work at different institutions or administrative levels; public servants are not considered a stakeholder group in our list.

[14] Some stakeholders can be more difficult to reach, while others might systematically refuse to be interviewed, for this reason, some stakeholder groups may be overrepresented (e.g., tourism-related) while others are underrepresented (e.g., national government and processors). Various normalization techniques are used to account for these discrepancies in the analysis; these are detailed below.

[15] The questionnaire was approved by the ethics committee of the University of Bern. For more details on the questionnaire and other research steps taken, please contact Henrique Sposito (henrique.sposito@wyssacademy.org) to request access to the "Stakeholder Network Analysis Handbook".

[16] We would like to thank both Ramona Michel and Lya Segovia Yanco who worked as field coordinators at different stages during data collection.

included an overview of social network concepts and ethical guidelines. The fieldwork took place between November 2024 and February 2025. A total of 49 interviews were conducted and, on average, each interview took 45 minutes. The data collected was then transcribed and cleaned. [17] Table 1 describes the stakeholder groups and the number of respondents per group. [18]

Table 1: **Description of stakeholder groups interviewed**

Stakeholder group	Description	Nr. of respondents
Agroforestry farmers	Farmers who integrate trees with crops and/or livestock to enhance productivity, biodiversity, and sustainability.	4
Conventional farmers	Conventional farmers who primarily grow crops and/or manage livestock	3
Loggers	Actors and associations involved in formal timber harvesting.	3
Non-timber collectors	Collectors of non-timber forest products, such as Amazon nuts.	2
Fishing	Fishing-related actors such as river fishers and aquaculture farmers.	4
Gold miners	Actors and associations involved in formal gold mining.	2
Extraction service providers	Service providers that support extractive practices such as mining and logging.	2
Traders	National and international traders of goods and commodities.	3
Processors	Actors involved in the transformation of primary agricultural products and/or non-timber forest products.	1
Tourism	Tourism-related actors for local and international visitors, such as tourism agencies and accommodation services.	7
Public service providers	Providers of utilities such as electricity, gas, and water services.	2
Military and defense	Military and defense-related actors.	2
NGOs	Environmental conservation and development NGOs.	3
Research institutions	Public and private research institutions.	2
National government	Peruvian government officials.	1
Department and provincial government	Tambopata municipality and Madre de Dios regional government officials.	4
Indigenous peoples	Members of ethnic/cultural groups indigenous to the region.	2
Finance	Actors in the private sector working in finance, such as local banks.	2

[17] There were small inconsistencies regarding how the data about social links were recorded in some of the interviews. In a few instances, information was provided by interviewees beyond what was requested. In those cases, we use only the requested information to ensure the data are consistent and comparable.

[18] Sometimes interviewees mentioned stakeholders not included in the groups described in the table, these are coded as “Other” in analysis below.

Social network analysis in environmental research

Human societies and the environment are interconnected, their interactions play a critical role in shaping how social-ecological systems function and evolve. [19] Environmental governance requires collaboration between various stakeholders. [20] Examining how these stakeholders connect to each other and to the ecological systems can provide a better understanding of their roles in the larger social-ecological systems in place. [21]

Social network analysis reveals the relationships between social units, representing various types of connections between them. Examples of such connections include friendships or the exchange of knowledge. These connections can have distinct characteristics, such as being directed (i.e., have a clear origin and target) or undirected, and take different values reflecting the strength, intensity, or frequency of interactions between social units. In network terminology, social units are commonly referred to as "nodes" and connections are called "edges". Nodes are graphically represented by points and edges by lines. The structure of social networks varies depending on the nature of the nodes and the characteristics of the edges between them. [22]

[19]For more information on the resilience of social-ecological networks, please refer to Janssen et al. (2006). For more information on how social-ecological systems are formed, change, and persist, see Folke et al. (2010).

[20]For more information on how network structures can foster collaboration on environmental governance, please refer to Bodin (2017).

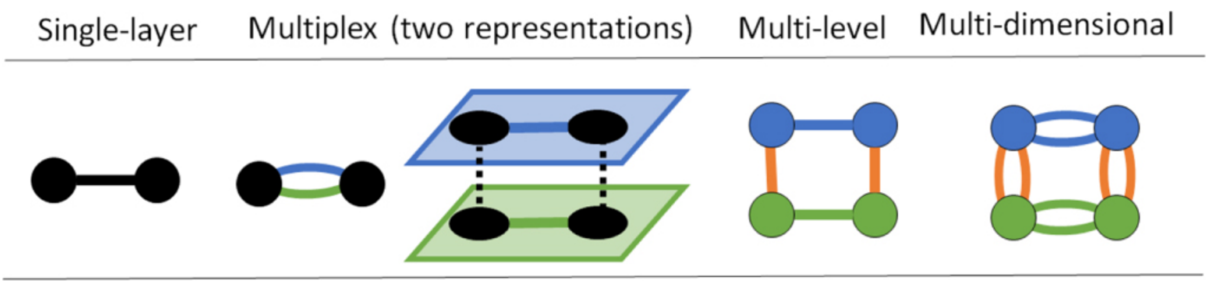
[21]The WA, in collaboration with the ETH Zurich, also works to unfold evidence of the transformative capacities in social-ecological systems in Madre de Dios. The TransSES project, led by Prof. Dr. Adrienne Grêt-Regamey and Paula Mayer, approaches social-ecological systems from a more granular, qualitative, perspective that accounts for how these networks are co-created at different levels. For more information about the project, please contact Paula Mayer (mayerpa@ethz.ch).

[22]For an introduction to social network analysis and an overview of various perspectives, methods, and applications, please refer to Scott and Carrington (2011).

Social network analysis also helps to analyze the complex relationships between social and ecological systems. [23] Social units (i.e., nodes) can relate to ecological systems through the demand and management of ecosystem services. [24] Links between nodes and the ecological systems can represent material (e.g., timber, mining, and food) and immaterial ecosystem services (e.g., cultural and well-being). That is, nodes can connect (e.g., share edges) with one another socially (e.g., collaborating) and to land cover types they use or manage. These land covers, in turn, can be connected among themselves through ecological processes.

There are different ways to represent social-ecological systems using social network analysis, as highlighted in Figure 2. Although boundaries between social and ecological systems are not easily defined in practice, we rely on single-layer and multi-level representations in the analysis below.

Figure 2: **Different representations of social-ecological systems as networks (Source: Sayles et al. 2019).** Circles are nodes and lines are edges. Black nodes/edges are social or ecological, defined by attribute values. Blue, green, and orange nodes/edges are social, ecological, and social-ecological respectively.



[23] For more information on how social networks influence natural resource governance, please refer to Bodin and Crona (2009). Social network analysis simplifies the complexity of social and ecological relations in favor of reproducibility and scalability, please refer to Bodin et al. (2019) for an overview of this and other network approaches to investigate social and ecological relations.

[24] For more information about how human relations to ecosystem services can be conceptualized using networks, please refer to Felipe-Lucia et al. (2022) and to Sayles et al. (2019).

Analysis

In the analysis below, we compare the 2025 configuration of the Tambopata social network with the one from 2023. Although there are small differences in the objectives and methods in the network analysis conducted in 2023 and the current study, the similar questions asked and overlap in study area (i.e., Tambopata province), and topic (i.e., local governance), allow for a cautious comparison of the two networks. [25] The subsequent comparisons between the networks focus on stakeholder groups (e.g., NGOs), rather than specific stakeholders. [26] Since this aggregation could introduce unforeseen biases, we normalized attribute values, such as frequency of contact, and analyze the number of edges received, rather than sent, by groups. [27] The analysis focus on descriptive network measures, such as network density (i.e., ratio of connections in relation to all possible ones) and, therefore, is exploratory and not causal.

We also compare changes in centrality in the Tambopata social network in 2023 and 2025. Social network analysis is helpful to examine certain types of relational power. Node centrality, for example, can be helpful to illustrate how influential certain stakeholders are regarding network dynamics, in relation to their position. There are several types of centralities in networks, such as the number of connections a

[25]Although both studies overlap at the Tambopata province level, the previous study had a slightly broader regional scope (i.e., Madre de Dios).

[26]Besides making the comparison possible, the aggregation by stakeholder group also facilitates that the network visualized and analyzed descriptively. This does not assume these groups are monolithic, rather that they are a partial and abstract representation of the relations of a certain stakeholder group at a point in time.

[27]We normalize values by keeping the average value for their attributes (e.g., frequency of contact) multiplied by half of the number of edges recorded (i.e., dependent on interview number). This means we aggregate edges and their values by stakeholder groups to facilitate visualization. If, for example, edges are duplicated (i.e., multiple stakeholders within a stakeholder group share the same edge with another group), we keep the average value for their attributes (e.g., frequency of contact) multiplied by half of the number of edges recorded. We choose to normalize edges, instead of extracting the network backbone (i.e. a subgraph of the network that contains only the most important edges), since it allows us to compare changes in network density and transitivity (i.e., clustering coefficient).

stakeholder has with others (i.e., degree centrality), the average distance of a stakeholder to others (i.e., closeness centrality), how often a stakeholder holds a gatekeeping position connecting different stakeholders (i.e., betweenness centrality), or how often a stakeholder connects to other highly influential ones (i.e., eigenvector centrality). [28]

We employ exponential random graph models (ERGM) to investigate the structure of the 2025 Tambopata social network. [29] ERGM is a flexible network modeling technique for cross-sectional network data (i.e., data collected at one point in time) that assumes that the observed network structure can be explained by a set of sufficient statistics. The dependent variable in ERGMs is the network structure (e.g., the presence or absence of edges between nodes), while the independent variables are the node or edge covariates (exogenous) and network effects refer to the (endogenous) structures that influence the formation of edges. We hypothesize that:

- *Stakeholders tend to cluster around common connections. That is, if stakeholder A is connected to stakeholder B, and stakeholder B is connected to stakeholder C, it is likely that stakeholder A also shares a connection with stakeholder C.*
- *Stakeholders that receive many edges are more likely to attract new ones, creating a pattern of preferential attachment based on their popularity. That is, if stakeholder A, B, and C are connected to stakeholder D, it is likely that stakeholder E is also connected to stakeholder D.*
- *Stakeholders' links to land cover types influence edge formation. That is, if stakeholder A and stakeholder B share a strong connection to the same land cover type, stakeholder A and stakeholder B are more likely to be connected.*

To investigate the hypotheses, we model the odds of observing the network based on the number of observed edges, the tendency of stakeholders to cluster around common connections, how in-degree centrality influence the probability of edge formation, and how sharing strong connections to land cover types influence edge formation. [30]

[28] Sources of power in social network analysis can differ from commonly used measures such as monetary or geopolitical power. However, network sources of power often implicitly account for formal institutions (e.g., laws and agreements) that shape, regulate, or precede connections.

[29] There are different ways to model networks; for more information please refer to Block et al. (2019).

Limitations

Before presenting the findings, we note some limitations of the data collection and subsequent analysis. First, the data collected is not exhaustive and likely misses stakeholders and relations in the network. It captures a picture of the network at a single point in time. Additionally, the network aggregation by groups makes the networks less sensitive to the number of stakeholders interviewed for each group, it limits, for example, what can be said about how changes in the network composition (e.g., the entry or exit of specific stakeholders) influence network dynamics. Social network changes can be caused by a combination of several drivers and feedback loops. Although the subsequent analysis can point to where network changes likely occurred, we cannot directly attribute these changes to specific interventions or stakeholders. [31]

Second, the analysis employs social network methods to investigate social-ecological systems. While we collected data about social-ecological connections, we did not collect data for the interactions between ecological systems (e.g., land cover spillovers, nutrient flows between different land covers). The analysis, therefore, focuses on social-ecological connections but does not examine feedback loops that originate from changes within the ecological system. [32]

Finally, we only model the most recent Tambopata social network. The aggregation of stakeholders necessary to compare the 2023 and the 2025 configurations of the network makes attribution of changes over time to specific stakeholders challenging.

[30] We select the most mentioned land use cover type by stakeholder group in interviews. If two or more land use cover types are mentioned equally frequently, we take the first value in alphabetical order. Please note that data about how stakeholders connect to land cover types was only collected in the 2025 study.

[31] Answering questions related to how edges may change over time for specific stakeholders might require a different research design, data collection, and hypotheses. Future studies should move beyond the initial overview presented in this report and provide more specific insights into how changes in the composition of stakeholders and changes in their connections influence local governance dynamics.

[32] Incorporating feedback loops that originate from changes within the ecological system is beyond the scope of this study, however, we encourage future studies to expand this analysis to include these interactions.

Alongside this, the differences in objectives and sample only allow us to descriptively compare both networks. [33]

[33] In order to improve the potential for attribution and impact measurement, future studies that leverage social network methods in the Tambopata landscape should ensure that similar data collection and methodological approaches are used.

Findings

A comparison between the 2023 and 2025 Tambopata social networks

We compare the 2025 configuration of the Tambopata social network with the one from 2023 in Figure 3. The Tambopata social network is denser (e.g., ratio of edges) in 2025 in comparison to 2023. This means that there are more connections between diverse stakeholder groups in the most recent network. [34]. This change appears to be driven by certain stakeholder groups, including NGOs, indigenous groups, farmers (both agroforestry and conventional), and non-timber forest product collectors, receiving more edges in 2025 in comparison to 2023. [35] While government-related groups remain relevant in the 2025 network, both the national government and, especially, department and provincial government receive fewer edges in comparison to 2023. [36] This suggests that stakeholder groups, such as NGOs, indigenous groups, farmers, and non-timber forest product collectors have become better integrated into the network and, likely, more relevant for the local governance dynamics.

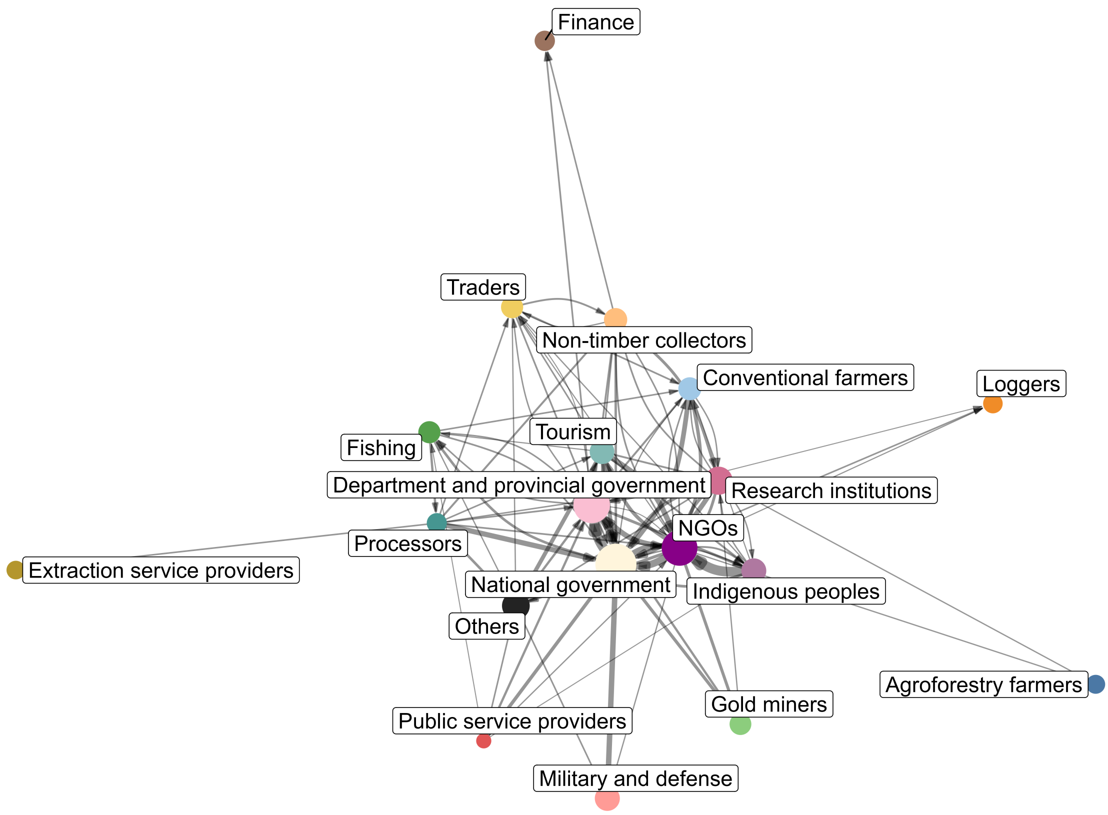
Figure 3: **Comparing the Tambopata social network in 2023 and 2025 by stakeholder group.** Node colors represent the stakeholder groups. Nodes are sized by number of edges received. Edges are sized by the (normalized) frequency of their interactions.

[34]The ratio of edges in relation to all possible edges, the network density, was 0.269 in 2023 and 0.316 in 2025. The ratio of the count of triangles and connected triples, the network transitivity, was 0.575 in 2023 and 0.615 in 2025. Please note that scores for the measures here, and throughout the report, are re-scaled to range from 0 to 1 in order to facilitate comparison.

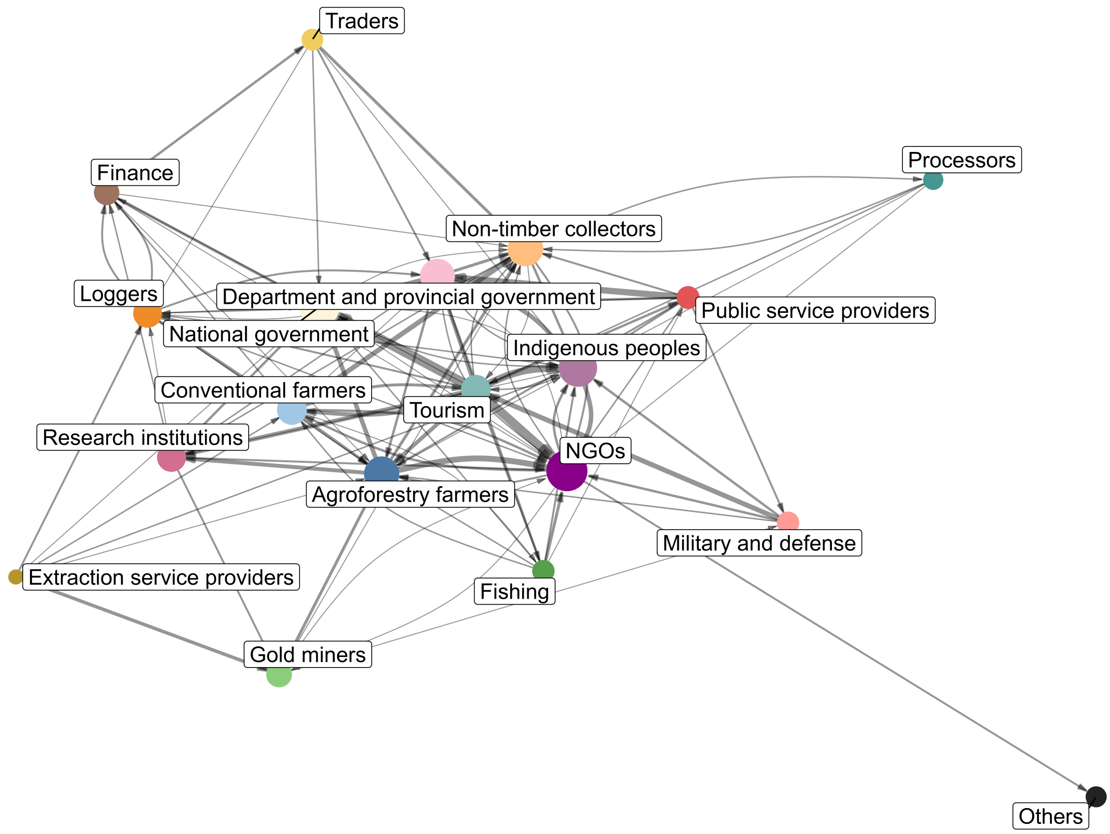
[35]The in-degree centrality of NGOs changed from 0.63 in the 2023 network to 1 in 2025, for indigenous groups it went from 0.14 to 0.79, for conventional it went from 0.09 to 0.32, for agroforestry farmers it went from 0.02 to 0.60, and for non-timber forest product collectors, it went from 0.10 to 0.61.

[36]The in-degree centrality of the department and provincial governments went from 0.68 in 2023 to 0.57 in 2025, and for national government, it went from 1 to 0.95.

2023


Finance
Traders
Non-timber collectors
Conventional farmers
Loggers
Fishing
Tourism
Department and provincial government
Research institutions
NGOs
Processors
Extraction service providers
National government
Indigenous peoples
Others
Agroforestry farmers
Gold miners
Public service providers
Military and defense

2025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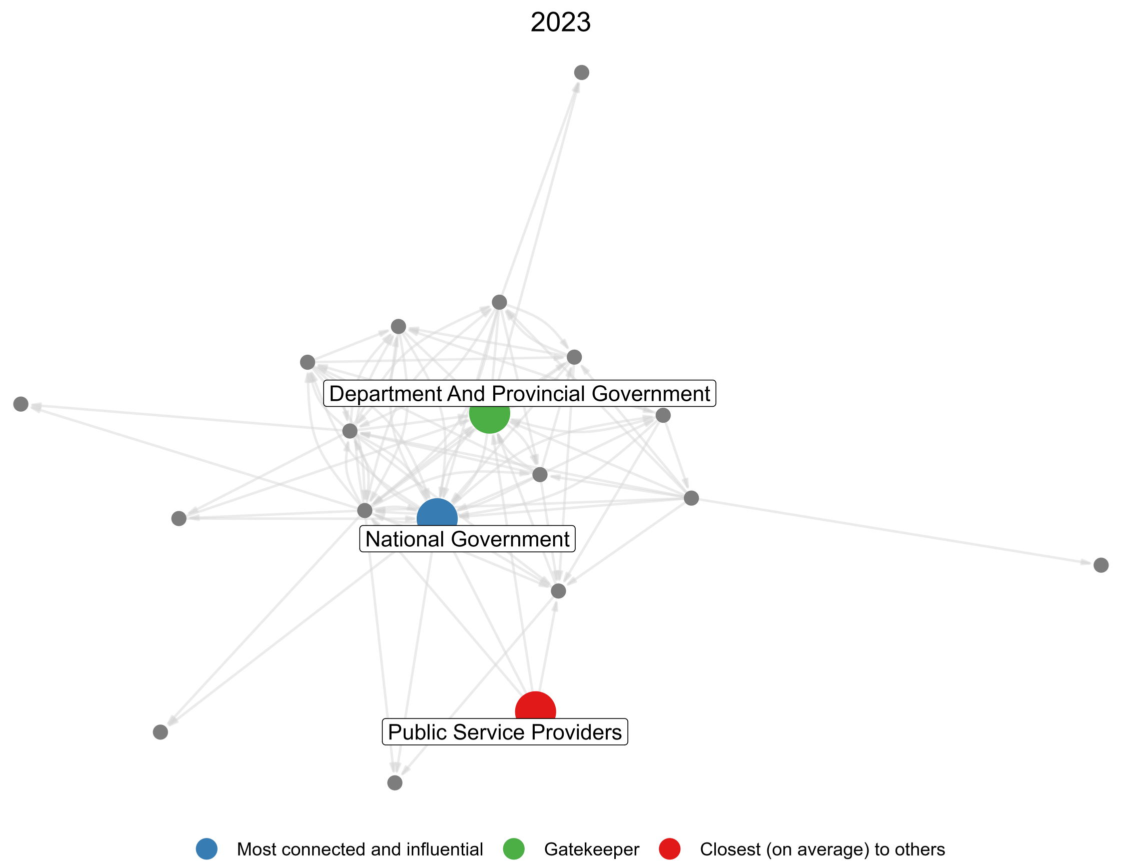
Indigenous peoples
Conventional farmers
Tourism
Research institutions
NGOs
Agroforestry farmers
Military and defense
Extraction service providers
Fishing
Gold miners
Others

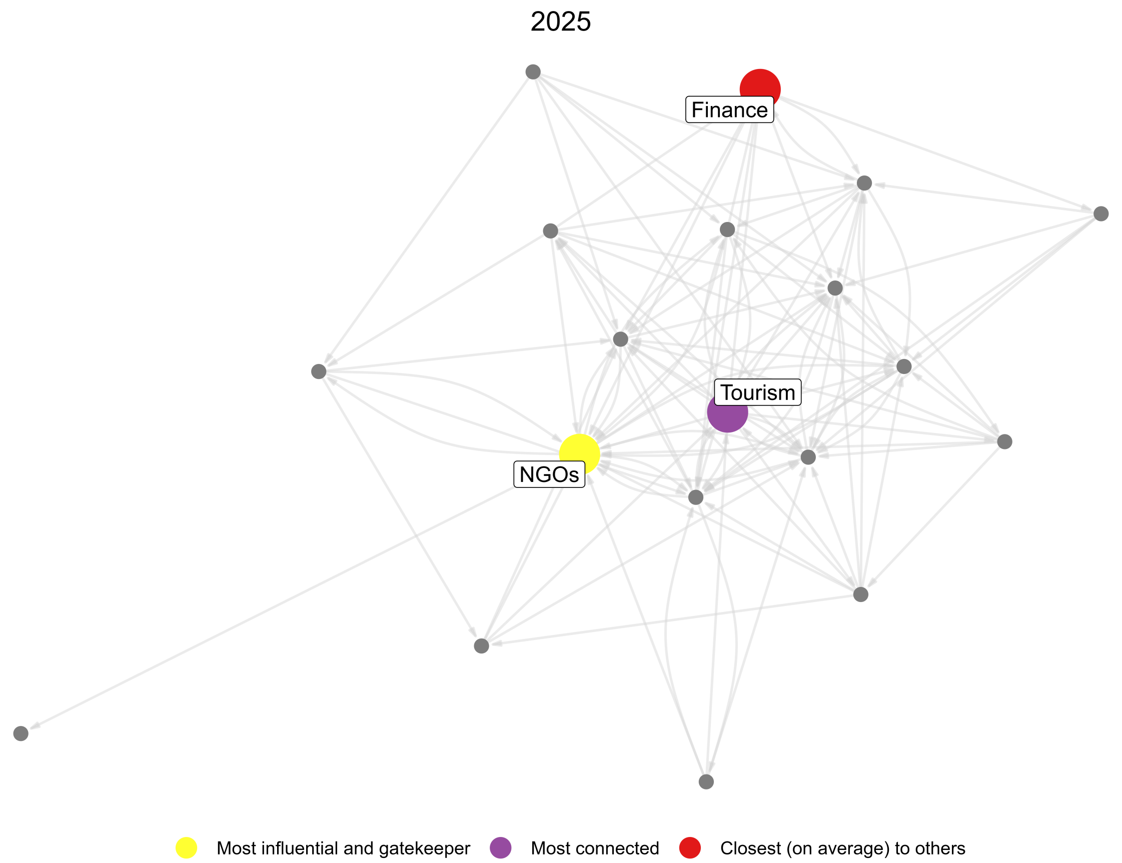
We compare different types of network centrality in the 2023 and 2025 configurations of the Tambopata social network in Figure 4. In the 2023 network, the Peruvian national government was the most connected and influential stakeholder group, while department and provincial government agencies were the gatekeepers connecting diverse stakeholder groups. [37] Public service providers (e.g., energy and water companies) were closest, on average, to other stakeholder groups in 2023. [38]

Figure 4: **Comparing the Tambopata social network in 2023 and 2025 by centrality of stakeholder group.** Node colors in the network represent the different types of network centralities. Central nodes are labelled and made bigger than others to facilitate visualization.

[37] In social network analysis, gatekeepers are nodes that have some control over access to different nodes or network communities (i.e., clusters of nodes). Their structural position allows them to control, for example, the flow of information or decide what types of information are shared. This does not necessarily mean they share or withhold information in practice, but that they are in a position that allows them to do so. Please refer to Corra and Willer (2002) for more information about gatekeepers in social networks.

[38] Although important gaps remain in the provision of energy and water services in Tambopata, these stakeholders provide essential services to most people who live there.


2023
Department And Provincial Government
National Government
Public Service Providers
Most connected and influential
Gatekeeper
Closest (on average) to others


2025
Finance
Tourism
NGOs
Most influential and gatekeeper
Most connected
Closest (on average) to others

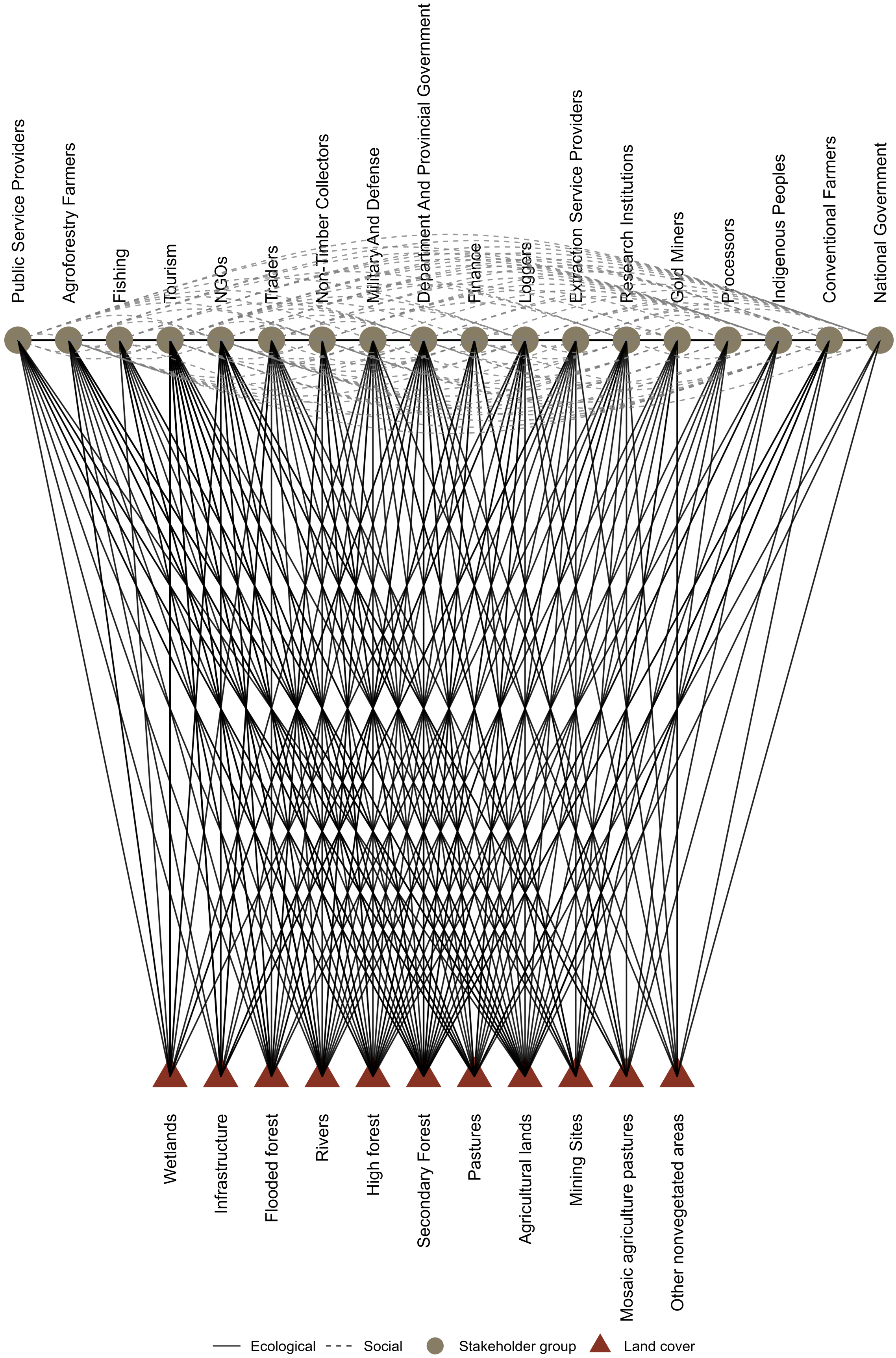
Different stakeholder groups became central in the 2025 configuration of the Tambopata social network. NGOs, for example, became the most influential stakeholder group and the gatekeepers connecting diverse stakeholder groups. This suggests that they have likely contributed to flattening the network by creating more connections and diffusing power previously held by government-related groups. This is corroborated by the fact that tourism-related stakeholders became the most connected ones in the 2025 network. Tambopata has increasingly become an eco-tourism destination for those searching for low-impact interactions with Amazonian environments and communities. Eco-tourism is an activity often promoted by, or done in collaboration with NGOs. As well, finance-related stakeholders became the closest on average to other groups in the network and able to reach many other groups quickly. As was the case with public service providers in 2023, finance-related stakeholders, such as local banks, provide important services to most of those who live in the area.

The social-ecological connections in the 2025 Tambopata social network

The complex connections between stakeholder groups and the land cover they use or manage are represented as a multi-level network in Figure 5. Stakeholder groups often connect to many land covers. This is especially true for stakeholder groups such as military and defense, loggers, traders, research institutions, and department and provincial government, all sharing connections with diverse land cover types. Primary forest, wetlands, secondary forests, pastures, agricultural lands, and rivers are some of the land covers used or managed in Tambopata. [39]

Figure 5: **The social-ecological connections in Tambopata social network represented as a multi-level network.** Node colors and shapes represent network levels, stakeholder and land cover types. Straight edges represent connections between stakeholders and land covers, dashed edges represent connections between stakeholder groups.

[39] Besides the land cover types in Figure 3, we also collected data about lakes, mosaic agriculture, and other non-vegetated areas. However, since these land covers were mentioned considerably less frequently than others, they were removed to facilitate visualization.


Public Service Providers
Agroforestry Farmers
Fishing
Tourism
NGOs
Traders
Non-Timber Collectors
Military And Defense
Department And Provincial Government
Finance
Loggers
Extraction Service Providers
Research Institutions
Gold Miners
Processors
Indigenous Peoples
Conventional Farmers
National Government
Wetlands
Infrastructure
Flooded forest
Rivers
High forest
Secondary Forest
Pastures
Agricultural lands
Mining Sites
Mosaic agriculture pastures
Other nonvegetated areas
Ecological
Social
Stakeholder group
Land cover

By visualizing how stakeholder groups connect to land cover types in Tambopata, we can better understand the specific ways in which environmental governance at the stakeholder level is not necessarily connected, or consistent, with how land covers are used or managed on the ground. For example, whereas the military and defense, traders, loggers, and gold miners are not central stakeholders in the Tambopata social network, they connect with diverse land covers and can be relevant for the management of various ecological systems. By accounting for the social and ecological dynamics in place, we can direct actions and promote governance changes, such as better integrating into the network of stakeholders that, on the ground, have a large impact on the environment.

The (unexpected) patterns in the 2025 Tambopata social network

We rely on ERGMs to explore how certain network effects and node attributes help understand the structure of the 2025 Tambopata social network. Table 2 displays the results for the ERGM models. The models start simple, accounting for the chances of observing the network at random based on the number of edges, and build upon one another by adding one network effect or node covariate at a time. The approach allows us to compare the models and to understand how the network effects and node attributes relate to one another.

Table 2: **Modelling the 2025 Tambopata social network using ERGMs**

	Model 1	Model 2	Model 3	Model 4
Edges	-0.77^{***}	-1.49^{**}	-0.67	-0.71
	(0.12)	(0.47)	(0.46)	(0.46)
Transitiveness		0.50	0.10	0.10
		(0.33)	(0.32)	(0.31)
In-degree centrality			-4.11^{***}	-4.05^{***}
			(0.86)	(0.82)
Land cover type				0.34
				(0.39)
AIC	428.58	428.11	412.73	413.96
BIC	432.41	435.78	424.24	429.30
Log Likelihood	-213.29	-212.06	-203.37	-202.98

Note: Edges are a network effect that refers to the odds of observing the network based on the number of observed edges. Transitiveness is a network effect that refers to the tendency of stakeholders to cluster around shared connections. In-degree centrality is a network effect that refer to how node in-degree centrality influences the probability of edge formation. Land cover type is a categorical node attribute that refers to a strong connection to a land cover type. Each column in the table represents a model. Model 1 accounts for how edges predict the network structure; model 2 includes edges and transitiveness; model 3 includes edges, transitiveness, and in-degree centrality; and Model 4 includes edges, transitiveness, in-degree centrality, and land cover type. Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) are statistical metrics to compare different models by balancing goodness of fit and model complexity. Significance: $^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$

Model 1 indicates that network connections are not likely to be formed at random (i.e., negative and statistically significant coefficient for edges). Model 2 illustrates that network transitiveness does not help to predict edge formation (i.e., positive but not statistically significant coefficient for transitiveness). This suggests sharing common edges does not necessarily increase the likelihood of clusters of stakeholders being formed in the network. The negative and statistically significant coefficients for in-degree centrality in Model 3 suggest that stakeholders that receive fewer edges are more likely to connect with one another (e.g., nearby ones) than to popular stakeholders within the network. [40] Connections to a land cover type, however, do not have an effect on edge formation, as illustrated in Model 4 (i.e., positive but not statistically significant coefficient for land cover type).

The models suggest that network transitiveness and land cover types are not helpful to explain the network structure (i.e., how stakeholders connect to one another). However, in-degree centrality helps understand the network structure and edge formation in

[40] Goodness of fit diagnosis of Model 3 indicates that the model fit is not ideal; it could be greatly improved with more data.

unexpected ways: stakeholders tend to connect locally and not necessarily around the most central ones. This suggests that although popular stakeholders receive many edges from diverse stakeholders in the network, these edges are not necessarily reciprocated.

Recommendations and conclusion

The Tambopata social network appears to have become more decentralized in 2025, with diverse stakeholders better integrated into the network. At the same time, the analysis highlights critical gaps, particularly in the inclusion of peripheral but environmentally impactful stakeholders. In particular, the network analysis highlights three priority areas for strengthening inclusive environmental governance and promoting nature–people co-benefits in Tambopata. The first area concerns the need to bridge the divide between central stakeholders and those at the margins of the network through more targeted engagement. Loggers, gold miners, and extractive service providers remain weakly connected within the network, despite their substantial impact on ecosystems and land use. Long-term commitment to structured dialogues or roundtables that bring these stakeholders into conversation with central ones (e.g., NGOs and governments) can help address this gap.

A second area of opportunity lies in enabling inclusive, multi-stakeholder platforms that reduce fragmentation and clustering. The current network structure shows that central, popular stakeholders tend to receive connections without reciprocating them, thereby reinforcing asymmetric flows of information and influence. Designing coordination mechanisms, for example, a dialogue forum with rotating facilitation responsibilities among stakeholders, can help flatten governance hierarchies and broaden participation in ecosystem management. Peer-learning exchanges on different land uses, economic needs, and relationships to ecosystems (e.g., between farmers and miners, or between indigenous groups and traders) can further contribute to building trust, fostering mutual understanding, and developing shared interests. These efforts can, in turn, help launch or strengthen coalitions of change that promote more sustainable land use.

Third, there is strategic value in supporting stakeholders who occupy bridging positions within the network. NGOs, tourism, and finance-related stakeholders have emerged as key connectors across otherwise fragmented parts of the stakeholder landscape. Providing these stakeholders with leadership development support, technical resources, and opportunities for structured collaboration can help amplify their influence and foster greater connectivity. Moreover, complementary efforts to enhance information flows that are tailored to specific stakeholders' needs can also reduce knowledge asymmetries within the network.

Taken together, these recommendations emphasize the importance of addressing both structural gaps in stakeholder engagement and the disconnects between institutional governance and ecological reality. Strengthening connectivity, reciprocity, and alignment across the stakeholder network represents a key step toward more adaptive, equitable, and sustainable governance in Tambopata. Importantly, the WA Hub South America has already begun implementing several of these recommended actions. These actions include, for example, collaborating with miners, strengthening ties with indigenous organizations, and engaging with administrations to advance an inclusive plan for local development. These early interventions form a promising foundation for improving local landscape governance in Madre de Dios and the Amazon basin. Ultimately, strengthening the stakeholder network in Tambopata is not only key to advancing co-benefits for nature and people there, it also offers a replicable model for transforming governance dynamics in other landscapes facing similar environmental and social pressures.

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