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Social network analysis of conservation and one health governance in Madagascar

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ABSTRACT

Madagascar, a globally recognised biodiversity hotspot, faces escalating biodiversity loss and zoonotic disease risks. Weak response systems and fragmented governance further exacerbate these threats. This study identifies key conservation and health actors and analyses their connections to understand decision-making and information flow. The findings emphasise the need to integrate One Health into conservation strategies to address interconnected public health and biodiversity challenges. Following the Laumann-Marsden-Prensky framework, a social network analysis (SNA) survey was conducted between March 14 and June 24, 2022. The study involved 30 senior leaders (≥5 years experience) in biodiversity conservation and health in Madagascar. Key network metrics, indegree, outdegree, and eigenvector centrality, identified influential actors, while network density and centralisation assessed structural cohesion. Participants listed collaborators in conservation and health projects and funding sources. The strength of One Health integration and interaction was quantified. Among 287 identified actors, 54.4 % are international entities. SNA shows that foreign organisations dominate collaboration and funding networks in conservation and public health governance, while local government bodies have limited involvement. Only a few stakeholders have effectively integrated the One Health approach into their conservation and health governance practices. These findings highlight a reliance on international actors, primarily due to funding access, with limited local participation. While international support provides crucial resources, greater national and local leadership is essential for the sustainable implementation of One Health. This study provides insights to enhance local involvement in conservation governance.

1. Introduction

Planetary boundaries, critical thresholds that sustain Earth's stability, are being crossed, with six of nine already surpassed, driving irreversible environmental change and posing a significant threat to global public health (Richardson et al., 2023). Madagascar, a biodiversity hotspot and global conservation priority, exemplifies the intersection of ecological and human health challenges (Brooks et al., 2006;

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Miller et al., 2013). The island harbours extraordinary biodiversity, with approximately 90 % of its species found nowhere else on Earth (Goodman et al., 2022). However, this natural wealth contrasts starkly with the severe poverty of its human population, which has one of the highest proportions of individuals living in extreme poverty globally (Roser et al., 2019). This socio-economic vulnerability exacerbates health disparities, increasing susceptibility to disease spillover from wildlife (Kemarau et al., 2024).

Madagascar's conservation and health challenges mirror those of other tropical biodiversity hotspots. Together with Brazil, Indonesia, and the Democratic Republic of the Congo, these four countries harbour 65 % of the world's primate species, with 60 % now threatened due to habitat loss and fragmentation (Estrada, 2011). Indonesia presents particularly relevant parallels, as both countries face escalating deforestation that fragments habitats, intensifies human-wildlife interactions, and increases the risks of zoonotic disease spillover (Gunawan et al., 2024). Like Madagascar, Indonesian islands such as Sulawesi have inadequate protected area coverage, with only 10 % forest cover, despite their rich biodiversity (Pusparini et al., 2023). Both nations have adopted social forestry approaches that attempt to balance biodiversity conservation with community welfare in occupied forest areas (Gunawan et al., 2022; Poudyal et al., 2016). These parallels underscore the global nature of the conservation-health-poverty nexus, highlighting opportunities for cross-regional learning in developing integrated One Health approaches that address both ecological and socio-economic drivers of environmental degradation.

Preserving Madagascar's biodiversity is essential for safeguarding its ecological uniqueness and maintaining critical ecosystem services, including carbon sequestration, water purification, and climate regulation, but also for supporting human health by reducing the risk of zoonotic diseases and ensuring access to essential natural resources (Everard et al., 2020; Neugarten et al., 2016; Ralimanana et al., 2022). These services are vital for local livelihoods and global environmental health. Madagascar has been a focus of international conservation efforts, ranking among the top ten recipients of biodiversity-related aid between 1993 and 2008 (Miller et al., 2013; Waeber et al., 2016). Despite these investments, Madagascar faces alarming deforestation rates, driven by the overexploitation of natural resources by impoverished communities that rely on them for survival (Fritz-Vietta et al., 2011; World Bank, 2024). This environmental crisis highlights a deeply intertwined conflict between conservation and poverty alleviation, one of Madagascar's most pressing issues (Pollini, 2011). Deforestation, driven by economic hardships and unsustainable practices, is a primary driver of biodiversity loss. This degradation destabilises ecosystems and heightens the risk of zoonotic disease emergence, a stark reminder of the fragile balance between human activity and nature, calling for an urgent shift toward integrated solutions (Garg and Banerjee, 2021; WHO, 2021).

In this context, the One Health (OH) approach is indispensable for addressing disease emergence at the intersection of environmental degradation, poverty, and weak health systems (Danasekaran, 2024). This integrative framework recognises the interconnectedness of human, animal, and ecosystem health, promoting interdisciplinary collaboration to tackle complex health and biodiversity challenges (Destoumieux-Garzón et al., 2018). The COVID-19 pandemic drew global attention to the importance of this approach, catalysing a renewed commitment that expanded its focus from zoonotic disease control to broader systemic health and sustainability issues (Mwatondo et al., 2023). In 2022, the Quadripartite Collaboration between FAO, WOAH, UNEP, and WHO established a global governance framework to strengthen One Health efforts (WHO, 2022). In Sub-Saharan Africa, Madagascar participates in regional One Health initiatives, including the Southern African Centre for Infectious Disease Surveillance (SACIDS), addressing antimicrobial resistance (AMR) through a One Health lens (Iyadi, 2023). Within the Western Indian Ocean region, the One Health approach is being implemented through the Indian Ocean Commission's SEGA-One Health network. This regional initiative aims to improve member states' prevention and response capacities to address pandemic and epidemic risks through targeted capacity building in disease monitoring and emergency response (Veerapa-Mangroo et al., 2024). Madagascar exemplifies both the potential and challenges of implementing One Health approaches in resource-constrained settings. Like many nations in the Global South, it faces a convergence of ecological degradation, poverty, and weak healthcare infrastructure, creating fertile ground for the emergence of zoonotic diseases (Bardosh et al., 2017). Frequent disease outbreaks, including plague, measles, and COVID-19, highlight the country's vulnerability and the critical need for resilient health systems (Aborode et al., 2021). Despite partnership support, the country's outbreak response is persistently constrained by limited healthcare infrastructure and funding. Addressing these constraints requires sustained international support and long-term investments to strengthen healthcare systems and outbreak preparedness (Sodjinou et al., 2020).

Madagascar established a national One Health platform in November 2023 (Decree N°2023–1356), under the leadership of the Prime Minister's Office. This platform unites the Ministries of Public Health, Agriculture, Livestock, and Environment to implement the OH approach, a collaborative framework endorsed by the FAO, UNEP, WHO, and WOAH. OH promotes well-being, addresses shared health threats and safeguards ecosystems by recognising the interdependence of human, animal, plant, and ecosystem health (FAO et al., 2022). Beyond wildlife conservation, OH aims to safeguard both ecosystems and the livelihoods of local communities that depend on their stability for survival. This national OH platform aligns with Madagascar's commitments under international biodiversity and health security frameworks. As a signatory to the Convention on Biological Diversity, Madagascar committed to the Aichi Biodiversity Targets, including Target 11's goal of protecting 17 % of terrestrial areas (CBD, 2016). The country's revised National Biodiversity Strategy emphasises ecosystem restoration as essential for sustaining the 70 % of the population dependent on agriculture while addressing climate change and poverty (Gardner et al., 2013). These intersecting global commitments demonstrate how international biodiversity and health policies create synergistic opportunities for One Health implementation at the national level. Madagascar's national OH platform is a notable step in aligning with global OH ambitions. Yet, it raises crucial questions about how effectively such frameworks are embedded in local conservation governance and what structural barriers may exist. Effective governance of natural resources is critical to tackling Madagascar's pressing issues (Brinkerhoff, 1996). One of the key factors in overcoming these challenges is fostering collaboration and interaction among stakeholders (Berardo et al., 2014; Dahdouh-Guebas et al., 2022). However, these actors, ranging from local communities and governmental bodies to international organisations, often have conflicting priorities shaped by different interests, motives, and influences on conservation efforts (Bodin, 2017; Rechciński et al., 2019). Understanding the power dynamics among these groups is essential for improving natural resource governance and achieving more effective conservation outcomes (Khan, 2018). Policy-making processes involve a wide range of stakeholders and significant fragmentation among various actors. Many international organisations, including NGOs and public organisations (technical and financial partners), contribute to the complexity of the political process. Social network analysis (SNA) provides a tool for the structural analysis of this complexity. SNA enables the mapping and quantification of stakeholder interactions by analysing their relationships (Bodin, 2017). It helps to understand the functioning of public policy based on patterns of stakeholder interactions and relationships, rather than individual attributes (Bodin and Prell, 2011).

This study aims to identify and analyse key stakeholders involved in terrestrial biodiversity conservation and the health sector in Madagascar. It focuses on inter-organisational relationships shaping policy-making and the integration of the One Health (OH) concept. By

examining these social networks, we seek to assess the structure of collaboration among stakeholders and evaluate the extent to which OH principles are embedded in conservation strategies. We assume that collaboration networks can reveal structural gaps and power imbalances that may hinder the effective implementation of One Health initiatives in Madagascar. The analysis will begin by examining the overall structure of the social network within the biodiversity conservation sector. It then focuses on key aspects, such as collaborations among conservation actors, interactions between conservation and the health sector, and funding partnerships. While previous research has applied SNA to assess disease surveillance and diseases' ecology in OH contexts (Albery et al., 2021; Herrera et al., 2016), to our knowledge, no studies have yet applied SNA to evaluate intersectoral interactions between terrestrial protected area (PA) management and the health sector, particularly in Madagascar. This study extends existing OH governance literature by bridging biodiversity conservation and zoonotic disease risk monitoring using a network-based approach.

This research aims to fill this gap by analysing the integration of biodiversity conservation efforts with health initiatives, focusing on zoonotic disease monitoring on wildlife. The findings highlight structural networks among stakeholders, the role of international funding in environmental and health governance, and the challenges posed by limited political commitment. This research provides critical insights to inform more cohesive, effective, and locally adaptable conservation policies.

2. Methods

2.1. Study design and sample

This study defines stakeholders (represented by organisations) as entities involved in biodiversity conservation and/or health institutions in Madagascar. Stakeholders include organisations that play a role in managing natural resources or contributing to health systems related to these resources. Additionally, local community representatives actively engaged in conservation initiatives were included and selected based on recommendations from other participants. Participants were contacted through email or phone, and interviews were conducted in person or online, depending on availability and accessibility. Of the 50 actors contacted, 30 responded to the survey conducted in French and Malagasy between March and June 2022, additional clarification was provided in June 2023. The selection criterion for participants was individuals holding leadership positions, such as managers, department heads, or experienced personnel with over five years of experience at their organisation.

We applied the Laumann-Marsden-Prensky framework to define network boundaries, a foundational approach in social network analysis that addresses how to delineate social networks while acknowledging that different boundary choices can significantly impact research outcomes and interpretations (Laumann et al., 1983). This framework emphasises that boundaries should be determined based on the research question and outlines five tactics for identifying representative actors. Our boundary definition employed multiple interconnected tactics to ensure comprehensive network coverage. (i) The **geographic** tactic focused on actors within specific regions in Madagascar, recognising that geographical proximity facilitates regular interaction, resource sharing, and collaborative networks. Local and regional actors often share similar environmental challenges and opportunities, making geographic clustering a key factor in identifying influential stakeholders. (ii) The **positional** tactic identified actors based on their formal organisational roles and institutional positions within biodiversity conservation and health sectors. This included representatives from government agencies, NGOs, research institutions, and international organisations who hold decision-making authority or strategic influence within their respective domains. (iii) The **interlock** tactic identified connections among actors through shared participation in key biodiversity and health initiatives, including One Health conferences, collaborative projects (such as the Africam Project under the Prezode initiative), zoonotic disease surveillance, and participatory monitoring involving international bodies, governments, and local communities. (iv) The **reputational** tactic relied on expert nominations to identify actors recognised for their expertise, credibility, and influence within the biodiversity conservation and health communities. (v) The **relational** tactic employed snowball sampling, where current network members recommended additional participants based on their knowledge of existing relationships and collaborative ties.

To complement Laumann's boundary definition approach, we employed a systematic two-pronged method to assess data collection completeness. We considered saturation achieved when two convergent criteria were met: (1) no new insights emerged from additional interviews about network structures, relationships, and conservation practices, and (2) no new stakeholder categories could be identified despite active diversification efforts (Guest et al., 2020). Our assessment involved continuous monitoring of interview content to document when successive interviews provided diminishing novel information, indicating informational redundancy and approaching saturation. In parallel, we actively diversified our sample by seeking new types of actors, while remaining within our research scope, to ensure comprehensive coverage of relevant stakeholder perspectives (Saunders et al., 2018). Saturation was confirmed when two convergent indicators emerged: referrals began looping back to previously interviewed individuals, and further recruitment failed to reveal substantially different stakeholder profiles (Saunders et al., 2018). This convergence signalled that we had reached both network boundaries and theoretical saturation, following established best practices for rigorous saturation assessment (Francis et al., 2010).

2.2. Survey design

A questionnaire survey was conducted to gain insights into the social network of stakeholders involved in conservation and their interactions with health entities concerning zoonotic disease monitoring in wildlife. The participants were asked to identify their direct collaborators in conservation projects and health-related initiatives, specifying operational stakeholders and funding partners. The survey here was adapted from Dahdouh-Guebas et al. (Dahdouh-Guebas et al., 2022). Interactions were categorised based on the type of resource sharing, such as financial support, infrastructure sharing, skill-building activities, or other forms of collaboration, indicating whether they were formal or informal. Data was cross-checked during interviews with other actors to enhance reliability. Participants were asked to specify the nature of their collaborations, including whether interactions were unidirectional or bidirectional, the intensity of interactions, the type of engagement (formal or informal), and the nature of the collaboration (e.g., financial support, health-related activities, conservation projects, infrastructure sharing, capacity building, or other resource-sharing mechanisms). In addition to the quantitative data collected, participants provided qualitative information to clarify or expand their responses. This qualitative data offers valuable context and deeper insights, linking the content of participant explanations to the positions of actors within the network. These insights enabled us to relate participants' statements to specific contexts, enriching the analysis and interpretation of the network.

2.3. Data analysis

2.3.1. One health implementation

This study developed a qualitative, context-specific approach to score One Health (OH) implementation by stakeholders. The assessment used a three-point scoring approach, being described as follows.

A score of "one" (low implementation) was assigned when activities were sectoral, hence involving only one OH component (human, animal, or environmental health) or were primarily focused on non-health areas

such as education, administration, or development. This score indicates minimal OH inclusion and limited or no recognition of the OH framework.

A score of "two" (moderate implementation) was given where sector-specific activities showed elements of the OH approach even if stakeholders did not fully understand or explicitly recognise the concept. Here, the stakeholders' work involved at least two OH components (e.g., human-animal health or animal-environmental health), showing a partial and possibly unintentional alignment with OH principles.

A score of "three" (high implementation) means the stakeholder demonstrates a clear understanding and deliberate application of the OH concept. Activities achieving this level encompassed all three OH components, human, animal, and environmental health, operating within a recognised OH framework. This level indicated a comprehensive approach in which stakeholders intentionally aligned their activities with the OH concept, demonstrating awareness and structured implementation across relevant domains.

This scoring enables an overall assessment of how effectively stakeholders understood and applied the OH concept to their initiatives. It reflects the extent of cross-sector collaboration and concept understanding across the study.

To provide comprehensive context and validate network analysis findings, qualitative data were transcribed and integrated as illustrative quotes. These quotes offer concrete examples of stakeholder perspectives, enabling deeper interpretation of Social Network Analysis (SNA) results and providing a more complete understanding of network structure and dynamics (Herz et al., 2015)

2.3.2. Social network analysis

The statistical analysis was conducted in RStudio (v2025.05.0) of the R package "iGraph" (Csárdi et al., 2025), and focuses on three specific network metrics: (1) in-degree centrality, which is calculated by counting the number of direct ties that a node receives, with each connection weighted by the intensity of interaction and (2) outdegree centrality, that considers the number of outgoing ties node sends to others, and (3) eigenvector centrality, which measures an actor's influence based on their connections to other influential nodes, it considers the incoming as well as the outgoing ties simultaneously. Eigenvector centrality offers a more nuanced assessment by assigning higher scores to actors linked to well-connected peers, thereby reflecting both the quantity and quality of their connections (Table 1). This approach highlights how links to well-connected actors amplify an individual's overall centrality and influence (Valente and Pumpuang, 2007).

Using degree centrality as a metric in geographically dispersed networks can introduce bias when the number of stakeholders varies widely across locations. Applying this metric uniformly across the network may lead to misleading comparisons, as some locations may include a larger number of stakeholders, many of whom exhibit actions that are strictly local. These actors would thus increase one node's degree without translating an influence at the broader scale. These strictly local actors, however, play a role in One Health implementation, ensuring a relay of leadership in specific locations or smaller communities. Therefore, it is interesting to analyse broader and local interactions separately. To address this, singletons, nodes connected only to one other actor without further connections in the broader network, were considered a proxy for highly local actors that increase one node's degree without translating essential features of the network (Kumar et al., 2006; Valente et al., 2008). In this study, the singletons represent either local communities or universities and international organisations that exclusively collaborate with NGOs within their specific protected areas of operation. The network analysis was performed with and without singletons. Removing singletons allowed us to examine the core structure of the network, isolating key nodes and connections that contribute to broader interactions and influence (Kumar et al., 2006). The role of strictly local actors has been analysed separately, as they contribute valuable insights into localised interactions (Kumar et al., 2006; Valente et al., 2008).

Table 1
Summary of the key metrics in social network analysis of conservation and health stakeholders.

SNA Concept	Definition / Description	References
Node	Represents an actor or stakeholder in the network. In this study, nodes refer to organisations and entities involved in the terrestrial conservation and health sectors.	(Laumann et al., 1983; Wasserman and Faust, 1994)
Types of Nodes	Governmental bodies, technical and financial partners, local and foreign-led NGOs, funding agencies, and local communities.	Current paper
Tie / Edge	Represents a connection between two nodes, indicating a relationship or interaction between them.	(Laumann et al., 1983; Wasserman and Faust, 1994)
Direction of Ties	Uni or bidirectional, indicating the flow of information and resources between nodes.	Current paper
Tie Strength	Measured on a scale from 1 to 3: 1 = Infrequent interaction 2 = Moderate 3 = Frequent	Current paper
Nature of Ties	Ties indicate the exchange of resources such as information, funding, technical support, or collaborative activities.	Current paper
Collaboration	Defined as joint activities to achieve shared goals, typically characterised by mutual (two-way) ties and higher interaction frequency.	Current paper
Indegree	Number of incoming ties to a node. Reflects the amount of attention, resources, or interaction a node receives from others.	(Wasserman and Faust, 1994)
Outdegree	Number of outgoing ties from a node. Reflects how proactive a node is in initiating relationships or distributing resources.	(Wasserman and Faust, 1994)
Eigenvector Centrality	Measures a node's influence within the network by considering not just the number of its connections, but also the importance of its connected nodes.	(Wasserman and Faust, 1994)
Centralisation	Describes how unevenly centrality scores are distributed in a network. It ranges from 0, where all nodes are equally central, to 1, where one node holds most of the centrality and others very little. This indicates whether power or influence is concentrated in a few actors or spread more evenly. Standard measures include indegree (the number of incoming ties), outdegree (the number of outgoing relations), and eigenvector centrality (which reflects how well an actor is connected to other well-connected actors).	(Ward et al., 2011)

Complementary to individual parameters, density and network centralisation captured the overall network structure. Density captures the overall cohesion of the graph, while Freeman's degree of centralisation quantifies the extent to which this cohesion is directed around central nodes. Both measures range from zero to one, providing a standardised assessment of the overall network structure (Freeman, 1978; Provan and Milward, 1995). Understanding network structure enhances insights into resilience, robustness, and information flow. Key concepts and metrics used in the SNA in this paper are summarised in Table 1, including definitions of nodes, ties, centrality measures, and collaboration dynamics.

3. Results

3.1. The network structure of conservation and health initiatives

The whole network analysis reveals that international entities and foreign-led NGOs serve as central actors connected to smaller components and isolated actors (Fig. 1). Our comprehensive mapping identified 287 distinct actors across seven institutional categories (Supplementary material 1), with the network comprising major components where international entities and foreign-led NGOs serve as central actors, representing 50.5 % of all stakeholders (Fig. 1A). Government institutions formed the largest single category (78 actors, 27.2%), spanning local (21), regional (37), and national authorities (40). At the same time, the network also includes 71 international organisations (24.7%), 50 national organisations (17.4%), 31 funding partners (10.8%), 26 academic institutions (9.1%), 21 foreign-led organisations (7.3%), eight local communities (2.8%), and two mining industries (0.7%). Key players in the whole network (conservation and health combined) include the Wildlife Conservation Society (WCS), USAID (USA), Cirad (CRD), the Commission de l'Ocean Indien (COI), and the Population Health Environment (PHE) platform, which hold prominent roles in both conservation and development efforts. The World Health Organisation (WHO) is strongly linked to national public health institutions. The whole network's Freeman degree of centralisation was 0.189, indicating a decentralised structure where interactions are broadly distributed, minimising reliance on central hubs and enhancing resilience. The network density, calculated at 0.011, reflects sparse connectivity, with only 1.18 % of possible edges present. This suggests limited collaboration and some isolated or minimally connected nodes.

After removing singletons (Fig. 1B), the centralisation increased to 0.298, revealing a moderately centralised structure within the core network. This shift indicates that low-degree peripheral nodes previously contributed to the network's decentralised appearance. The core network's density rose to 0.064, suggesting a more cohesive structure with stronger interactions among well-connected actors, although the network remains relatively sparse. This is reflected in the fact that peripheral organisations, local authorities, and local communities remain exclusively connected to NGOs operating within their respective protected areas, limiting their engagement with the broader network. For instance, a community group VMT (Local community Unit in Tsinjoarivo) exhibits low network influence, with an in-degree and out-degree centrality of 6 and an eigenvector centrality of 0.06. In contrast, Sadabe (SDB), the NGO managing the protected area where VMT operates, holds more influence, with an in-degree centrality of 13, an out-degree centrality of 12, and an eigenvector centrality of 0.36.

Local NGOs, such as Association Fanamby (ASF) and Madagascar Voakajy (MV), along with foreign-led organisations, like SDB and the Research Center ValBio (CVM), primarily focus on conservation. These organisations also integrate development into their biodiversity conservation efforts and serve as the primary contact points for local communities and authorities. Academic institutions, 77 % of which are international universities, are closely linked with NGOs, facilitating research and conservation collaborations. The network's funding partners are primarily international, except the Madagascar Protected Areas and Biodiversity Fund (FAM).[3] Nevertheless, FAM is financed by the European Union and several international organisations, including the World Bank (WBG), KfW Development Bank (KFW), Conservation International (CI), Agence Française de Développement (AFD), the French Facility for Global Environment (FFE), and the World Wildlife Fund (WWF).

Panel (A) displays the complete network of all 287 interviewed actors, providing an overview of the entire network, while Panel (B) shows the core network with isolated actors (singletons) removed. Stakeholders are categorised by type: governmental bodies, national NGOs, local communities, funding partners, foreign NGOs, international organisations, and mining industries, with each category represented by distinct node colours (see legend). Node size reflects connectivity level (degree centrality), where larger circles indicate actors with more collaborative relationships. Collaboration relationships are represented by arrows between actors, with edge thickness indicating the strength of collaboration: thicker arrows represent stronger ties, while thinner arrows reflect weaker connections. Arrow directionality shows relationship patterns: one-way arrows indicate unidirectional ties, while two-way arrows signify reciprocal relationships. The network analysis reveals that international organisations (in green) occupy a central, dominant position within this collaborative structure. Abbreviations for all organisations are provided in Table S1.

3.2. Power-law fit and structural dynamics of stakeholders' networks in conservation and health

Our network exhibits classic scale-free properties, characterised by a degree distribution that follows a power-law model for nodes with 10 or higher degrees. This indicates the presence of a few highly connected "hubs" alongside many nodes with low connectivity in the conservation and health sectors combined (Fig. 2). The 15 most connected nodes include 11 international organisations, comprising eight foreign institutions (WHO, CVM, WCS, CRD, FAO, USA, COI), three foreign-led NGOs (PHE, CVM, SDB), and four national organisations, which consist of a national NGO (ASF), two governmental institutions (MED and DSV), and a local academic institution (EEA). The scale-free structure suggests that while the loss of a few non-critical nodes may have minimal impact, removing key hub nodes could significantly destabilise the network. These hubs are critical for knowledge sharing and coordination, serving as central links between individuals or organisations. Their failure would disrupt connectivity and compromise the network's integrity.

3.3. Distinct network (A) in conservation and (B) in the health sector

The Freeman degree centralisation and graph density metrics, before and after the removal of singletons, reveal key structural differences similar to those in the sub-networks of conservation and health actors (Fig. 3).

In the conservation-actor network (Fig. 3A), the initial centralisation of 0.158 reflects a relatively decentralised network influenced by peripheral, minimally connected nodes. Upon removing singletons, centralisation increased to 0.302, indicating a more concentrated structure in the core network. Similarly, graph density has risen from 0.007 to 0.078, marking a transition from a sparse, fragmented network to a more cohesive core of well-connected actors in conservation. In the conservation sector, 10 of the 15 most nominated actors are international, with three being foreign-led organisations (Table 2). CVM, PHE, and MV are among the most connected actors distinguished by their high indegree and outdegree centrality. PHE and WCS emerge as the most influential actors, holding the highest eigenvector centrality score of 1, followed by MV, a local NGO, with an eigenvector centrality score of 0.87. The Ministry of Environment (MED) also plays a significant role, with an eigenvector centrality score of 0.74.

In the health-actor network (Fig. 3B), centralisation shifted from 0.142 to 0.222 after removing singletons, revealing a moderately centralised structure. The low initial density of 0.004, indicative of weak cohesion, increased to 0.098, suggesting a denser and more interconnected subnetwork among core actors. These findings reveal a dual structure in both networks: a sparse periphery dominated by singletons

[3] The abbreviations for stakeholders in the text follow the format used in the graph, which for some may differ from the standard abbreviations commonly associated with these organizations. This ensures consistency with the graph's representation.

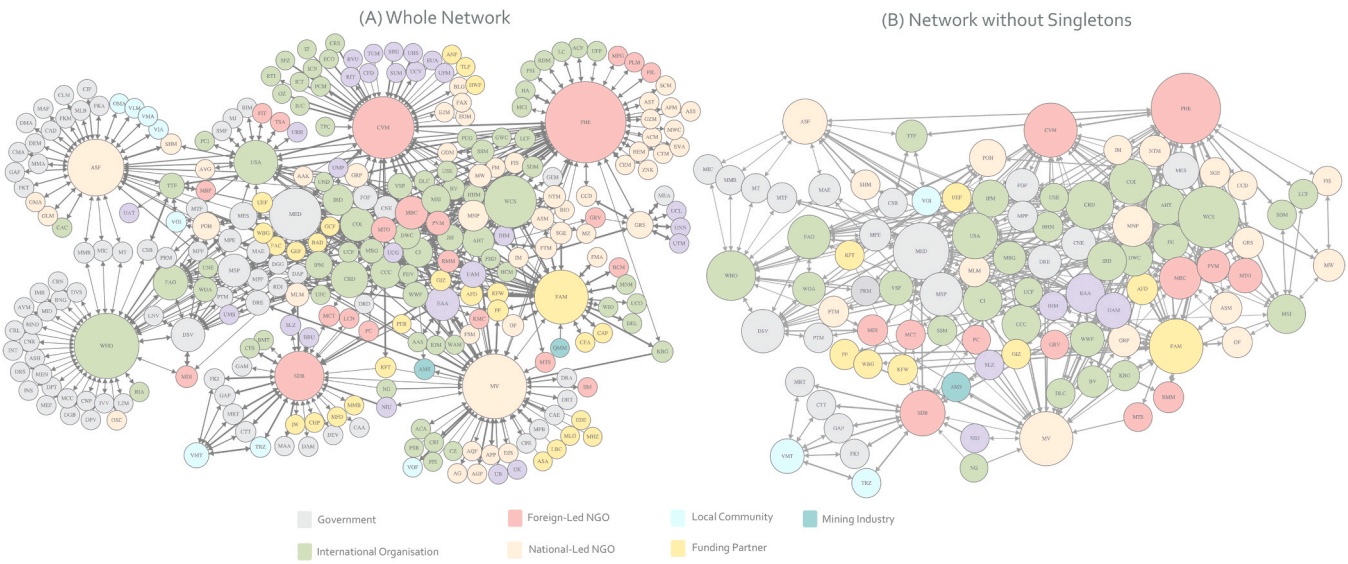

Fig. 1. The overall network structure of stakeholders involved in madagascar's conservation and health initiatives. Source: Semi-structured interviews with 287 stakeholders (march-june 2022).

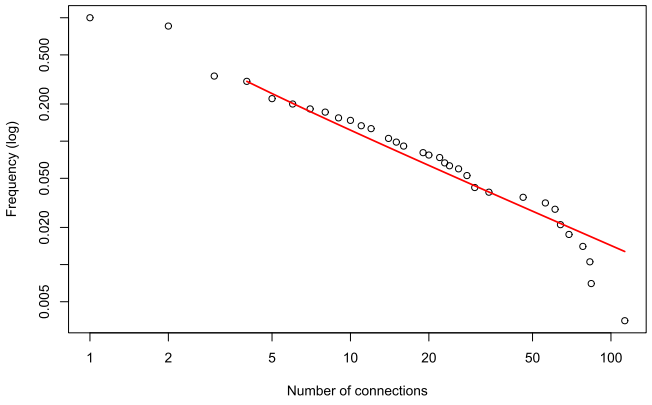

Fig. 2. Degree distribution and power-law fit of stakeholder network in conservation and health governance. The power-law fit of degree distribution with estimated Xmin = 10, estimated alpha (y)= 2·10, and Goodness-of-fit test p-value = 0·312. the x-axis shows the degree (the number of connections a node has), and the y-axis represents the frequency of nodes with a specific degree. The close alignment of the red line with the circles suggests a solid fit for the model, with a scaling parameter (α) of 2·10 within the typical range for scale-free networks (2–3). the goodness-of-fit p-value of 0·312 (greater than 0·05) further supports the plausibility of this fit.

and a cohesive core of interconnected actors driving the network's dynamics. Actors connected to singletons act as links, serving as liaisons or brokers that bridge the peripheral actors to the central core. International organisations dominate both networks, with 52.7 % of international actors involved in conservation and 61.1 % engaged in the health sector.

The network includes 72 interconnected actors, excluding singletons, with key hubs identified. Stakeholders comprise five academic institutions (two national), ten foreign-led NGOs, 14 national-led NGOs, six financial partners, 11 governmental bodies, one mining industry, 22 international organisations, two local communities, and one mining industry. (B) **Network of Stakeholders in Health Sectors in Madagascar.** The network features 67 active actors, highlighting key hubs and connections while excluding singletons. Stakeholder groups include two academic institutions (one national), eight foreign-led NGOs, 12 national-led NGOs (eight of which are involved in conservation and development), three financial partners, 12 governmental institutions, and 29 international organisations. Abbreviations for all organisations are provided in Table S1.

WHO and WCS are the most well-connected actors in the health sector, alongside FAO. The WHO primarily connects to governmental entities and exhibits a high eigenvector centrality of 0.88. The DSV (Direction des Services Vétérinaires) holds the highest eigenvector centrality at 1.00; following closely are FAO, with an eigenvector centrality of 0.95, and COI, an intergovernmental organisation focused on conservation and development. IRD, a French institute dedicated to research and development, and WCS (Wildlife Conservation Society), each with an eigenvector centrality of 0.92. Although PHE, a networking platform promoting development and conservation, and EEA (École Supérieure des Sciences Agronomiques, Madagascar) are not among the top 15 most mentioned actors in the health sector, they hold the highest outdegree centrality scores, with 23 and 20, respectively.

Among the 15 health sector stakeholders, 12 demonstrate a strong commitment to the OH approach, including three national institutions (DSV, MSP, and POH) and nine international organisations. The POH is led by the Prime Minister's office and supported by FAO, WHO, WOAH, and UNEP with USAID funding. DSV, WCS, and the Indian Ocean Commission (COI) exhibit the highest eigenvector centrality within the network.

3.3.1. One health implementation and stakeholders' perspectives

a) Implementation score distribution

– **High OH implementation (score 3)**

Of the 15 prominent conservation actors in Madagascar, five organisations, which are CVM, PHE, WCS, CRD, and FAO, scored **three** for OH integration. These international actors demonstrate a commitment to community development alongside conservation goals. CVM and WCS focus on research-driven conservation, while PHE, CRD, DSV, and FAO prioritise capacity building, development, and health-related initiatives. Organisations achieving a score of three demonstrate a deliberate application of the OH concept, with all three components operating within a recognised framework. A manager in an NGO stated, *"All three sectors were represented at the kickoff workshop. That shows strong integration. Now, each team is implementing their activities based on its expertise. We'll compile the final report together."* A manager in an international organisation reported: *"In the field, we observe that stakeholders*

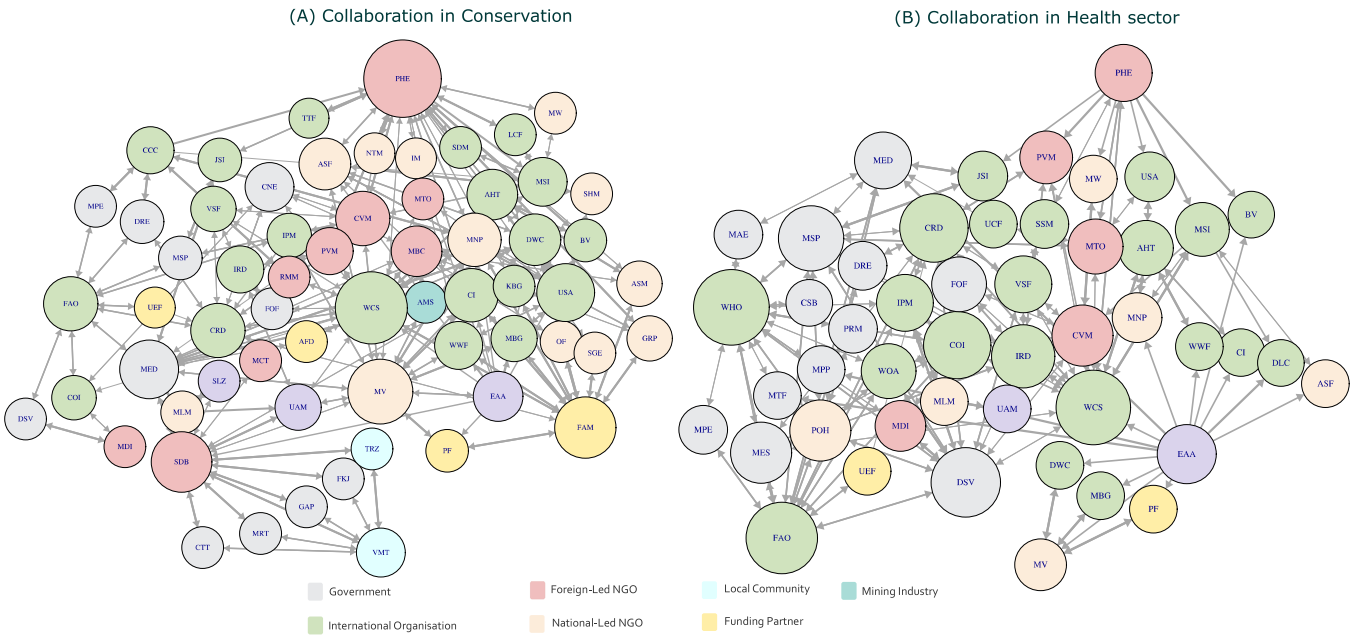

Fig. 3. A distinct network of stakeholders in madagascar's conservation and health initiatives. (A) network of stakeholders in conservation in madagascar. source: semi-structured interviews with 287 stakeholders (march-june 2022).

Table 2
Top 15 actors by indegree centrality in madagascar's conservation and health networks. This table ranks the top 15 actors (excluding singletons) based on in-degree centrality, highlighting the most connected stakeholders in Madagascar's conservation (Section 1) and health sector (Section 2). actors are ranked from highest to lowest in-degree, indicating their prominence within the network. Eigenvector centrality evaluates their connections to other influential actors. Focus_oh measures the integration of the one health (OH) concept into their activities on a scale from 1 (low integration) to 3 (high integration). NR_User identifies whether actors directly benefit from forest resources for livelihoods (local communities) or research (academics). abbreviations for all organisations are provided in Table S1.

Section 1: Conservation							
Actors	**Indegree centrality**	**Outdegree centrality**	**Eigenvector centrality**	**Actor_Attributes**	**Activities**	**Focus OH**	**NR User**
PHE	23	23	1·00	Affiliated Org	Development Conservation	3	No
WCS	19	19	1·00	International Org	Development Conservation	3	No
MV	15	15	0·87	National Org	Development Conservation	2	No
CVM	14	9	0·44	Affiliated Org	Research Conservation	3	No
FAM	13	14	0·71	Fund	Development Conservation	2	No
SDB	13	12	0·41	Affiliated Org	Research Conservation	2	No
MED	12	11	0·74	Government	Administration	2	No
USA	11	11	0·79	International Org	Development Conservation	2	No
CRD	10	8	0·40	International Org	Development Conservation	3	No
CI	9	8	0·75	International Org	Development Conservation	2	No
FAO	9	9	0·22	International Org	Development Conservation	3	No
MNP	9	8	0·72	National Org	Development Conservation	2	No
ASF	8	7	0·53	National Org	Development Conservation	2	No
DWC	8	7	0·70	International Org	Development Conservation	2	No
AHT	7	7	0·52	International Org	Development Conservation	1	No
Section 2: Health Sector							
Actors	**Indegree Centrality**	**Outdegree centrality**	**Eigenvector centrality**	**Actor Attributes**	**Activities**	**Focus OH**	**NR User**
WCS	15	14	0·92	International Org	Development Conservation	3	No
WHO	15	15	0·89	International Org	Health	3	No
FAO	13	13	0·95	International Org	Development Conservation	3	No
DSV	12	12	1·00	Government	Health	3	No
CRD	12	11	0·92	International Org	Development_Conservation	3	No
COI	11	11	0·92	International Org	Health	3	No
MSP	10	10	0·81	Government	Health	2	No
IRD	9	9	0·71	International Org	Research_Conservation	3	No
MES	8	8	0·78	Government	Research_Conservation	2	No
POH	8	8	0·65	National Org	health	3	No
CVM	8	8	0·58	Affiliated Org	Research Conservation	3	No
MED	7	5	0·33	Government	Administration	2	No
IPM	6	6	0·57	International Org	Health	3	No
VSF	6	6	0·50	International Org	Health	3	No
WOA	5	5	0·53	International Org	Health	3	No

understand integration as collaborating on a common project, while each one remains within their own area of expertise during implementation."

– **Moderate OH implementation**

Among a broader group of 30 actors spanning both conservation and health sectors, only five organisations (CRD, CVM, FAO, MED, and WCS) actively operate across both domains. Twelve organisations scored **two**, indicating moderate implementation, where sector-specific activities show elements of the OH approach involving at least two OH components, showing partial alignment with OH principles, even when stakeholders may not fully understand or explicitly recognise the concept. A representative from Conservation NGOs reported: *"We were only contacted after the main activities had started. We're not yet sure how our role fits in, but we'll do our best to contribute what we can. It feels like we're just tagging along."*

A representative of the Ministry of Environment reported: *"Since 2023, the role of the environmental sector in the One Health approach has evolved significantly. It is no longer sufficient to mention the environment as a stakeholder; it must now be recognised and engaged as a central actor. However, the Ministry of Environment and Sustainable Development (MEDD) currently faces a major constraint: a shortage of qualified personnel to operationalise the One Health strategy effectively."*

A participant of the Animal Health department within the Madagascar OH platform highlighted the platform's current priorities, stating, *"For now, its primary goal is building the capacity of health professionals in epidemic surveillance. However, even if progress has been made in fostering collaboration between the human and animal health sectors, the environmental sector's involvement remains limited"*.

– **Low OH implementation**

One entity (AHT) scored **one**, indicating low implementation, where activities remain sectoral. AHT's role remains primarily technical, assisting in the sustainable governance of natural resources within a single sectoral framework.

b) Implementation patterns

The most commonly cited joint OH initiatives in Madagascar include the PREZODE project (Chevalier and Andres, 2023), coordinated by CIRAD and IRD, which focuses on zoonotic disease prevention, and the PPSB (Pandemic Preparedness and Basic Health Services) initiative launched by the World Bank (Ministère de la Santé Publique, Madagascar, 2022).

– **Top-Down Implementation**

A local manager working in an international organisation described implementation patterns in the AfriCam project: *"I've been closely observing the implementation of the AfriCam project, led by CIRAD and IRD, which was launched in 2023 across five countries, including Madagascar. The initiative is ambitious, with a first phase, "PREZODE", aiming to prevent the emergence of zoonotic diseases through a global health lens. Although the project emphasises co-construction in its official narrative, the reality on the ground often feels quite different. What we observe in the field is a largely top-down implementation model, where each institution or expert domain focuses on executing tasks within its area of expertise. This vertical organisation limits true interdisciplinary collaboration, resulting in fragmented interventions rather than an integrated, holistic response.*

The same manager reported resource management patterns: *"One critical issue that continues to undermine genuine local engagement is the lack of decentralised financial management. There is little to no direct funding managed by local institutions or project managers. This not only weakens ownership at the country level but also severely affects motivation. It becomes difficult for local actors to fully commit when they are essentially implementing someone else's vision, with limited capacity to adapt or influence decision-making in meaningful ways"*.

– **International to Local Implementation Model**

A representative from WHO, part of the OH quadripartite, talked about the International Health Regulations (IHR) (Kamradt-Scott, 2019), noting: *"The binding nature of the IHR compels us to advocate for its implementation. While Madagascar's progress has been limited, establishing the OH platform is a critical step forward. To support its operationalisation, we are providing targeted financial and technical assistance. Additionally, International funding increasingly prioritises cross-disciplinary approaches to tackle today's complex health challenges, reinforcing the importance of integrated strategies like OH."*

A local manager described community-driven approaches: *"When we talk about true integration and sustainability, a more efficient model can be seen in the establishment of Locally Managed Marine Areas (LMMAs) under the coordination of the MIHARI network in Madagascar… where local communities themselves take the lead in managing their marine ecosystems and resources with a sense of ownership and commitment of the community members. These areas are powerful examples of locally driven conservation that works… This level of local implication, trust and shared responsibility is exactly what's missing in many externally led One Health initiatives."*

3.4. Fund flow in conservation project support

Few stakeholders mentioned their funding sources during the interviews; however, this subset revealed critical patterns in the diverse and often informal ways funding flows within the network, influencing conservation efforts.

Initially, the Freeman degree centralisation of funding partners was calculated at 0·052, indicating a highly decentralised network with dispersed connections in fund flow (Fig. 4). However, removing singletons significantly increased centralisation to 0.439, uncovering a more organised core where specific funding actors occupy prominent, interconnected roles. Network density showed a similar trend. When singletons were included, the network density was 0.0014, highlighting a fragmented structure dominated by isolated nodes. After removing singletons, the density increased to 0.143, indicating a more cohesive network where 14.38 % of possible connections are realised.

These findings demonstrate that singletons obscure the underlying structure of the network. By focusing on the core, the network reveals a more collaborative and interconnected framework, which is critical for effective conservation coordination.

MED (Ministry of Environment) is the most influential actor in the network, with the highest eigenvector centrality value of 1, underscoring its central role. CVM (Valbio Center), FAM (Madagascar Protected Areas and Biodiversity Fund), and CI (Conservation International) follow with values of 0.80, 0.76, and 0.71, respectively. Meanwhile, KFW (Kreditanstalt für Wiederaufbau), WBG (World Bank Group), WWF, and AFD (Agence Française de Développement) each have an eigenvector value of 0·26 (Table 3). While MED holds the most central position, FAM, CI, and MNP also play key roles in shaping network interactions.

Panel (a) shows NGOs linked to their specific financial supporters. Some organisations share primary funding sources, such as the Rainforest Trust (RFT) and the Madagascar Protected Areas and Biodiversity Fund (FAM), which support multiple NGOs. The Ministry of Environment (MED) relies primarily on international funding, while Population, Health, and Environment (PHE) operates exclusively with support from its founding partner, Blue Ventures (BV). This analysis highlights the overlapping funding pathways and the complex financial landscape that sustains conservation efforts. **Panel (b)** refines the network by removing singletons and focusing on shared funding relationships. The resulting graph reveals a tightly connected network of joint funding partners, with key international organisations: Conservation International (CI), Wildlife Conservation Society (WCS), WWF, and National Geographic,

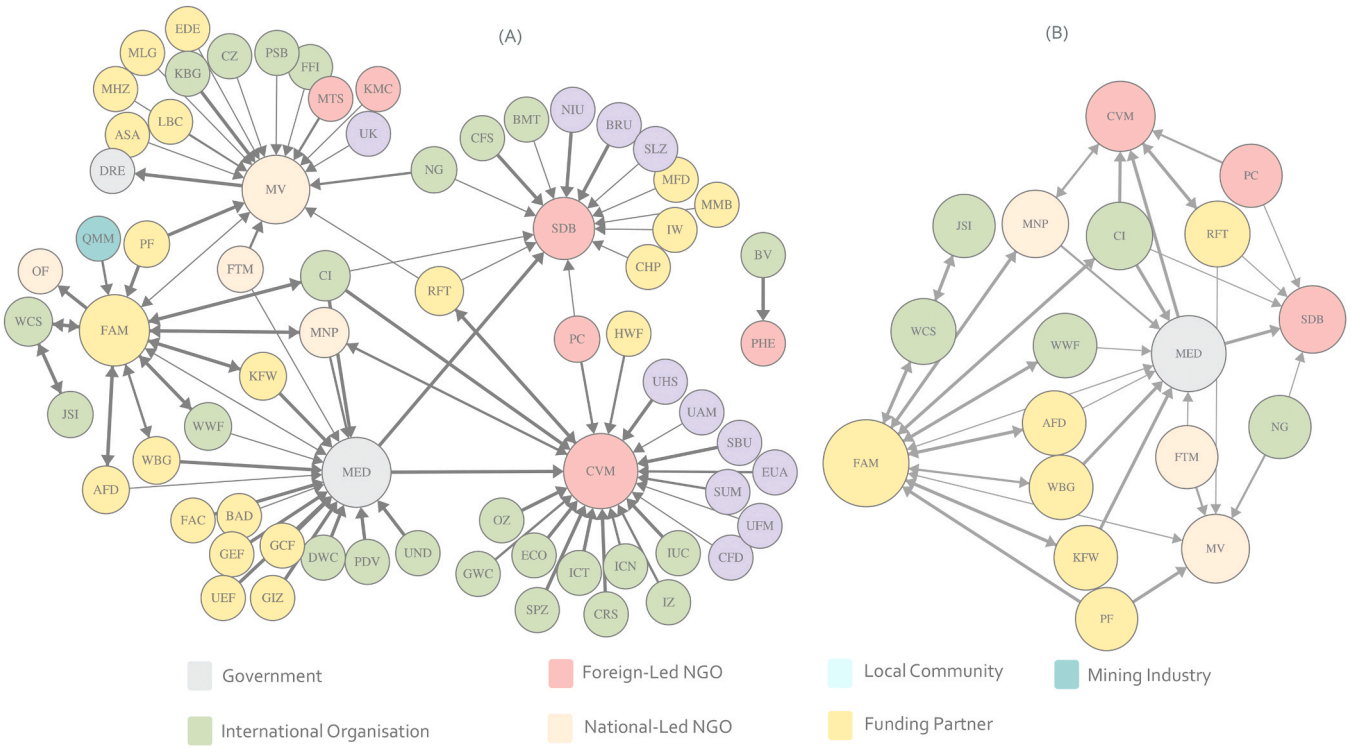

Fig. 4. Network of relationships between conservation ngos and their funding sources in madagascar. source: semi-structured interviews with 287 stakeholders (march-june 2022).

Table 3
Top 15 actors involved in financial support (excluding singletons). these actors comprise one governmental body (MED), two national NGOs, two affiliated NGOs, FAM (The National Biodiversity Fund), and eight international organisations. This list is sorted from highest to lowest to highlight the most influential actors within the network. Eigenvector centrality measures the extent to which an actor is connected to other influential actors. The Focus_OH metric assesses the degree to which the OH concept is integrated into the activities of the actors, using a scale from 1 (no integration) to 3 (high integration). the NR_User designation indicates whether an actor directly benefits from the forest, such as through livelihoods for the local community or knowledge for researchers. Abbreviations for all organisations are provided in Table S1.

Actors	Indegree centrality	Outdegree centrality	Eigenvector centrality	Actor Attributes	Activities	Focus OH	NR User
MED	21	0	1·00	Government	Administration	2	No
CVM	4	5	0·80	Affiliated_Org	Research_Conservation	3	No
FAM	10	3	0·76	Fund	Development_Conservation	2	No
CI	2	4	0·71	International_Org	Development_Conservation	2	No
SDB	6	4	0·68	Affiliated_Org	Research_Conservation	2	No
MNP	2	3	0·62	National_Org	Development_Conservation	2	No
PC	2	2	0·44	Affiliated_Org	Research_Conservation	2	No
MV	8	2	0·41	National_Org	Development_Conservation	2	No
RFT	1	3	0·40	Fund	Development_Conservation	2	No
NG	2	2	0·33	International_Org	Research_Conservation	3	No
WCS	1	3	0·29	International_Org	Health	2	No
FTM	1	2	0·27	Fund	Development_Conservation	2	No
AFD	0	2	0·26	Fund	Development_Conservation	3	No
KFW	0	2	0·26	Fund	Development_Conservation	1	No
WBG	0	2	0·26	Fund	Development_Conservation	2	No

emerging as central contributors. These organisations provide financial support and foster community-driven conservation projects, underscoring the interconnected funding ecosystem underpinning biodiversity conservation in Madagascar. Abbreviations for all organisations are provided in Table S1.

4. Discussion

4.1. The influence of international organisations in the policy-making process

Our network analysis reveals a critical tension in Madagascar's One Health implementation: while international organisations provide essential resources and technical expertise, their dominance may inadvertently undermine the development of sustainable local capacity, which is crucial for long-term success. The concentration of network influence among international actors (11 of 15 most connected nodes being foreign entities) reflects what Biehl and Petryna (2013) term "therapeutic sovereignty," where external entities shape national health policies through conditional funding and technical assistance (Biehl and Petryna, 2013).

Madagascar's environmental governance exemplifies this dynamic. Organisations like the Madagascar National Parks (MNP) operate as private entities, funded by Conservation International, the World Bank,

and WWF, with support from international consulting firms such as AHT Group (Gardner et al., 2018). This structure represents Harrison's (2004) concept of "political post-conditionality", where external networks redefine sovereignty boundaries by framing and influencing environmental policies, contrasting with earlier direct political conditionality that tied aid to specific reforms (Harrison, 2004). Madagascar's status as a biodiversity hotspot has intensified this external involvement. Extensive donor and NGO engagement has become deeply embedded in national governance structures (Ralimanana et al., 2022). While the WHO interviewee emphasises the "binding nature of the IHR" and positions international funding as driving cross-disciplinary approaches, this narrative must be understood in a context of profound structural inequalities in global health governance that may maintain dependency rather than build autonomous capacity. In practice, bilateral donors, international financial institutions, and environmental NGOs collaborate in ways that often relegate the Malagasy government to a secondary role. Global actors such as WWF, Conservation International, and the Global Environment Facility (GEF) hold significant influence, creating a governance system heavily dependent on transnational networks that effectively supplant state authority in key environmental decision-making areas.

The International Health Regulations (Kamradt-Scott, 2019) and Madagascar's recent establishment of a national One Health (OH) platform underscore the critical role of international organisations in shaping national policies. In many low-income countries, including Madagascar, OH platforms have been developed in collaboration with the FAO and WHO, aligning with IHR commitments to foster cross-sectoral coordination. Amended in 2016, these regulations further emphasise the importance of cross-sectoral coordination to strengthen global health security and prevent disease transmission (Kamradt-Scott, 2019). Madagascar's One Health platform aims to establish coordinated, integrated responses to pressing health challenges. However, its delayed implementation reveals systemic barriers and highlights the urgent need for accelerated action that builds genuine local capacity alongside international support.

4.2. Fragmented conservation and health networks hinder one health integration

The identification of only five actors bridging conservation and health domains (CRD, CVM, FAO, MED, WCS) reveals fundamental institutional design flaws that extend beyond simple coordination challenges. These sectoral silos represent competing bureaucratic cultures, funding streams, and professional identities that actively resist integration (Hitziger et al., 2018). The concentration of One Health alignment among just five actors, among which three are international entities, suggests that the framework may be perceived as an externally imposed concept rather than a locally owned priority, raising critical questions about implementation sustainability.

Madagascar's efforts to institutionalise One Health approaches demonstrate these structural challenges. The 2021 National Health Security Plan, launched by the Ministry of Public Health in collaboration with WHO and FAO, successfully convened multidisciplinary experts from human and animal health sectors to enhance epidemic preparedness (Ministère de la santé Publique, Madagascar, 2014). However, the fragmentation of institutional networks reflects what Romanelli et al. (2014) identify as critical gaps in biodiversity integration within One Health strategies. The neglect of biodiversity within these frameworks limits efforts to address ecosystem service disruptions that are vital for both public health and conservation goals, thereby preventing the achievement of synergistic outcomes between health and conservation policies (Romanelli et al., 2014). Overcoming these disciplinary silos requires more than technical coordination, it demands fundamental shifts in institutional structure, funding mechanisms, and accountability systems; Wardani et al. (2024) advocate for adopting transdisciplinary frameworks that promote collaboration across sectors, enabling systemic solutions for managing sustainable and effective socio-ecological challenges (Wardani et al., 2024).

Despite decentralisation efforts, such as Integrated Conservation and Development Projects (ICDPs) and Community-Based Natural Resource Management (CBNRM), challenges persist due to NGO dominance, weak local leadership, and low community participation. The network analysis reveals important distinctions in organisational influence: while organisations like PHE (a platform promoting development and conservation managed by a marine conservation group) and EAA (an agronomic institute) may not rank among the top 15 entities with highest in-degree centrality in the health network, their high out-degree centrality demonstrates their pivotal role in disseminating information, allocating resources, and fostering collaborations. Similarly, the World Health Organisation (WHO) exemplifies the importance of high out-degree centrality through its active provision of technical support, policy guidance, and funding to multiple stakeholders, highlighting its role as a key influencer and enabler within the system. This pattern suggests that effective One Health implementation depends not only on receiving connections but equally on the capacity to reach out and connect diverse actors across sectoral boundaries.

4.3. Exclusion of local communities

Peripheral organisations play a crucial role in enhancing the robustness of the network. These often marginalised groups, which include local communities, regional and local authorities, universities, regional health services (e.g., *centres de santé de base*), conservation stakeholders near protected areas, and international entities such as foreign universities and financial partners collaborating with local NGOs within specific protected areas, are often overlooked. They bring diverse perspectives that strengthen decision-making processes. Including singletons can mitigate risks associated with over-centralisation and reliance on core actors, fostering a more adaptive and flexible governance structure that can respond to region-specific challenges (Culloch-Jones et al., 2022; Rigo et al., 2022).

The disparity in network influence between local community groups and NGOs underscores how local actors remain largely peripheral, primarily engaging with NGOs operating within specific protected areas rather than influencing broader governance frameworks. This pattern perpetuates top-down approaches that overlook indigenous ecological knowledge and limit communities' ability to shape conservation policies or contribute meaningfully to management decisions. As Ma et al. (2023) emphasise, strengthening community representation, fostering equitable partnerships, and integrating governance structures are essential prerequisites for sustainable conservation (Ma et al., 2023). This marginalisation also represents what Freeman (1978) identifies as missed opportunities for critical bridge-building. Actors connected to peripheral organisations could serve as vital information brokers, improving collaboration and information flow across networks. The absence of such bridging mechanisms perpetuates fragmentation, reduces adaptive capacity, and limits the network's ability to address the complex, interconnected challenges that characterise conservation governance (Freeman, 1978).

Effective governance in complex conservation contexts requires bridging knowledge across disciplines, resolving competing priorities, and fostering shared goals (Hitziger et al., 2018). Adopting transdisciplinary approaches that genuinely integrate local stakeholders can enhance governance by encouraging meaningful collaboration and ensuring decision-making processes are grounded in both scientific evidence and local ecological knowledge. Without such integration, conservation initiatives risk perpetuating exclusionary practices that ultimately undermine their own sustainability and effectiveness.

4.4. Integration versus collaboration: a critical distinction

Madagascar's One Health implementation highlights a critical

distinction between collaboration and integration, with important implications for public health outcomes. While the country has successfully built cross-sectoral collaborative structures, such as the national One Health platform and multi-sector partnerships, these efforts have not achieved the deeper integration necessary for effective One Health implementation. Proper integration goes beyond collaboration between sectors. As Hitziger et al. (2018) emphasise, it requires policy and knowledge integration through shared mental models and unified frameworks that combine diverse knowledge systems into coherent strategies. This process involves aligning different perspectives into a central, actionable vision using tools such as multicriteria analysis, systems thinking, and transdisciplinary methods, which are specifically designed to tackle complex and interconnected health issues (Hitziger et al., 2018).

In Madagascar, however, institutional barriers continue to hinder this level of integration. Despite the appearance of collaboration, competing institutional agendas, resource rivalries, and deeply rooted organisational cultures have preserved sectoral silos (Hough, 1994). The issue of "sectoralisation", as described by Billé and Mermet (2002) as the fragmentation of integration efforts into parallel, isolated operations, is clearly at play, preventing the alignment of goals and the effective synthesis of knowledge across the health, agriculture, and environmental sectors (Billé and Mermet, 2002). These insights suggest that while collaborative structures are essential, they are not sufficient to address the complex challenges One Health aims to resolve. Without addressing the institutional and epistemological divides that hinder proper integration (Antoine-Moussiaux et al., 2025), One Health initiatives risk falling short of their full potential to comprehensively protect public health and prevent disease.

5. Conclusion

This study employs Social Network Analysis (SNA) to critically evaluate the implementation of One Health in Madagascar, revealing significant gaps between the framework's rhetoric and operational reality. Our findings challenge assumptions about the effectiveness of One Health by demonstrating that international actor dominance, sectoral fragmentation, and local marginalisation may undermine the framework's core collaborative principles.

Rather than accepting One Health as a comprehensive solution to complex health challenges, our network analysis provides an assessment of actual collaboration patterns. The concentration of influence among international actors and persistent institutional silos suggests that One Health may inadvertently reproduce existing power imbalances rather than fostering locally owned integration. The Madagascar case demonstrates that establishing One Health platforms and securing multisectoral participation do not automatically translate into meaningful integration or improved outcomes. This distinction between formal collaboration and substantive integration represents a critical gap in current One Health discourse that requires more rigorous evaluation and evidence-based assessment. Our findings suggest specific pathways to move beyond current limitations:

- **Institutional Redesign**: Establish joint funding, performance indicators, and integrated reporting systems that break down administrative silos.
- **Capacity Building with Local Ownership:** Implement graduated transition programs that systematically transfer leadership from international to local actors, ensuring a smooth and sustainable handover.
- **Community Inclusion**: Establish formal roles for local communities through participatory governance, traditional authority involvement, and participatory decision-making processes that recognise indigenous knowledge systems.
- **Evaluation and Accountability:** Develop context-specific metrics that capture not only collaboration frequency but also integration depth, local ownership levels, and the quality of community participation, using SNA as a regular monitoring tool.

These findings have significant implications for global health governance and environmental conservation policy. They demonstrate that effective One Health implementation requires a fundamental attention to power dynamics, institutional capacity, and local ownership, factors that are often overlooked in technical coordination approaches. The study contributes to a growing body of literature calling for more critical evaluation of global health interventions, suggesting that One Health success should be measured not only by cross-sectoral participation but by the quality of integration, equity of participation, and sustainability of local ownership. The SNA framework we present is replicable and valuable for future comparative studies on OH governance.

6. Limitations of the study

While this study comprehensively analyses Madagascar's conservation and health governance network, it has limitations. First, our data primarily reflect formal collaborations, potentially underestimating informal interactions that could contribute to OH integration. Second, the study focuses on key actors within established networks, potentially overlooking smaller-scale or emerging initiatives that might operate outside these structures. Third, our sampling approach, while following the established Laumann-Marsden-Prensky framework for network boundary definition through snowball sampling, may have inadvertently favoured more visible or well-connected actors. This could result in the underrepresentation of grassroots and hyperlocal stakeholders, particularly those operating in remote areas or with limited institutional connections, despite their potential importance for One Health implementation at the community level. Fourth, the reliance on self-reported collaboration should be interpreted cautiously, as actors may overstate their involvement or fail to mention key partnerships that are not directly involved. Finally, the quality of the study depends significantly on the interviewee's experience and breadth of perspective, highlighting the importance of selecting respondents with comprehensive expertise in their field. While our systematic sampling approach and saturation assessment help mitigate these risks, we recognise that network studies inherently face trade-offs balancing comprehensive analysis of core networks with complete coverage of all potential stakeholders.

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CRediT authorship contribution statement

Raf Aerts: Writing – review & editing, Visualization, Supervision, Resources, Project administration, Funding acquisition, Conceptualization. **Jean Hugé:** Writing – review & editing, Validation, Conceptualization. **Moussiaux Nicolas Antoine:** Writing – review & editing, Visualization, Validation, Conceptualization. **Ellen Decaestecker:** Writing – review & editing, Supervision, Resources, Project administration, Funding acquisition, Conceptualization. **Leo Delpy:** Writing – review & editing, Methodology, Formal analysis, Data curation. **Karine L. Mahefarisoa:** Writing – original draft, Visualization, Validation, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Ratsimbazafy Hajainaina A.:** Writing – review & editing, Methodology, Formal analysis, Data curation, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no conflict of interest.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.envsci.2025.104132.

Data availability

Data will be made available on request.

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