Power asymmetries in ecosystem services governance: insights from social network analysis

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Abstract

Understanding how power asymmetries arise and how they can affect policy outcomes are crucial questions for ecosystem services (ES) research. In political sciences and sociology, the distribution of power among individuals has been widely studied with social network analysis (SNA). SNA have also been used to understand natural resource governance, for example in the context of fisheries, REDD+ or urban green areas. This paper specifically aims at identifying who are the stakeholders who exert power over others in action arenas related to ES governance, on whom they exert their power, and what are the consequences in terms of conflicts. We propose an easily replicable method to analyze power distribution using tools from social sciences, such as interviews and workshops. We apply this method to the Mariño watershed in the Peruvian Andes considering a set of eight ES. We explicitly consider two dimensions of power: influence and domination. First, we quantify individual domination and influence scores using network degree centrality. Second, we analyze power distribution between stakeholder groups (such as sector or level of intervention) using student t tests, Clopper-Pearson exact confidence interval and chi-squared test with standardized residuals analysis. Third, we apply the quadratic assignment procedure (QAP) to explain the existence of (i) influence and domination relationships and (ii) conflicts between stakeholders. Our work provide a comprehensive assessment of power asymmetries in the governance of ES. We found that the business sector was much less influential than other actors regarding ES governance, while public sector showed higher scores of domination. We highlighted the importance of domination in the existence of conflicts between actors, and the limited effect of influence. More interdisciplinary

research at the frontiers of political sciences and sustainability science is needed to understand power issues in the governance of ES.

Introduction

Ecosystem Service (ES) governance is profoundly affected by power asymmetries. Social power relations determine the production and management of ES [1,2] and mediate access, use or distribution of ES benefits [3,4]. The mismatches between those who control ES production and access, and those who benefit from them create complex power asymmetries, the ES producers not being always in a dominant position [1,5,6]. ES governance and policies are in turn shaped by the preferences, the interests and the values of the stakeholders participating in the decision-making process, with power differentials [7–9]. Moreover, several authors have observed that conflicts can arise from disregarding the issue of power distribution among stakeholders and from the inequitable distribution of roles in ES governance [1,10,11].

However, power relations are rarely explicitly considered in existing studies on ES governance. Some conceptual frameworks have been proposed in the literature to better integrate them [1,2,12], but empirical studies remain scarce and limited to Payment for Ecosystem Services schemes (see for example : [13–17]). Existing tools for ES analysis usually poorly consider power, as they were initially developed for biophysical assessments rather than for the social aspects such as actor's diversity and power. There is a need to develop a more critical understanding of how power operates in ES governance in order to ultimately engage towards environmental sustainability and social justice. This involves (1) identifying who are the stakeholders who exert power over others in a given action arena related to ES governance, (2) determining on who they exert their power, and finally (3) elucidating the origin of their power and how it is exerted [8,18]. Some methods can be adopted from other disciplines, including sociology and political sciences [1,9].

Social sciences have a long tradition of studying power in human structures, which resulted in numerous definitions and conceptualizations of power. Power is usually either described as the capacity to act or accomplish something (i.e. "power to") [19–21], or as the capacity to enforce one's own intentions over those of others (i.e. "power over"), which thus requires the existence of a social interaction between two or more social actors (individuals, groups, governments, offices, or any other human collective) [22–28]. This paper focuses on the assessment of the relational dimension of power in the governance of ES ("power over", what we will simply call power in the following) and does not cover "power to" influence the ES cascade through coproduction or management, since the later was studied more in detail in a companion paper [6]. We adopt a relatively simple definition of

power suggested by Goldhamer and Shils: “A person may be said to have power to the extent that he influences the behaviour of others in accordance with his own intentions” [29]. Power relations are said to be asymmetrical when one actor hold more control over the behavior of another than the reverse [27].

There are different ways through which power can be exerted in a social relation, and many typologies have been proposed to classify these different “forms of power” [27,29,30], also called “power bases” [24,31]. The one we use in this paper considers two facets of power: domination and influence [28,32]. Domination refers to the capacity to offer or withhold benefit or harms. It encompasses different forms of power such as force, coercion and authority (Table 1) [24,26,27,29,33,34]. Influence consist of providing information in order to change an actor’s attitude, behavior and opinion. Forms of influence include manipulation, persuasion, referent and expert powers (Table 1) [24,27,28,33,35]. In contrast with domination, it does not engender resistance since it occurs through the subjective acceptance of the dominated actor that will process the new information. It is worth noting that these forms of power are often articulated one with each other [27,30]. For example, David Knoke identified four stakeholder types depending on the level of articulation between influence and domination: coercive power (which depends on domination exclusively), persuasive power (which relies on influence exclusively), authoritative power (which relies on both influence and domination) as well as egalitarian “power” (which is not a form of power *per se* since it corresponds to low level of domination and influence) [28]. It is important to note that asymmetric relationships do not systematically lead to conflicts. Conflicts rather depend on the forms of power relationships involved, the power differentials between stakeholders, the legitimacy of the dominant as well as the response capacity (including in psychological terms) of the dominated [36–38].

Social Network Analysis (SNA) has often been used to empirically understand power distribution in organizations (see for example: [31,39–41]). Reasons are twofold: first power creates complex social structures and interdependencies among actors that can be analyzed or represented graphically with SNA; and second, as power is a relational concept, SNA is useful to account for actors’ multiple interactions. From a network perspective, power distribution can be explained by actors’ position in one or more networks [28,42]. In terms of power theories, SNA approach consequently adopt a structural perspective to analyze power at individual level [28,40]. For example, actors who are in the center of communication or knowledge-sharing networks are better positioned to influence others [28,43,44]. Different network centralities can be used to quantify individual power - including degree, closeness and betweenness. They offer different insights on power distribution [28,44,45]. Applications of SNA to ES governance are limited (see for example: [5,46,47]), and when existing, they rarely focus on power distribution (with a few exceptions: [48–50]).

Table 1: Forms of "Power over" identified in the literature

Forms of power	Definition	Examples	References
Domination			
Reward power	Capacity to administer positive valences or to decrease negative ones in order to change ones' behavior. It requires the receiver to perceive and give importance to the reward.	Result-based bonus	[24]
Force	Physical ability of an actor to keep another from doing what he would prefer to do. It can ultimately result into violence.	Military repression	[27,29,30,33,34]
Coercion	Non-legitimate capacity to achieve one's ends in the face of resistance (command, rule, request, etc). *Macht* in Weber theory of power.	Sanction	[24,26,29,33,34,51]
Authority	Legitimate capacity to get others to obey because of tradition, charisma or legal rationality. *Herrschaft* in Weber theory of power.	Head of a village, religious leaders	[24,26,29,33,34,51]
Influence			
Persuasion	One actor presents arguments, appeals or exhortations to another that independently changes is behavior in light of his own values and preferences.	Communication medias (newspaper, radio, television)	[27,34,35]
Manipulation	One actor influence another in order to conceal the ground for his own action.	Political propaganda, commercial advertising	[27,30,33,34]
Referent power	This power is based on the identification, of one actor with another, the desire of oneness and of being closely associated.	Popular people	[24]
Expert power	One actor has some special knowledge or expertness that can influence the behavior of others	Doctors, scientists	[24,52,53]

The objective of this paper is to explore the potential of SNA for the quantification of power asymmetries in ES governance. We address two salient research questions: (1) How to conceptualize and quantify influence and domination in ES governance using SNA? (2) What are the power asymmetries related to the governance of ecosystem services in a given study case? We specifically aim at identifying who are the stakeholders who exert power over others in action arenas related to ES governance in our study site, on whom they exert their power, and what are the consequences in terms of conflicts. We propose an easily replicable method to analyze power distribution using tools

100 from social sciences, such as interviews and workshops, in order to build domination and influence
101 networks. We apply this method to the Mariño watershed in the Peruvian Andes considering a set of
102 eight ES. First, we quantify individual domination and influence scores using network degree
103 centrality. Second, we analyze power distribution between stakeholder groups (such as sector or
104 level of intervention) using Student's t-tests, Clopper-Pearson exact confidence interval and chi-
105 squared test with standardized residuals analysis [54,55]. Third, we apply the quadratic assignment
106 procedure (QAP) to explain the existence of (i) influence and domination relationships and (ii)
107 conflicts between stakeholders [56,57]. Our work provide a comprehensive assessment of power
108 asymmetries in the governance of ES. We observed a high variability of influence and domination
109 scores, depending on actors' sector and level of intervention. Knoke's four types of power
110 corresponded to different actor's profiles.

111 # Results

112 ## Structure of influence and domination networks

113 In the Mariño watershed, 52 actors were selected for the SNA during two preliminary workshops.
114 These actors were either managing directly or indirectly ES in the area or benefiting from them. They
115 were from different sectors (businesses, civil society, NGOs and public organizations) and acted at
116 different scale, from local and regional (i.e. subnational level), to national and international levels (SI
117 Table 1). The relational data used to build the influence and domination networks was collected
118 during 65 interviews with representatives of each of these actors (for some actors, we conducted
119 several interviews with different representatives). We considered domination as a directional
120 network (i.e. one actor is identified as the initiator of the relationship and the other as the receiver)
121 but influence as a non-directional one (i.e. both actors participate in the relationship equally) (Figure
122 1). The two networks were weighted since they resulted from the combination of several primary
123 relationships (Table 1, SI Table 2). We used networks degree centrality as a proxy of individual
124 influence and domination scores (Table 1). These proxies varied from 3 to 45 for influence and from -

12 to 21 for domination (with mean values of 22.6 and 0 respectively). During the interviews, information about cooperation and existing conflicts between actors was also collected, which resulted in the identification of 666 undirected weighted ties for cooperation network and 135 undirected ties for conflicts (SI Figure 1 and 2).

Figure 1: Influence (straight light grey ties) and domination (curved dark grey ties) networks. The size of the ties is proportional to the weight of the relationship (between 0 and 1).

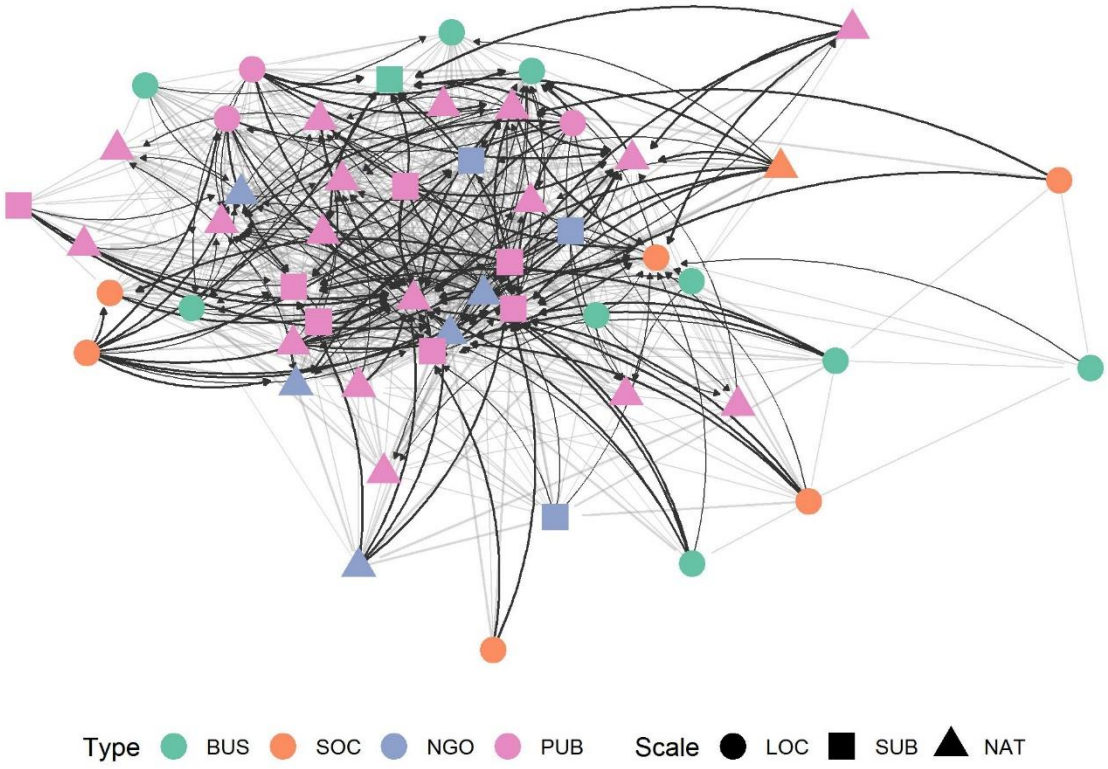


Table 2: Main characteristics of influence and domination networks. Dens: Density of the network (number of actual ties divided by total number of potential ties); Diam: Unweighted diameter of the network (the longest of all the shortest paths in the network); Trans: Transitivity of the network (number of actual triangles in the graph, divided by total number of connected triples of nodes. It is closely related to the presence of clustering); Recip: Reciprocity of ties in the networks (only for directed ones).

	Type of network	**Primary relationships included**	**Proxies**	**Dens**	**Diam**	**Trans**	**Recip**
Influence	Undirected Weighted	Information sharing and advise	Degree	0.44	3	0.64	-
Domination	Directed Weighted	Supervision and restriction	Outdegree - Indegree	0.07	7	0.26	0.04

The influence network was much denser than the domination network (i.e. there were much more ties between actors), which logically led to a shorter diameter in the influence network (Table1). Transitivity was higher for the influence network than for the domination network, which might suggest that the additional ties in the influence network were not equally distributed but rather clustered between some specific actors. Reciprocity of domination network was very low (4%), which suggest that there is no mechanism of retro-control when one actor is dominated by another. The two networks were poorly correlated ($\rho = 0.20$, p-value < 0.001), which suggests that influential actors are not necessarily dominant ones.

The influence network showed a clear structure, with actors from the business sector being significantly less in the core of the network, and more in the periphery, while civil society and public sector were significantly more in the core and less in the periphery. Regional actors were significantly more in the core than other actors, and less in the periphery (SI Tables 5 and 6, Figure 3). NGOs were significantly less in the core of the domination network, and more in the periphery than other actors, while public sector showed the opposite trend (SI Table 5). National and internationals actors were less in the core and more in the periphery than other actors (Si Table 6)

Understanding the determinants of influence and domination relationships: who exerts power over who?

We applied the quadratic assignment procedure (QAP) to model the existence of influence and domination relationships. Several explanatory variables were selected for the analysis – such as actors' sector and level of intervention, or two actors' similarity - following different theoretical mechanisms and variable types (SI Table 7).

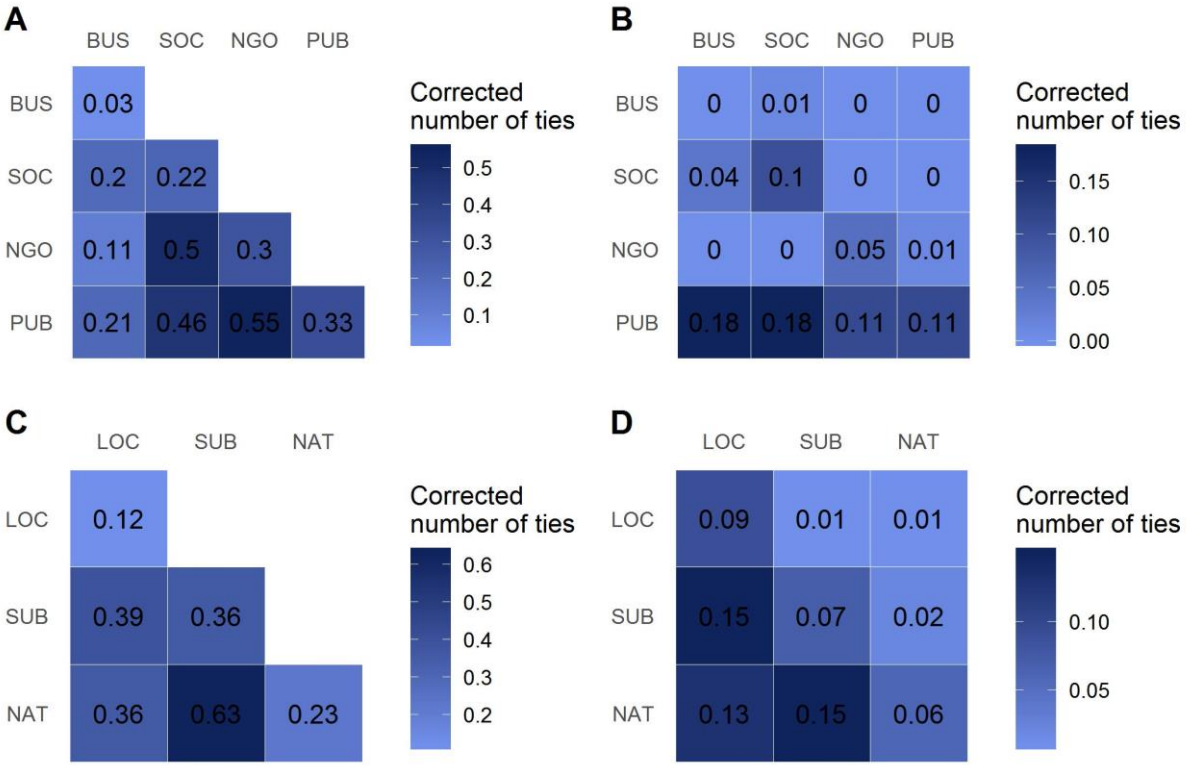
The existence of an influence relationship significantly depended on the sector of the actors engaged in the relationship. Having one actor from the business sector or from the public sector respectively decreased or increased the probability of an influence relationship (SI Table 7). Actors from the business sector were less engaged in influence relationships, while actors from the public sector were significantly more involved (Figure 2). The similarity of actors' level of intervention negatively affected the existence of influence relationship, which means that influence mainly occurred between actors of different levels (Figure 2, SI Table 7).

The existence of a domination relationship significantly depended on the sector of the sender, and the sector of the receiver (SI table 7). Actors from the business sector were more likely to be receiver of the domination relationship, while actors from the public sector were more likely to be sender (SI Table 7, Figure 2). The difference of actors' level of intervention (coded as a discrete variable, with positive values describing top-down domination) positively affected the existence of a domination relationship, which suggests that domination relationships are strongly associated with hierarchical mechanisms (SI Table 7, Figure 2). Finally, the existence of a domination relationship, was also positively related to sector homophily (i.e. the tendency of individuals to connect to similar others) (SI Table 7, Figure 2).

The existence of cooperation relationship positively affected the existence of both influence and domination ties (SI Table 10), which means that two actors that cooperate are more likely to influence or dominate each other. The importance of actors' in the cooperation network (that was

assessed using degree centrality) also significantly increased the probability of having a domination relationship.

Figure 2: Heatmaps displaying the number of ties for different sectors in panels A and B (BUS=Business, SOC=Civil Society, NGO=Non-Governmental Organizations, PUB=Public Sector) and levels of intervention in Panel C and D (LOC=Local, SUB=Sub-national, NAT=National and International). The total number of ties between two groups is corrected by the number of actors in each of the two groups. For domination (Panels B and D), senders are on the lines and receivers on the columns.



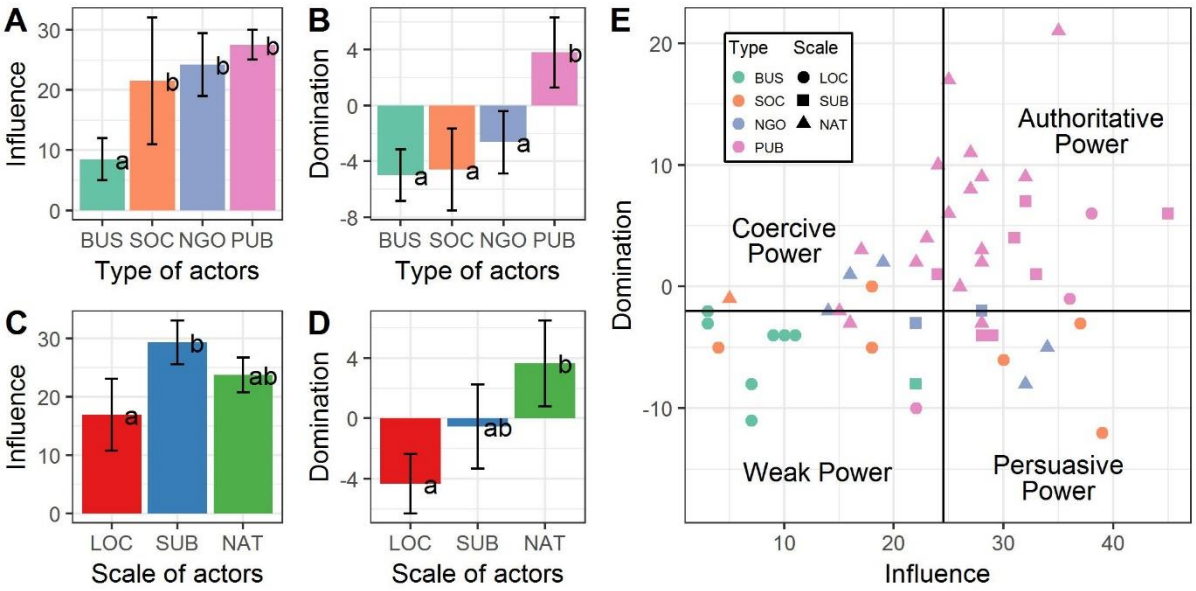
Power distribution amongst stakeholders

Actors from the business sector showed significantly lower scores of influence (Figure 3A). On the contrary, actors from the public sector showed significantly higher domination scores (Figure 3B). Domination score significantly increased with scale of influence, but not influence score, which was significantly higher for regional actors than for local ones (Figures 3C and 3D).

Four types of power were identified using the influence and domination proxies, as well as the typology proposed by David Knoke (Figure 3E). These types of power corresponded to different actor's profiles (SI Tables 8 and 9, Figure 7). For example, actors handling authoritative power (high levels of both influence and domination) were significantly less from the business sector, from the

NGOs sector and from the local scale, but significantly more from the public sector. Detailed results for the four power categories are presented in SI.

Figure 3: Influence and domination scores in relation to actors' characteristics and forms of power handled. Panel A to D: Mean influence (Panel A and B) and domination (Panel C and D) scores according to sector (BUS=Business, SOC=Civil Society, NGO=Nongovernmental Organizations, PUB=Public Sector) and level of intervention (LOC=Local, SUB=Subnational, NAT=National and International). Error bars represent confidence interval. Letters indicate significant differences (pairwise Student t-test, with alpha=0.05). Panel E: Influence and domination scores for each actor, with David Knoke (1990) typology of forms of power. Lines indicate median values on both axes.



Consequences in terms of conflicts

We investigated the links between the existence of conflicts and different variables related to power, influence and domination networks using QAP (Table 3). Model 1 showed a good predictive ability (SI Figure 8). The existence of a domination relationship between two actors strongly increased the probability of the existence of conflicts. Influence relationship also had a significant positive effect, but adding this variable to model 2 decrease the overall model fit (SI Figure 9). A high difference of domination score between two actors also significantly increased conflict probability (Table 3). Conflicts were more likely to occur when actors from regional and national levels were involved, which might suggest that there are conflicting policy preferences regarding ES governance between scales. On the contrary, the probability of conflicts existence decreased when actors from the business sector and from NGOs were involved, as well national actors (Table 3). Finally, conflicts

were less likely to occur when actors were from the same sector, which might suggest that conflicts are also partially driven by conflicting policy preferences between sectors.

*Table 3: QAP models estimations for conflicts prediction. Symbols display each variable significance level: . for p<0.10; * for p<0.05; ** for p<0.01 and *** for p<0.001.*

		Model 1		Model 2	
Baseline	Intercept	-1.17	***	-1.95	***
Actors' attributes	One of the actor is from BUS	-1.46	***	-1.05	*
	One of the actor is from NGO	-1.20	***	-1.12	*
	One of the actor is from NAT	-1.87	***	-1.74	***
Paired actors' attributes	Same actor type	-0.94	**	-0.89	***
	Actors are from SUB and NAT	1.08	**	1.05	***
	Absolute difference of domination score	0.09	***	0.08	***
	Absolute difference of influence score	-		0.01	
Covariate network	Domination network	1.57	***	1.26	***
	Influence network	-		1.57	***
Pseudo adjusted R2		0.46		0.46	
BIC		1494		1392	
AIC		1447		1450	

Discussion

Although power asymmetries are frequently recognized as a major challenge to the implementation of sustainable and equitable development pathways, these are rarely assessed in ES literature. Our paper offers an original approach, deeply rooted in social and political sciences, to describe two different facets of power (influence and domination), quantify power asymmetries at individual levels and understand the determinants of power relationships. We found that the business sector was much less influential than other actors regarding ES governance, while public sector showed higher scores of domination. The four categories of power identified by David Knoke proved to be particularly relevant to our analysis [28]. We observed highly contrasted profiles in each power category; for example public sector was predominant in the authoritative power group, and business sector prevailed in the weak power group. In the case of domination, we observed that the receiver of the relationship (i.e. the dominated actor) was more likely to be from the business sector and civil society. We showed that the existence of influence and domination relationships depended on various characteristics of actors, and on the existence of cooperation ties between actors. Finally, we highlighted the importance of domination in the existence of conflicts between actors, and the limited effect of influence, as noted by others [30]. In this respect, this study adresses to several of the literature gaps identified in the introduction.

Our approach relies on SNA and network degree centrality to quantify individual influence and domination scores. If there are numerous publications in the SNA literature that associate central network positions with higher levels of power [28,44,45], some called for more caution in generalizing this pattern. Measures of centrality might not always relate to power, for example in the case of exchange networks or decentralized/highly clustered networks (which was not the case in our study) [39,44]. Their findings also pointed out the need of considering network relationships that are relevant to power analysis. A second debate exists about the measures of network centrality and their use in power studies. Three measures of centrality are usually related to power: degree (number of ties),

closeness (distance to other actors) and betweenness (middleman role). These measures reveal different insights on power relationships in the networks: degree is useful to characterize general activity, betweenness to measure the control of information, while closeness can be used to describe independence and control avoidance [44,45,58]. In this study, since network centralities were correlated (SI Figure 10 and 11), selecting one centrality or the other did not make much difference. Further research efforts could focus the construction of indicators that combine multiple centrality measures in the context of power analysis. Interviews respondents could also be asked to evaluate the individual power of each actor in the network, as it is sometimes done in network studies [59–61]. These declared levels of power, in addition to inform on the perceived distribution of power, could also be compared to influence and domination scores obtained using network centralities.

Several statistical tools have been proposed in the SNA literature to model network structure and test the effect of endogenous (e.g. reciprocity of ties) or exogenous (e.g. actors characteristics) variables (for a review of existing tools and their respective limits refer to: [62–65]). In this study, we used the quadratic assignment procedure (QAP) to explain the existence of (i) influence and domination relationships and (ii) conflicts between stakeholders. QAP tests the existence of statistical associations between a dependent matrix and several explanatory matrices using permutations on their rows and columns. This is one of the major limits of QAP : it basically treats the relational dependencies between actors as a nuisance, and not as an interesting feature to model [65]. More advanced tools have been proposed for inferential network analysis such as latent space models (LSM) [66] and Exponential Random Graph Models (ERGM) [67]. In comparison with QAP, these models explicitly consider relational dependencies between actors, either using endogenous parameters related to the structure of the network in the case of ERGM or a latent space (such as Euclidean distance). Because of the high density of the influence and cooperation networks, we faced various degeneracy and collinearity issues when modeling endogenous variables with ERGM, as observed by others [65]. With LSM, we were limited by the correlation between covariate networks and

the outcome networks. However, as this paper does not aim at modeling network structure, but rather focuses on the effect of some exogenous covariates, QAP is perfectly adapted [65].

In this study we highlighted the effect of two actors' characteristics (sector and level of intervention) on the existence of influence, domination and conflicts relationships. Questions remain about the effect of other exogenous factors such as institutional and legal frameworks or individual forms of capitals (financial, natural, produced, human, social). Existing studies suggested that these also have an effect on actors' capacity to manage, use, or benefit from ecosystems and their services [12,51,68]. More research is needed to understanding these mechanisms more in detail. Additional research efforts could also focus on the solutions to ensure a more equitable distribution of power in relation to ES (to the extent this is desirable, which might not always be the case). In our study site, existing participatory a committees or management boards already exist, but with a limited participation of actors from the business sector (those who prevailed in the weak power group). Why do these actors do not seize this opportunity to gain power? Further research could focus on the links between power and participatory / co-adaptive management, in order to understand under which conditions the joint management of ecosystems and their services can truly improve power sharing [69–71].

This paper supports the view of power as a multifacet and complex concept. Our approach explicitly addresses the articulation of two dimensions of power: influence and domination. We propose an easily replicable approach to highlight power asymmetries in the governance of ES, using tools from social and political sciences. SNA proved to be remarkably convenient to analyze through a quantitative approach the information collected during workshops and interviews. It was also very performant to simultaneously analyze different types of relationships between actors, as well as their interactions. This study is the first of this kind to present empirical evidences of power asymmetries in ES governance. These power asymmetries raise several concerns because they may create conflicts (as observed in our results), cause the population's mistrust in institutions, or diminish the resilience and the adaptive capacity of a social-ecological system [70,72]. More interdisciplinary research at the

frontiers of political sciences and sustainability science is needed to understand power issues in the governance of ES.

Methods

Study site

The study was conducted in the Mariño watershed on the eastern slopes of the Peruvian Andes (Apurimac region). It includes two urban areas (Abancay and Tamburco) that cumulate approximately 60000 inhabitants [73]. Rural areas are less densely populated, and are the place for mixed small-scale family farming (crops and livestock). Natural areas includes natural grasslands, scrub or shrub lands, as well as patches of *Podocarpus glomeratus* (Intimpa), an endangered conifer species native of Peru, Bolivia and Ecuador [74].

Selection of ES and actors

The SNA focused on 52 actors involved in the governance of eight ES. Following Folke et al., we define governance as the structures and processes that enable collective action, decision-making and power-sharing [69]. The eight ES were selected during a preliminary workshop hold in September 2015, which resulted in the following list: agricultural production, medicinal plants, water quantity, water quality, mass erosion, sheet erosion, global climate regulation and ecotourism. The 52 actors were selected during a second workshop organized in May 2016, where participants were asked to identify the actors that participate in the governance of the eight ES (i.e. those who either benefit or manage directly and indirectly the eight ES). These actors were classified into three levels of intervention (local, subnational, as well as national and international) and four sectors (businesses, civil society, NGOs and public organizations). Details about the ES and actors selection can be found in a companion paper [6].

Collecting and processing relational data

We then conducted a total of 65 interviews with representatives of these 52 actors (June 2016). They were recorded with the interviewees' agreement. For some actors (such as farmers, regional government or rural population - refer to SI for the detailed list), we conducted several interviews, with different representatives, in order to capture the diversity and the complexity of their social relationships. When the interviews did not bring any additional information, we stopped and combined the collected information.

The interviews consisted of two parts. First actors were asked, through a semi-structured discussion, to describe their activities related to ES, natural resources and development. This included understanding how they benefited and managed the eight ES, and interacted with other actors in order to do so (Interview guide is provided in SI). Second, the interviewees were presented a thematic list of the 52 selected actors, and were asked to identify the actors with whom they interact. We distinguished between nine kinds of "primary relationships" (SI Table 2): information sharing (e.g. sending reports or data), advice (e.g. technical trainings), both at the basis of influence; supervision (e.g. reporting back) and restriction (e.g. control of one's behavior through the application of the law) at the basis of domination; common projects (e.g. shared or joint initiatives), regular professional meetings (i.e. work platforms), un-regular professional meetings (i.e. occasional meetings), business (i.e. selling or buying products), at the basis of cooperation. At the end of the discussion, the interviewees were also asked to indicate the actors with whom they had troubled or tensed relationships and to explain why. The second part of the interview was coded into 11 binary matrices of size 52 by 52 (Refer to SI for details on the creation of these matrices). The first part of the interviews was also used to complete the matrices when relational information was mentioned by the interviewees.

Correction of primary relationships

First, we assessed the reciprocity of the "primary relationships" ties. Reciprocity is the degree to which a relationship is commonly perceived and agreed on by all parties [59,75]. In other words, we checked to which extent when an actor *x* reported a relationship with an actor *y*, the actor *y* also reported a tie with *x* (refer to SI for more information about how reciprocity was computed). Reciprocity ranged from 75% to 97%, with a mean value of 88 ± 8.48% (SI Table 3 and 4). The lowest reciprocity was found for un-regular meetings, which might suggest that non-reciprocal ties were due to omission, which is logically more frequent between people that rarely met.

For this reason, and since the divergence of perception about relationships is not the focus of our paper, we applied some transformation to the primary relationships matrices and considered that a tie existed between actor *x* and *y* if it was reported either by *x* or *y,* or both. We finally obtained a set of nine matrices of size 52 by 52 (SI Table 2). The matrices corresponding to the "primary relationships" of influence, cooperation and conflicts ended up symmetric. The matrices corresponding to the "primary relationships" involved in domination were combined into asymmetrical matrices that informed on the direction (from the initiator to the receiver) of the domination tie (SI Table 2).

Construction of influence and domination networks

Influence and domination matrices were obtained from the non-weighted sum of their respective "primary relationships" matrices (Table 1). The matrices were then scaled between 0 and 1. We used R software and the network package [76] to build the influence and domination networks. Influence was considered as a non-directional weighted network, while domination as a directional weighted one. All weights ranged between 0 and 1 since the socio-matrices were previously scaled up. Individual proxies of influence and domination were based on networks degree centrality. We considered degree (number of undirected ties) as a proxy of influence, and the difference between

outdegree (number of outcoming ties) and indegree (number of incoming ties) as a proxy of domination.

We used the sna package [77] for the extraction of degree centralities, igraph [78] for the computation of basic characteristics of networks (density, diameter, and transitivity) as well as ggnetwork [79] for the visualization of networks.

Network analysis

All network analysis were conducted using R [80] and the ggplot2 package for creating graphs [81]. We distinguished central from peripheral actors in the influence and domination networks using UCINET categorical partitioning algorithm, with 100 random starts and 5000 maximum iterations [82].

We tested the effect of sector and level of intervention on two categorical network characteristics: (1) the position in the network and (2) Knoke's typology of power using Clopper-Pearson exact Confidence intervals for proportions (CPCI) [54] and chi-squared test with standardized residual analysis [55].

The CPCI can be used instead of a normal approximation method in order to address its deficiencies when the sample is relatively small (like in our case) or when an approximation of confidence interval is needed for extreme proportions, such as 0 and 1 (like in our case too). CPCI inform on the possible proportions of actors in a given group of actors. Non-overlapping CPCI denote significantly different proportions among groups, what we represent with different significance letters. CPCI was calculated with the PropCIs R package [83].

Chi-squared test were computed using Pearson chi-squared statistic (X^2):

$$X^2 = \sum \frac{(n_{ij} - \hat{\mu}_{ij})^2}{\hat{\mu}_{ij}}$$

where $\hat{\mu}_{ij}$ denotes the estimated expected frequencies and n_{ij} the observed frequencies in the sample [55]. The test statistic inform on the existence of an association between two variables (e.g.

position in the network and sector or level of intervention). Chi-squared test was complemented by a Standardized Residual (SR) analysis, which is useful to understand the nature of the associations detected by the test statistic [55]. SR were computed as the following:

$$SR = \frac{n_{ij} - \hat{\mu}_{ij}}{\sqrt{\hat{\mu}_{ij}\,(1 - p_{i+})(1 - p_{+j})}}$$

with $\hat{\mu}_{ij}\ p_{i+}$ the marginal proportion of the first variable and p_{+j} the marginal proportion of the second variable. Contingency tables and SR were represented as mosaic graphs [84]. Blue and red gradients indicate SR with absolute values exceeding critical values (i.e. significant differences at the 99%, 95% and 90% percentiles in the distribution of SR), and highlight a lack of independence between the two variables. Blue boxes indicate positive residuals (i.e. it is more likely to find stakeholders in this category than expected if the variables were independent) and red boxes indicate negative residuals. Boxes with absolute residuals below the critical value of 90% are white if the Chi-squared test based on Pearson statistics is significant, and grey otherwise. The plots were drawn with the vcd package and R software [80,85–87].

We also used pairwise Student's t-test to determine if the mean values of influence and domination scores for different actors' groups (such as sector and level of intervention) were significantly different from each other.

We applied the quadratic assignment procedure (QAP) to explain the existence of (i) influence and domination relationships and (ii) conflicts between stakeholders. QAP tests the existence of statistical associations between a dependent matrix and several explanatory matrices using permutations on their rows and columns. The explanatory matrices can either describe true relationships between actors (e.g. a covariate of the outcome network), some individual actors attributes (e.g. quantitative attribute such as network centralities, a categorical characteristic), or the difference, the match - as well as the mismatch - between two actors attributes (e.g. homophily). The

410 interpretation of QAP results is straightforward, since the outputs are similar to other regression
411 technics.

412 Weighted influence and domination network were converted into two binary networks before being
413 used in the QAP. The QAP models were fitted using the netlogit function included in the sna package
414 [77], with 200 iterations for quantile estimation. Several explanatory variables were selected following
415 different theoretical mechanisms and variable types (Table 3, SI Table 7). For example, we used the
416 cooperation network as a covariate in the QAP models explaining the existence of influence and
417 domination relationships. Model goodness-of-fit was assessed before analyzing model terms
418 significance and effect. The distribution of four characteristics of the modeled networks were plotted
419 against those of observed networks: number of shared partners per edges, path distances, actors'
420 degree centrality (in and out degrees were differentiated for domination since the network is
421 directed) and k-star (tendency for actors to have multiple partners, as a sender or as a receiver in the
422 case of directed networks). Goodness-of-fit analysis was conducted using btergm package [88].

423 The correlation between the influence and the domination network was computed using the
424 Quadratic Assignment Procedure (QAP) included in the qaptest function of the sna package.

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