Using networks to explore social-ecological systems

From network patterns to governance outcomes in social-ecological systems

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Die Fakultät hat diese Arbeit am 30. März 2023 auf Antrag der Gutachter Prof. Dr. Karin Ingold, Dr. Manuel Fischer und Prof. Dr. Örjan Bodin als Dissertation angenommen, one damit zu den darin ausgesprochenen Auffassungen Stellung nehmen zu wollen.

While working on my PhD, I went through many different stages, from curious exploration to desperate searching for answers. Regardless of what stage of my PhD journey I found myself in, I was happy to work in the very supportive environment of the PEGO group at Eawag and the University of Bern, with many people encouraging me. First and foremost, I am grateful to my supervisor Manuel Fischer who, in his calm and supportive way, gave me enough space to explore and find my own way while still always being there when I needed support. I also want to thank Karin Ingold, my co-supervisor, for always keeping the big picture in mind and helping me to avoid any potential obstacles before they even appeared on my radar. Also, I am grateful to Mario Angst, who helped me to make my first steps as a researcher, and always saw a way forward regardless of the problems ahead. I also want to thank all the other people from the PEGO group or working at Eawag who always made my office days fun and entertaining – especially Liliane Manny: together we shared not only the office but also the ups and downs of our PhD journey. Finally, I also want to thank my family and friends, who never gave up trying to understand what I exactly was working on, and always helped me to forget about my writing struggles and to spend some nice time at the lake enjoying the sun.

Summary

The governance of scarce resources in complex social-ecological systems (SESs) is challenging, in large part because fully grasping relevant interdependencies in SESs requires high conceptual efforts, as the governance of SES is highly complex. Network approaches offer great features for conceptualizing complex interdependencies of SESs based on nodes and ties. Novel network approaches conceptualize SESs based on networks with nodes and ties representing relevant social and ecological entities and dependencies between them. Such network conceptualization can help allocate and distribute resources such as knowledge and financial or natural resources efficiently. Allocation and distribution are important, as the need and availability of resources are often decoupled from each other. However, the distribution of resources is no trivial task as interdependencies within SESs, such as interaction patterns between actors from different governance sectors or causal links between environmental issues, and all the ensuing dynamics, are highly complex. Such complex governance systems can be described by interdependent social and ecological governance issues accounted for by interacting actors, each with their own interests and goals, reflecting the underlying environmental challenge this thesis addresses.

To contribute to the understanding of complex social-ecological interdependencies of SESs, this PhD thesis analyzes multi-level networks for the governance of SESs in two steps, each based on two papers. First, the dependency between governance settings and the emergence of network patterns is analyzed. In Paper 1, the focus is on the impact of cross-sectoral structures on actor networks. Cross-sectoral structures are an important driver for actor interaction, as actors tend to prefer interaction with actors from the same sector (e.g., energy and farming). Understanding drivers shaping interaction patterns is important, as actor interaction is important for successful governance of SES. For Paper 2, the focus of the analysis is on the impact of different conditions of complexity on interaction patterns, for example, the impact of the size of an SES on the observed interaction patterns. In order to interpret the emergent network patterns, normative assumptions were made common in the analysis of governance networks, such as that actor interaction or social-ecological fit – the alignment of social and ecological governance issues – are beneficial for environmental governance. Second, the thesis analyzes how network patterns, such as social-ecological fit or bridging and bonding ties, can be linked to governance outcomes. Paper 3 looks specifically at bridging and bonding structures as a vehicle for power for actors to analyze how network patterns can be linked to governance outcomes. Paper 4 analyzes network motifs of social-ecological fit and how they are linked to governance outcomes. Together the four papers of this thesis provide information on the environmental governance of SESs building on network conceptualizations. The results show that cross-sectoral governance structures [Paper 1] and exogenous governance complexity [Paper 2] can influence interaction patterns and motifs of social-ecological fit in networks. Further, the results show that network structures, such as bonding ties of actors [Paper 3] or motifs of social-ecological fit [Paper 4], indeed can be linked to governance outcomes such as local biodiversity or economic profitability.

To analyze networks of SESs and how patterns in these network conceptualizations can be linked to governance outcomes, this thesis looks at water-based ecosystems. Water-based ecosystems such as wetlands are among the ecosystems with the highest biodiversity both in Switzerland and worldwide. A loss of wetlands can have dramatic consequences not only for the local ecosystem but also for many other dependent ecosystems. In Switzerland, there exists special legislation for the protection of water-based ecosystems– the Water Protection Act of 1991. However, despite it, many water bodies in Switzerland are in poor condition. To change this, the recent revision of the Water Protection Act requires the restoration of one-quarter of the water bodies and provides 40 Mio CHF/year of funding to achieve this. Based on the research results linking interaction patterns in networks and governance outcomes, this thesis yields guidance for allocating and distributing public funding resources more meaningfully and efficiently and using natural resources more consciously. Further, the research results on the dependency between governance settings on the emergence of network patterns promote the understanding of social and ecological system interdependencies using theories and methods of multi-level networks.

Contents

List of Figures

List of Tables

Introduction

The loss of ecosystem services is accelerating across the globe due to manifold societal pressure (Reid et al., 2005). Ecosystem services are conceptualized as some form of benefits provided to society by healthy ecosystems, such as the pollination of many crops by insects or the recreational value of intact ecosystems. The origin of the decrease in ecosystem services is manifold, but often associated with the governance of SESs. The governance of social-ecological systems (SESs) can relate to harvesting fish stocks or managing the ppm of CO_2 in the atmosphere. When the governance of SESs is not conducted in a sustainable way that keeps the resource stocks in balance, the result is a loss of ecosystem services over the long term. In line with a loss in ecosystem services, biodiversity – essentially the source of all ecosystem services – is decreasing as well. (Gómez-Baggethun et al., 2013).

Governance of SES that achieves maintenance of ecosystem services on a high level essentially builds on stakeholder interaction. Stakeholders are here defined as collective actors like public actors such as cantonal offices or private actors such as local companies. Actor interaction is key for SES governance because responsibilities and capacities to manage policy problems lie typically with different actors. Based on interactions between actors of different types, it is possible to engage in a consensus-orientated decision-making process. A consensus-orientated decision-making process increases the legitimacy and support of policy decisions that account for the different needs and interests of the individual actors (Ansell & Gash, 2008; Emerson et al., 2012). While such bottom-up ways of collective problem-solving can improve governance outcomes (Berkes, 2002; Lubell & Morrison, 2021a; Newig, 2012), the challenge is that SES governance is not only driven by solution-orientated policy-making, but many factors can also hinder collective problem-solving. For example, interaction patterns essential for collective problem-solving are strongly driven by power, resources, or the problem perceptions of actors, which can result in asymmetries in interaction patterns hindering solution-orientated policy-making (Berardo & Scholz, 2010; Fischer & Sciarini, 2016; Lubell et al., 2010). Further, challenges for collective problem-solving also concern the fragmentation across sectors or different areas of jurisdiction (Fischer & Ingold, 2020). Fragmentation across sectors or different areas of jurisdiction is an issue highly relevant to the management of wetlands or river systems more generally, as this not only influences actors' interaction patterns but is also a reason for differences in actors' preferences for governance outcomes [Paper 1 & 2]. To holistically account for different governance dimensions, the SES governance concept for this thesis builds on multiple governance concepts, such as collaborative governance, polycentric sustainability governance, or environmental governance. SES governance can therefore support accounting for environmental challenges characterized by multidimensionality, complex processes, and diverse actors relevant to the governance of SESs.

To conceptualize and analyze interaction patterns between actors and relevant ecosystems interdependencies, this thesis builds on network theory and methods (Kluger et al., 2020; Lubell et al., 2012). Actor interaction includes activities such as collaboration on common projects [Paper 2 – 3] or being in regular contact [Paper 1], but on a more general level also concerns the exchange of information and resources. Networks representing actor interaction and ecosystem interdependencies have nodes and ties representing social and/or ecological entities and the ways in which they are dependent on each other. As these networks have different types of nodes, they can be conceptualized as multi-level networks with separate network levels for each node type, such as a social network level with actors as nodes.

The challenge of working with networks in general and multi-level networks, in particular, is to identify network patterns beneficial for the governance of SESs (Lubell & Morrison, 2021a).

Often actor interaction is generally assumed to be beneficial for the governance of SESs (Bodin & Crona, 2009). Multi-level networks can provide additional system information to evaluate whether interactions are potentially beneficial, accounting also for ecosystem interdependencies (see Figure 1). Grounded in the concept of social-ecological fit, interaction is particularly important between actors responsible for managing the same or dependent resources. If actors responsible for managing the same resources interact, the interdependencies of the SESs are aligned (also referred to as social-ecological fit (Bergsten et al., 2014; Treml et al., 2015)), which increases the odds of achieving a well-balanced, sustainable resource management (Epstein et al., 2015b; Hedlund et al., 2021). For example, two tourism operators that provide river excursions are likely to benefit from interactions, as this can help distribute the visiting tourists better over one day and prevent traffic jams during peak hours. Further actor interaction supports sharing of knowledge and facilitates learning from past governance mistakes. Together this can increase the resilience of SESs, as actors are aware of the governance mistakes of others and can act based on their interaction ties to close potential governance gaps (Lubell & Morrison, 2021a).

The understanding of SESs for this PhD thesis builds on the SES framework by Ostrom (2009). The SES framework characterizes ecological systems based on resource systems (e.g., a protected wetland containing forested areas and water systems) and resource units (e.g., amount and flow of water, biodiversity, or the number of species). The social system is defined by the governance system (e.g., governmental or other organizations setting up rules in a specified area) and actors (e.g., individuals or organizations active in the area). The social and ecological systems both influence action situations (e.g., the harvesting level of different actors) and emergent governance outcomes. Furthermore, the governance outcomes are influenced by additional contextual factors such as the social, economic, and political setting, as well as other associated SESs. To create beneficial governance outcomes based on the available ecosystem services, actors must efficiently navigate these complex SESs (Lubell & Morrison, 2021a).

To help actors navigate in the presence of complex SESs, it is beneficial to make the system complexity explicit (see Figure 4 for the complexity of SESs and Figure 10 from Paper 2 for a schematic structurization of such a network). One way to do so is based on networks. Networks can support accounting for the complexity of SESs and achieve long-term beneficial governance outcomes (Gonzalès & Parrott, 2012; Waltner-Toews et al., 2008). However, not all elements of the SES framework and the interdependencies between them are easily conceptualized as networks. While resource units or actors can be conceptualized as nodes in a social-ecological network (see Bodin and Tengö (2012) or Sayles and Baggio (2017a) for examples of such social-ecological networks), other elements are more challenging to be conceptualized as networks. Two elements of the SES framework that are particularly difficult to be conceptualized as networks are the rules and regulations of the social system and the emergence of governance outcomes from interaction situations.

Emergent patterns of actor interaction and related governance outcomes in complex social-ecological systems

What makes the governance of SESs challenging for actors is that SESs are often complex. The complexity of SESs is characterized here by 1) cross-sectoral actor interaction varying depending on the governance issue at stake or 2) interdependencies within and across the social and ecological systems. While the complexity of SESs is not necessarily something new, the awareness of this complexity and how the complexity of SESs shapes the emergence of actors' interaction patterns is increasing (Burch et al., 2019; Lubell & Morrison, 2021a).

For the first characterization of complexity in SESs, the focus lies on actor interaction across multiple parallel governance sectors [Paper 1]. Interaction across multiple governance sectors is important as governance issues (e.g., water governance) cut across multiple governance sectors and can hardly be resolved in isolation. In the example of water governance, relevant sectors concern energy or agriculture, depending on water availability. While interaction across sectors is important, actors tend to focus on interactions within rather than across sectors. One reason for this is that interactions across sectors are often associated with higher costs, as actors are less similar to each other and therefore need to invest more to establish or maintain interaction ties (Buchli, 2005; Hileman & Bodin, 2019a). Still, interaction across sectors is important as this helps to account for interdependencies and support achieving independent governance goals.

The second characterization of complexity addresses the issue that social and ecological entities in SESs are interdependent [Paper 2]. Entities within the social system are interdependent as actors often, in one way or another, impact each other. In Paper 2, the actors' impact on each other is analyzed based on their collaboration behavior and how this collaboration behavior is influenced by and influences the present governance system. Additionally, SES governance also includes interdependent ecological entities. Ecological entities are interdependent, as many resources can be transformed into other resources. For example, resources such as soil can be converted into pastureland that can be used to feed livestock. Further, interdependencies between the social and ecological systems exist as actors often simultaneously manage and depend on the same natural resources. For example, a farmer who cultivates land depends on the quality of the soil and water availability. Finally, different qualities of interdependencies are possible that, for example, have an increasing or decreasing impact on soil quality. Paper 2 accounts for different qualities of interdependencies in SESs using a multi-level network perspective on the governance of SES.

Understanding how different dimensions of complexity in SESs influence actors' decisions to interact with other actors is essential in SES governance. Furthermore, it is also important to understand how these emergent interaction patterns shape governance outcomes. Different theories and concepts exist for evaluating and interpreting the link between network patterns and governance outcomes. Governance outcomes relate here to outcomes of SES governance that can be grouped into socio-economic (e.g., economic productivity or security issues) and biophysical (e.g., biodiversity) outcome categories. Therefore, governance outcomes are based mainly on environmental resources or ecosystem services that provide for the quality of the different governance outcomes. Examples of governance outcomes based on environmental resources and ecosystem services are the recreation value of a protected area or the agricultural productivity influenced by soil fertility. The state (or degree of success) of the governance outcomes is heavily dependent on governance decisions and strategies of the relevant actors. Actors' involvement in shaping governance outcomes is essential to consider, as certain trade-offs exist between governance outcomes. Therefore, improving the state of one governance outcome often comes with decreasing the state of another governance outcome. For the purposes of this thesis, the governance outcomes are elicited based on a survey with local actors that were able to quantify some relevant governance outcomes for their activity region (for more details on the survey, see dataset Paper). To evaluate how governance outcomes are influenced by the governance setting in place the concept of social-ecological fit (Bergsten et al., 2014; Bodin & Tengö, 2012; Epstein et al., 2015b) and bonding/bridging ties (Burt, 2000; Granovetter, 1973; Putnam et al., 1992) are used to analyze the link between actors' interaction patterns and governance outcomes.

The concept of social-ecological fit [Paper 2 & 4] is used to analyze how actors account for governance settings of changing complexity based on their interaction activities with other actors. Interaction among actors helps align the interdependent social and ecological systems (Enqvist et al., 2020; Epstein et al., 2015b; Guerrero et al., 2015). However, to achieve such alignment, actors need to be aware of social-ecological interdependencies that are often difficult to unravel. Alternately, bonding and bridging [Papers 3 & 4] indicate how the governance setting influences the emergence of interaction patterns. In the literature analyzing interaction patterns in governance networks, bonding structures characterized by dense interaction patterns between actors are associated with higher levels of trust, while bridging structures benefit sharing of information or knowledge efficiently across different actors (Burt, 2000; Peng & Wang, 2013). Investing in bonding or bridging based on specific interaction patterns is a strategy for actors to react to different governance settings. In Paper 3, we analyze how network embedding characterized by bonding and bridging ties can be a source of power (Mancilla García & Bodin, 2019b) and how this compares to other forms of power (Morrison et al., 2019b) that altogether contribute to actors' capacity to shape governance outcomes. Based on the risk hypotheses by Berardo and Scholz (2010), bonding ties are particularly beneficial in governance settings characterized by high risk, and bridging ties in governance settings of low risk. The riskiness of governance settings can be characterized by different factors, such as the emergence of new policy arenas (Berardo & Scholz, 2010), the associated levels of environmental stress (Berardo, 2014b), or the state of governance outcomes. In Paper 4, governance outcomes' state is used to characterize the riskiness of governance settings as poor states of governance outcomes are likely characteristic of higher levels of risk, and good governance outcomes are likely characteristic of lower levels of risk. The riskiness of governance settings and the level of social-ecological fit are then used as two potential explanations for linking observed network patterns with empirical data on governance outcomes. In continuously developing governance settings, likely both the riskiness of governance settings and the level of social-ecological fit, as well as associated network patterns such as bonding/bridging ties and network motifs of fit, are shaping governance outcomes.

Networks of social-ecological systems

So far, the characterization of complex SESs has relied on multiple entities, such as actors or resource units, and on the nature of their interdependence (see Figure 1). In line with the claim that it is important to move away from a strictly reductionistic approach where only the most essential information is conceptualized as a network (e.g., a collaboration network where everything else is context information), it is important to make interdependencies between different entities of the SESs explicit (Gonzalès & Parrott, 2012; Waltner-Toews et al., 2008; Wasserman & Faust, 1994b). To make the relationships between these different entities of complex SESs explicit, this thesis builds on networks of SESs. Networks of social-ecological systems are composed of two distinct elements: nodes (e.g., actors or resource units) representing discrete entities of the SESs, and ties (e.g., actor interactions such as collaboration or causal biophysical effects) representing the interdependencies between the nodes. Nodes, as well as ties, can have various attributes that help to distinguish and characterize them. Different types of ties can help to differentiate between multiple forms of actor interactions, for example, directed and undirected collaboration ties. Networks can have one or multiple categories of nodes and ties (Gonzalès & Parrott, 2012; Scott & Ulibarri, 2019). Here the focus is on networks with distinct types of nodes and ties for the social and ecological systems they represent.

The benefit of network-analytic approaches for analyzing SESs is that they can be employed using both qualitative and quantitative data and various epistemological aims, from theory building to theory testing (Scott & Ulibarri, 2019). Further network-analytic approaches help scholars to test and build upon long-standing theoretical frameworks, such as collective action or the SES framework, that address interdependencies of complex governance issues. Network-analytic approaches are particularly helpful for the purpose of analyzing interdependencies across intertwined social and ecological systems characteristic of governance or policy systems (Bodin et al., 2016).

Difficulties working with network-analytic approaches concern issues that cannot be easily conceptualized as nodes or ties but still influence the network structure (Scott & Ulibarri, 2019). Such factors concern, for example, different types of rules (e.g., payoff rules which specify the distribution of benefits and costs (McGinnis, 2011)) or environmental settings (e.g., differences in resource flows in up/downstream settings (Harvey et al., 2020)) that shape the network patterns. Further network-analytic approaches often face issues distinguishing between drivers and outcomes (e.g., resource flows can be both driver and outcome of actor interactions (Emerson & Nabatchi, 2015)), as the analysis in Paper 4 also demonstrates.

Network-analytic approaches have a long research tradition of analyzing interdependencies in social science (Burt, 2018; Freeman, 1996; Granovetter, 1973) as well as in ecology (Fath & Patten, 1999; Finn, 1976; Ulanowicz, 1980). Network-analytic approaches have proven to be a powerful and versatile method and theory crafted to describe and quantify aspects related – but not limited – to the governance of SESs (Janssen et al., 2006; Scott & Ulibarri, 2019). Examples of how network approaches can advance research on SESs include studies on the resource exchange (Baggio et al., 2016), actor coordination for natural resource governance (Angst et al., 2018), or collective action situations in water management (Lubell et al., 2014). While networks can be used to model SESs holistically, most network applications focus on either the social or the ecological systems (Cumming et al., 2010). Nevertheless, it is commonly accepted that networks can contribute a wide range of tools and concepts to study interdependencies within SESs holistically (Bodin & Crona, 2016; Cumming et al., 2010; Gonzalès & Parrott, 2012; Janssen et al., 2006).

Different concepts exist to structure and further develop network approaches of SESs. The articles of this thesis all build more or less on the social-ecological networks (SEN) concept (see Figure 1 for different conceptualizations of SENs). The SEN concept has its foundation in network research from sociology, political science, physics, and complex systems (Bodin et al., 2019). Further, the SEN concept grounds its theoretical assumptions in the literature of Cumming et al. (2006); Folke et al. (2005); Janssen et al. (2006); Ostrom (1990); Young and Gasser (2002). SENs do not need to be rooted in geographic space, but rather need only to represent abstract or theoretical entities of SESs and interdependencies between them as nodes and ties (for examples, see Bergsten et al. (2014); Hamilton et al. (2019); Sayles and Baggio (2017a)). SEN research mainly focuses on aligning social and ecological interdependencies using different research foci, such as managing common-pool resources (Bodin et al., 2019; Sayles et al., 2019).

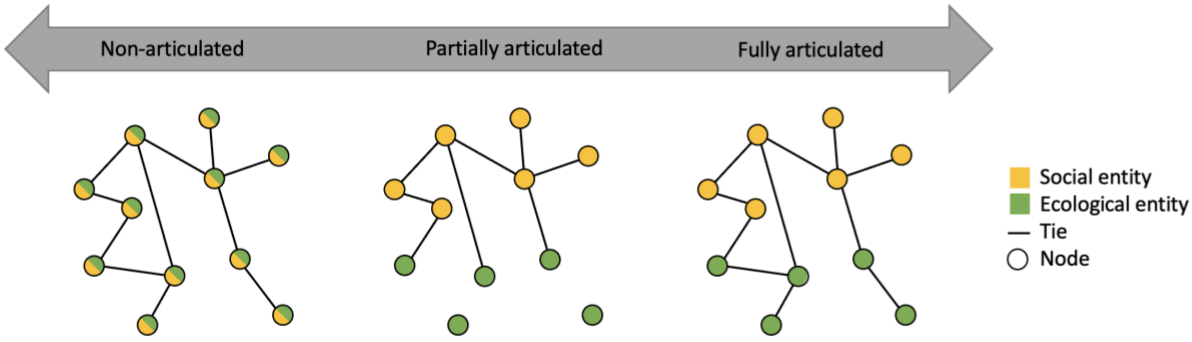

Figure 1: SENs can be characterized along a spectrum from non-articulate SENs to fully articulated SENs, specifying the degree of explicity of network representations of social and ecological entities (nodes) and interdependencies (ties) between them. For the non-articulated SENs, social and ecological entities of nodes are combined, while for the more articulated SENs, social and ecological entities form two distinct types of nodes. (Figure adapted from Kluger et al. (2020); Sayles et al. (2019))

Networks of SESs that account for within and across system interdependencies can make important contributions to increasing our understanding of SESs and potentially benefit the environmental governance of SESs (Sayles et al., 2019; Scott & Ulibarri, 2019). As networks help to account for social-ecological interdependencies, network analytics can contribute to analyzing and interpreting collective action problems characterizing environmental challenges, such as the governance of SESs (Lubell, 2013; Lubell & Morrison, 2021a). What makes collective action problems challenging to be analyzed – the interdependencies between actors' decisions to interact and the governance problem(s) at stake – is the same reason that network structures offer an excellent opportunity for its analysis. Due to the advantages of network-analytic approaches of SESs an increasing number of scholars use networks for analyzing the governance of SESs, and the respective literature is rapidly developing (Kluger et al., 2020). This rapid development of the literature revealed different theoretical, methodological, and empirical challenges for progressing network-analytic approaches to study the governance of SESs (Bodin et al., 2019; Felipe-Lucia et al., 2022b; Sayles et al., 2019). This thesis contributes to some particularly pressing challenges of network studies of SESs.

First, this thesis elaborates on how highly detailed empirical data on the interdependencies of SESs can be used to conceptualize relevant networks characterizing the governance of SESs. Relevant network interdependencies can concern network ties between social entities, ecological entities, or across social and ecological entities (Kluger et al., 2020; Sayles et al., 2019). Such network ties can further have different qualities (increasing/decreasing effect or collaboration/conflict between actors) that shape the interpretation of the networks. For example, while it is possible to describe the relationship between a hydropower plant and the water flow of a river based on a simple tie, this description would not contain any information on whether the water flow is increased or decreased by the hydropower plant. As the residual water flow of hydropower fluctuates and a resulting extremely high or low water flow of the river can in both cases cause damage to the river ecosystem, it is critical to have information on tie quality to interpret the network structure correctly. Therefore, accounting for different ties qualities can help improve network conceptualizations of complex SESs. Paper 2 elaborates under which circumstances different ties' qualities, such as increasing or decreasing causal effects between environmental issues, can help improve networks' predictive capacity for understanding the emergence of collaboration ties between actors using exponential random graph models (ERGMs). ERGMs can be used to model how the emergence of network ties depends on a set of interacting network exogenous and endogenous factors (Cranmer et al., 2017; Robins, Snijders, et al., 2007). ERGMs to account for social-ecological interdependencies in so much detail is rarely done so far in network studies of SESs (Bodin et al., 2019; Jasny et al., 2021; Sayles et al., 2019; Vasudeva et al., 2020).

Second, this thesis analyzes how external factors can influence the structures of networks of SESs. Accounting for external factors influencing network structures is essential, as not all data is equally suitable to be conceptualized as networks (Scott & Ulibarri, 2019). Nevertheless, such information can be highly relevant to interpret the observed networks. Paper 1 analyzes how cross-sectoral dependencies shape actor networks. While cross-sectoral dependencies are recognized to be important, assessing how such cross-sectoral structures shape actor networks is a much more recent endeavor (Bodin et al., 2019; Bodin & Tengö, 2012; Van Bommel et al., 2009; Vos et al., 2018). Paper 2 focuses on how different contextual factors shape the level of social-ecological fit in SES governance. For example, how the size of SESs (e.g., the area of a nature protection zone) and the associated number of actors impact the level of social-ecological fit. By analyzing the impact of network external factors on social-ecological fit, Paper 2 provides an innovative perspective that helps improve the interpretation of social-ecological fit, going beyond merely network-related data. More generally, Paper 2 contributes to integrating network data from ERGMs and non-network data (contextual factors) to explore methodological options for their combined analyzes, such as the use of a qualitative meta-regression analysis.

Third, this thesis explores methodological and theoretical options for linking network patterns to governance outcomes. Theoretical concepts for interpreting network patterns, such as the concept of social-ecological fit or bonding/bridging ties, generally assume a link between governance (network) patterns and outcomes. However, most of these network studies building on social-ecological fit or bonding/bridging ties draw conclusions on governance outcomes without having much empirical data on the quality of governance outcomes, such as the biodiversity of a protected area (Barnes et al., 2019; Hamilton et al., 2019). In Papers 3 & 4, a Bayesian modeling approach is used to link network data of SESs with empirical data on governance outcomes. Combining network data on SESs with empirical data on governance outcomes allows for testing theoretical assumptions linking network patterns with governance outcomes.

What makes the contributions of Papers 2 - 4 particularly noteworthy is that the results are based on the analysis of a multi-case study with up to ten combined cases of SES governance. Therefore, the observed results are based on general trends across multiple separate yet comparable cases, and are likely to remain robust for further cases of SES governance. This is particularly relevant as longitudinal data for network-based SES research is still rare, and multi-case studies nevertheless offer an opportunity to identify trends in the governance of SESs. Building on a dataset of ten cases of wetland governance in Switzerland (presented in the dataset Paper), this thesis responds to the call in the SEN literature to move beyond single case studies (Bodin et al., 2019; Sayles et al., 2019). Moving beyond single case studies of SESs is important to further develop theories and methods for (multi-level) networks of SESs (Felipe-Lucia et al., 2022b; Kluger et al., 2020). Further multi-case studies are important for accumulating knowledge that goes beyond isolated case studies and for drawing more general conclusions linking network patterns and governance outcomes.

To further develop network concepts of SESs, this thesis also proposes a new network approach to strengthen the conceptual link between networks of SESs and governance outcomes and shows how the conceptualization of networks of SESs could be more standardized. Standardization of networks of SESs could benefit the comparison across multiple case studies, which is important to avoid isolated silos of knowledge from separate case studies that do not cumulate (Bodin et al., 2019; Ostrom, 2009; Sayles et al., 2019). Only if knowledge from different case studies is synthesized is it possible to further develop network concepts of SES, such as SENs, at a certain point. As such theoretical development of network concepts of SESs spans multiple papers, the results are not presented in one specific paper but rather at the end of this thesis in the Synthesis section. I call the new network concept presented in this thesis "resource-governance network".

Integration of the research questions into the thesis's papers

To analyze how the complexity of SESs influences the governance of the SESs, this PhD thesis asks how social-ecological interdependencies (e.g., actors' interaction patterns or biophysical interdependencies) affect the governance outcomes for water-based ecosystems in Switzerland. To answer this overarching research question, the thesis builds on novel and innovative network-analytic approaches for SESs, such as the SEN concept (Bodin et al., 2016; Bodin & Tengö, 2012; Felipe-Lucia et al., 2022b). Building on network concepts of SESs, the thesis asks the following three specific research questions to structure the overarching research question:

- *RQ1: What social and ecological units are part of networks of SESs of water-based ecosystems? [Paper 1 – 4]*
- *RQ2: How do cross-system interdependencies and contextual factors influence actor interactions in networks of SESs? [Paper 1 & 2]*
- *RQ3: How do network patterns in networks of SESs impact governance outcomes in water-based ecosystems? [Paper 3 & 4]*

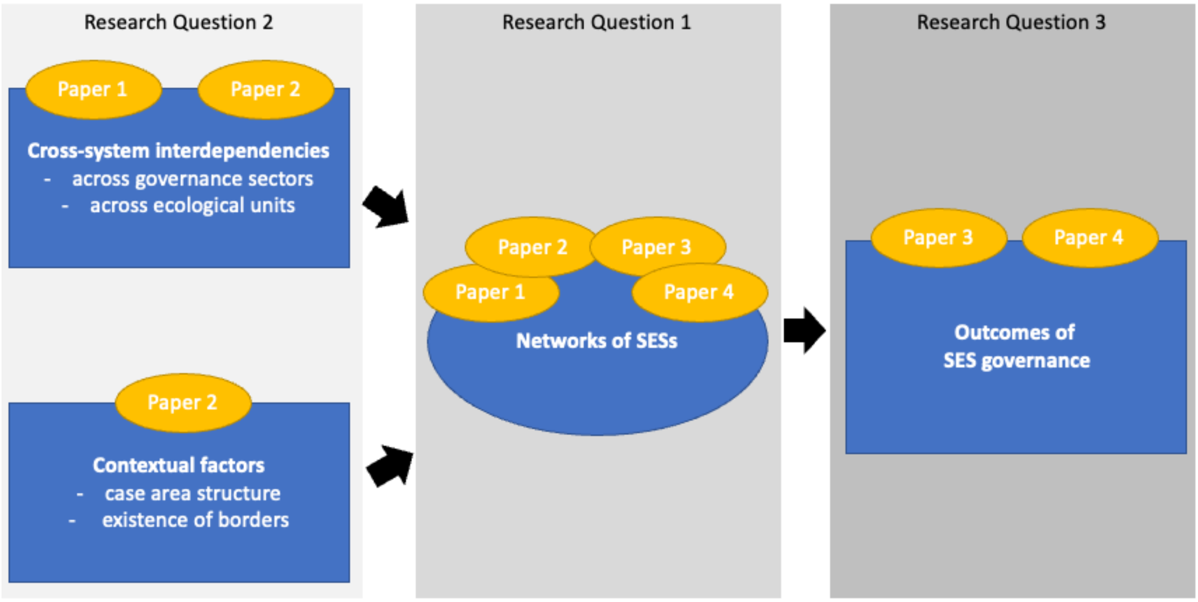

Figure 2: Illustration of how the three research questions build upon each other. Research question 1 essentially lays the foundation for the other research question by providing a network conceptualization of the SESs. Research question 2 adds additional information to the networks that are not directly conceptualized as nodes or ties. Research question 3 analyzes how the network conceptualization of SES governance helps to explain governance outcomes.

Together these three research questions help to gather information explaining what shapes the governance of ecosystems, clarify the importance of actor interaction therein, and illustrate how this information can be used to shape governance outcomes and account for environmental challenges. Further responding to the overarching research question more generally helps to further develop network-analytic approaches to study SESs. In order to do so, this thesis relies on network methods and theory to analyze how the governance of water-based ecosystems is influenced by complex social-ecological interdependencies characterized based on research questions 1 & 2. Furthermore, it is analyzed how such characteristics influence governance outcomes based on research question 3. Subsequently, the three research questions are embedded in the four PhD papers. Additionally, there is one more paper, which is not a classical research paper but rather presents the dataset used for Papers 2 - 4. Additional information on the dataset is only presented for Papers 2 – 4 as those three papers are all part of the same project on wetland governance, while Paper 1 is based on another project located in the Swiss alps (see Table A10 for a detailed comparison of the papers presented in this thesis).

The level of complexity and number of analyzed case studies increases from papers 1 to 4. For Paper 1, which lays the groundwork for the following papers, the focus of analysis is on the social network of one single case study. In Papers 2 - 4, the focus is on multiple combined cases of SES governance. Paper 2 focuses on how those cases' interdependent social and ecological network levels are aligned. In Papers 3 & 4, a step forward is taken to analyze how network patterns of SESs can be linked to governance outcomes of SES.

Paper 1 – The impact of cross-sectoral knowledge on actor networks in natural resource governance

Paper 1 looks at the governance of natural resources based on one case study in a valley in the Swiss Alps. The paper focuses on challenges that arise as the governance of natural resources often cuts across multiple dependent sectors. While resource governance cuts across multiple related sectors, previous research indicates that this tendency is not fully reflected in actor networks, as such networks often show clusters of higher exchange within sectors, while the connectivity is sparser across sectors (Lemos & Agrawal, 2006; Roux et al., 2008; Vangen et al., 2015). This paper analyzes the impact of contextual factors [RQ2], based on governance sectors, on actor exchange [RQ1] within and across governance sectors. Based on this, we ask: *how actors' information about other sectors relates to their network contacts within and across sectors in natural resource governance.*

To study how cross-sectoral dependencies influence actor networks, we analyze the contact network of actors active in water governance (see Figure 3) using ERGMs. The ERGMs are used to test how cross-sectoral management structures shape the emergence of contact ties of actors. Further, the results from the ERGMs are complemented with descriptive and inferential network analysis. Combined, the results show that actors with a higher level of cross-sectoral knowledge tend to have more contact ties – particularly with actors active in other sectors. From this we conclude that actors' cross-sectoral knowledge is key for promoting actors' decisions to establish contact with actors from other sectors and improve the integration of the sectoral network clusters. Increasing contact between sectoral network clusters helps integrate governance issues of otherwise disconnected sectors. As the integration of governance issues is associated with successful governance (Bodin & Crona, 2009; Lubell, 2013; Pittman & Armitage, 2017; Prell et al., 2009), increasing actors' cross-sectoral knowledge benefits the governance of natural resources.

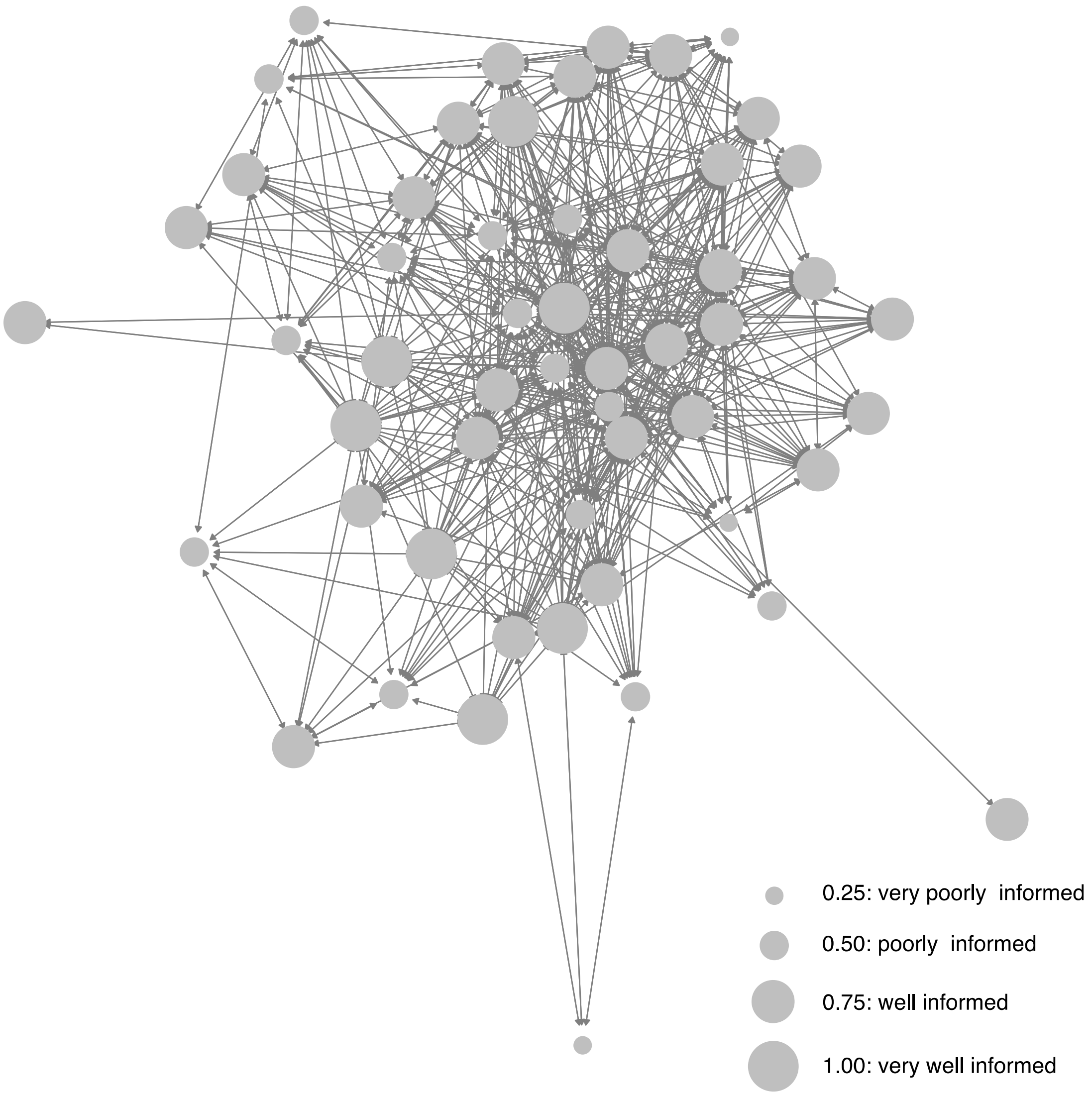

Figure 3: Illustration of the water governance contact network between actors for Paper 1. The size of the dots indicates the actors' level of cross-sectoral information, with bigger dots indicating higher levels of cross-sectoral information.

Paper 2 – How the qualities of actor-issue interdependencies influence collaboration patterns

Paper 2 essentially builds on Paper 1 but develops certain concepts further. As with Paper 1, we look at actor networks in water governance. However, while Paper 1 focuses on one case study of water governance in the Swiss Alps, Paper 2 looks at eight separate yet comparable case studies of wetlands in Switzerland. Another similarity between the two papers is that both analyze how actors account for interdependencies in the governance of SESs. But instead of doing this based on governance sectors, Paper 2 analyzes interdependencies of environmental issues based on network conceptualizations of the SESs [RQ2]. Besides environmental issues, the network conceptualizations of wetland governance also include relevant actors as an additional node type. As the SES networks have distinct nodes for the social and ecological network levels and ties within and across those levels, Paper 2's analysis builds on a fully articulated SEN (Sayles et al., 2019) (see Figure 4) [RQ1]. Based on this SEN representation of the wetlands, Paper 2 analyzes *how different qualities of actor-issue paths influence the probability of actors sharing a collaboration tie.*

An actor-issue path is a network path that connects two actors via one or multiple environmental issues. The quality of actor-issue paths can be described based on different criteria of actor issues paths: the length (how closely environmental issues connect actors), multiplexity (if actors have multiple parallel paths connecting them through environmental issues), and similarity (whether actors' environmental impact is similar to one of their potential collaboration partners). These different criteria of actors-issue paths make it possible to account for a level of detail in network motifs of SESs in a way that has been rarely done before (Berardo & Scholz, 2010; Enqvist et al., 2020; Epstein et al., 2015b; Moon et al., 2019). Similar to Paper 1, the assumption is that actor collaboration benefits the governance of SESs. Actor collaboration is particularly beneficial if the collaboration contributes to increasing the alignment of social-ecological network patterns in SENs characterized based on actor-issue paths qualities (Epstein et al., 2015b; Lubell et al., 2014; Ostrom, 2009; Pittman & Armitage, 2017). To analyze if actor-issue path qualities increase actors' chance of collaborating, separate ERGMs are calculated for every case. Further, the ERGM results are compared across the cases using a qualitative meta-regression analysis (see Figure 11). The goal of the qualitative meta-regression analysis is to combine the ERGM results from all eight cases and to see how differences in governance complexity impact the level of social-ecological fit characterized based on actor-issue paths and collaboration ties of actors.

The qualitative meta-regression analysis reveals that the increase of collaboration ties based on actor-issue path qualities is particularly strong in cases of low governance complexity characterized based on the case area structure. Therefore, the social-ecological alignment is particularly high in cases with a case area structure indicating a low governance complexity. In other governance settings the results are not so clear, as the impact of actor-issue path qualities on collaboration ties ranges from positive to negative. Differences in the impact of actor-issue path qualities on collaboration ties between the cases show the importance of multi-case studies to identify trends across cases, as such trends could not be inferred from a single case only.

Paper 3 – Who is satisfied with their inclusion in polycentric sustainability governance? Network embedding, power and procedural justice in Swiss wetlands

Sustainability governance in polycentric systems addresses procedural justice as well as effectiveness for governing SESs (Burch et al., 2019; Lubell & Morrison, 2021a). Paper 3, therefore, looks at actors' satisfaction with their inclusion in polycentric sustainability governance as a measure of procedural justice. As procedural justice is linked to power dynamics in polycentric sustainability governance, it is important to account for different types, sources, and effects of power (Berardo & Lubell, 2019a; Morrison et al., 2019b). This paper focuses on the network embedding of actors as one particular source of power in polycentric sustainability governance, shaping actors' capacity to achieve prioritized governance outcomes. To analyze how the network embedding of actors can be a source of power, we ask: *How does network embedding translate into power in polycentric governance systems?* To further test how power based on actors' network embedding compares to other forms of power regarding procedural justice, we also ask: *How does network embedding derived power influence satisfaction with inclusion in polycentric sustainability governance, compared to other sources of power?*

We relate network embedding to power and procedural justice in governance processes building on the same SEN for ten cases of Swiss wetlands as already used for Paper 2 (see Figure 4) [RQ1]. The difference between the two papers is that the state of environmental outcomes (in Paper 3, also referred to as governance issues) is used as a measure of procedural justice. Better governance outcomes are associated with higher levels of procedural justice, which can be described as actors' satisfaction with inclusion. Satisfaction with inclusion is shaped by the actors' capacity to achieve prioritized governance outcomes. Achieving prioritized governance outcomes depends on actors' power, captured here by actors' network embedding based on bonding and bridging ties. To test a) how actors' bonding and bridging ties translate into power and b) how power shapes actors' capacity to achieve governance outcomes [RQ3], a Bayesian multi-level regression model is applied.

The results suggest that network embedding is indeed a source of power for actors , but only in cases where network embedding is based on actors' bonding ties, while bridging structures in networks are less relevant. Further, the results also show that other non-network related sources of power are important for actors to achieve their prioritized governance outcomes and consequently for their satisfaction with inclusion in the governance process. Therefore, research and practice of polycentric sustainability governance need to be careful to account for different sources of power, as power does not only influences the capacity to achieve governance outcomes but also is important with regard to procedural justice and governance effectiveness more generally.

Paper 4 – The link between social-ecological network fit and outcomes: a rare empirical assessment of a prominent hypothesis

The focus of Paper 4 is on the impact of network structures of SENs on the state of governance outcomes [RQ3]. There are abundant claims that collaborative governance approaches paired with social-ecological fit promote sustainable ecosystem governance, good ecological states, and environmental outcomes in general (Bodin et al., 2016; Epstein et al., 2015b; Folke et al., 2007). Yet, few empirical studies test the link between levels of social-ecological fit in governance networks and outcomes (Bodin et al., 2019; Kluger et al., 2020). This Paper analyzes how network motifs of social-ecological fit are associated with the assessment of governance outcomes in ten cases of Swiss wetlands governance (for detail on the dataset, see dataset Paper). To respond to the claim that social-ecological fit promotes sustainable ecosystem governance, this paper asks: *How do network motifs of social-ecological fit relate to governance outcomes?*

To test for the link between network motifs of social-ecological fit and governance outcomes, the analysis builds on a Bayesian multi-level ordinal regression model. Based on this model, the link between actors' assessment of governance outcomes and the proportion of closed triangle and four-cycle motifs representing social-ecological fit is analyzed. The results show that contrary to the claim of social-ecological fit, higher levels of fit are linked to worse governance outcomes. This does not necessarily mean that social-ecological fit has a negative impact on governance outcomes. But as causality between network patterns and governance outcomes is likely to go both ways and co-evolve, it is also possible that the observed governance outcomes impact the network patterns and associated motifs of fit. To explain how network motifs of fit are potentially influenced by the state of governance outcomes, the risk hypothesis Berardo and Scholz (2010) is used to emphasize the complicated co-dependency between network patterns and governance outcomes from a different angle. The risk hypothesis claims that bonding structures (similar not closed network motifs) are more likely in high-risk governance settings (similar to poor governance outcomes). Summarizing, the results likely highlight a complicated causal process between performance and adjustment to risk at play in the relationship between network structures and outcomes which is important to consider for future studies linking network motifs of social-ecological fit to outcomes of SES governance.

Dataset Paper – Multi-level network dataset of ten Swiss wetlands governance cases based on qualitative interviews and quantitative surveys

The dataset Paper presents the dataset used for Papers 2 – 4 (link to the dataset on Zenodo: 10.5281/zenodo.6907175). While research Papers 2 - 4 analyze the governance of wetlands in Switzerland, the dataset Paper is not part of the relevant PhD papers as it is not a typical research paper, but rather presents the dataset (see Figure 4) and how the data was collected without any interpretations.

The data gathering of the dataset Paper is based on quantitative online surveys and qualitative expert interviews with organizational actors relevant to the governance of ten Swiss wetlands from 2019 to 2021. The qualitative expert interviews were organized as semi-structured face-to-face interviews. The statement of the experts was used to construct a conceptual map of the ecosystems of the wetlands (represented by the nodes of ecosystem management activities, environmental issues, and governance outcomes integrated into Figure 4). The online surveys targeted 521 actors identified as relevant to the ten cases of wetland governance. Based on the survey data on the actor's collaboration partners, activities and other actor characteristics were gathered (represented by the nodes of actors and forums integrated into Figure 4). Together the data from the quantitative online surveys and qualitative expert interviews were used to conceptualize a multi-level network of the SESs for each wetland. These multi-level networks have different types of nodes and ties representing interdependencies within and across the social and ecological levels of analysis. The most critical nodes of these multi-level networks are actors (e.g., public actors such as municipalities or private actors such as NGOs) and environmental issues (e.g., water quality, bever population, or disturbances by visitors), but other types of nodes such as governance outcomes or forums are included in the networks as well.

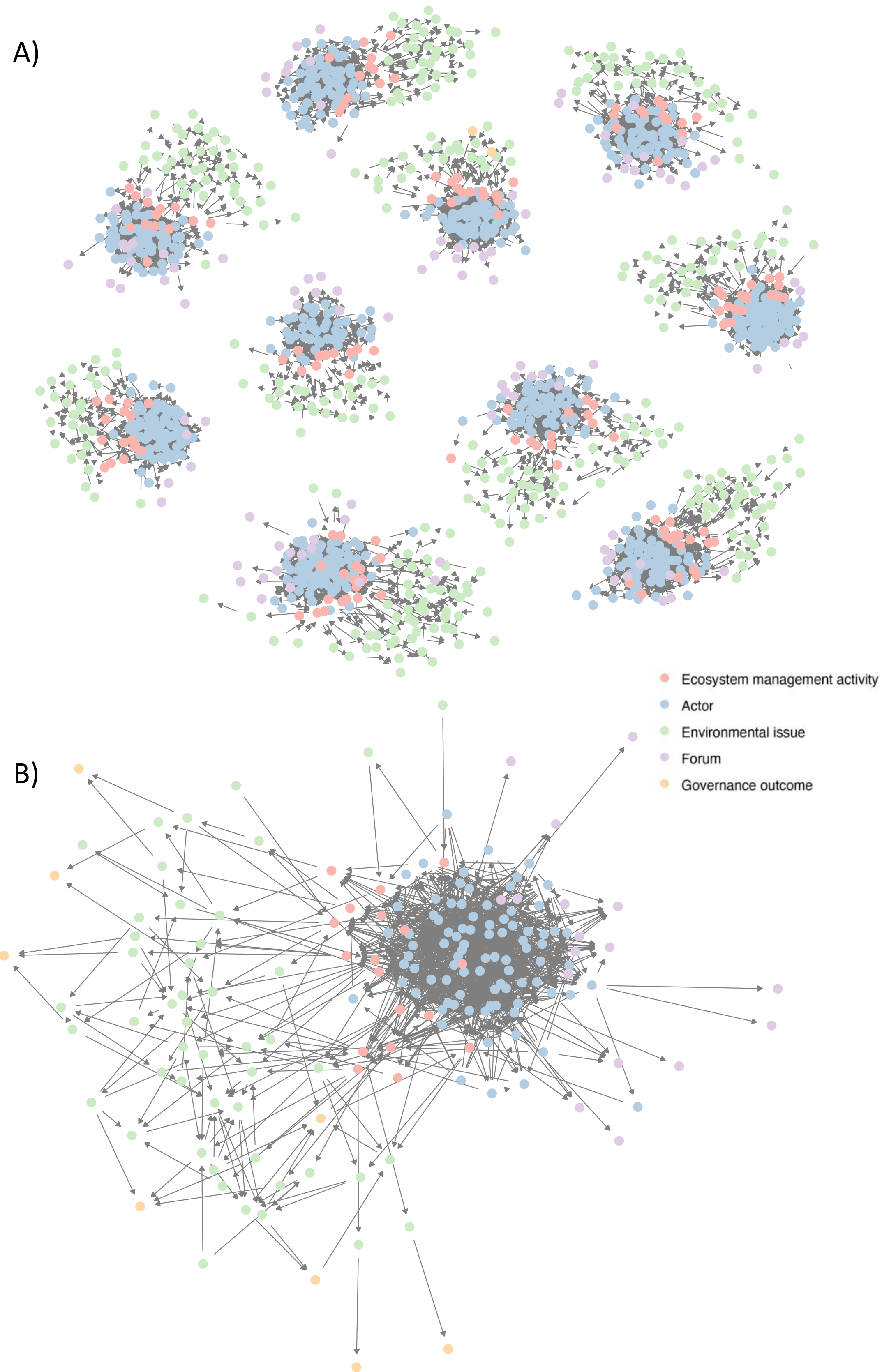

Figure 4: Two illustrations of multi-level networks of the SESs of wetlands presented in the dataset Paper and analyzed in Papers 2 - 4. The multi-level networks have five types of nodes (actors, activities, environmental issues, governance outcomes, and targets) and ties between those different types of nodes. For details on the conceptualization of the network representation, see the dataset Paper.
A) Overview Illustrations of the multi-level networks for the ten cases of wetland governance and B) Illustration of the multi-level network of the case at the river Rhine.

Synthesis

Network approaches analyzing the governance of SESs contribute to our understanding of interdependencies in SESs and to achieving ecologically and socially sustainable governance outcomes. In this section, I summarize the thesis's theoretical, methodological, and practical contributions to network-analytic approaches of SESs and, more generally, to the governance of SESs. As the contributions of this thesis are essentially based on the four PhD papers, individual contributions of these papers are taken up again and combined to highlight the overall contributions of this PhD thesis. Furthermore, the individual contributions are linked back to the relevant research questions to illustrate how the paper's results contribute to answering them.

Key contribution I: Perceptions and qualities of interdependencies in SESs [RQ2]

While interdependencies in SESs are generally acknowledged to be important for the governance of SESs (Bergsten et al., 2019; Gonzalès & Parrott, 2012; Hedlund et al., 2021), it remains a challenge to distinguish between more and less relevant social and ecological entities where connectivity should be accounted for. This thesis contributes to the challenge of interdependencies in network conceptualizations of SESs in two ways. First, it is analyzed how actors perceive interdependencies based on overlapping governance sectors and how this can be linked to patterns in the contact network of actors [Paper 1]. Second, the possibility of increasing the level of detail for the conceptualization of interdependencies is analyzed. One possibility to increase the level of detail of interdependencies explored in Paper 2 involves different qualities of network ties (for further information on qualities of network ties, see Paper 2). Exploring the potential of such detailed network conceptualizations of SESs for explaining actors' decision-making processes is highly relevant for literature on social-ecological systems, social-ecological networks, collaborative governance, and ecosystem governance and, more generally, for improving the governance of SESs (Bodin et al., 2019; Jasny et al., 2021; Sayles et al., 2019).

Highly detailed network conceptualizations are important to account for the complexity of SES governance. To account for the complexity of SES governance, the network conceptualization of wetlands governance used for Papers 2 - 4 builds on multi-level networks with six types of nodes (actors, ecosystem management activities, environmental issues (chances, direct and indirect threats), and outcomes). While for the individual papers, the multiplexity of these networks was reduced to fit the scope of the papers' analyzes; it illustrates the high complexity of networks of SES governance. To achieve such highly detailed network conceptualizations, an adaptation of the open standards approach (Schwartz et al., 2012) is used (for details on data gathering, see the dataset Paper). As the original open standards approach is designed for any governance settings of SESs, in the future this approach can help achieve detailed system mappings supporting enriching network-analytic methods and theories for the integrative analysis of SESs.

Further, results show that awareness of interdependencies can shape the network patterns of actor networks under certain settings. In Paper 1, actors' chance to establish contacts across sectors increases with actors' level of information on other sectors. However, the impact of interdependencies on actor networks is not always as straightforward, as the results of Paper 2 demonstrate. In Paper 2, which analyzes interdependencies based on actor-issue path qualities, the results indicate that the impact of interdependencies on actor collaboration strongly depends on the level of governance complexity. In cases with a high governance complexity due to large and heterogeneous case areas, actor-issue path qualities have a negative impact on the probability of collaboration ties, while in cases of low governance complexity, actor-issue path qualities increase the chance of collaboration ties and the associated level of social-ecological fit. This implies that actors are more likely to establish collaboration ties when actors easily perceive the actor-issue path qualities. More generally, knowledge about qualities of interdependencies in SESs and actors' perception thereof helps to understand differences in how actors account for governance settings and consequently improves the practical relevance of the research findings.

Key contribution II: Inclusion of governance outcomes in network studies of SESs [RQ3]

The ultimate goal of analyzing the governance of SESs is to improve governance outcomes accounting for social, ecological, and economic needs. Analyzing how SES governance structures and governance outcomes are mutually dependent is inherently difficult – particularly in settings where longitudinal data is rare (Barnes et al., 2017; Berardo & Lubell, 2019a; Bodin & Tengö, 2012). Many network studies on the governance of SESs try to identify certain patterns (e.g., collaboration patterns or social-ecological fit motifs) that are associated with beneficial governance outcomes for SESs based on some social, ecological, or economic criteria (Bodin et al., 2016; Kininmonth et al., 2015; Meek, 2013). However, those network studies focusing on the governance of SESs rarely include empirical data on governance outcomes, but rather rely on theoretical assumptions about governance outcomes instead. Relying only on theoretical assumptions about governance outcomes makes it difficult to develop an in-depth understanding of beneficial structures and processes for the governance of SESs (Kluger et al., 2020; Lubell & Morrison, 2021a). Here empirical data on governance outcomes are integrated into networks of SESs for ten cases of wetland governance (see Figure 4). By doing so, this thesis explores how theories for networks of SESs could be extended to also account for governance outcomes. The benefit of connecting empirical data on outcomes with network data is that the interpretation of causal dependencies between network patterns and governance outcomes does not solely rely on the assumption that network patterns are beneficial, but is rather grounded in empirical data for the state of governance outcomes.

In this PhD thesis, the link between network patterns and governance outcomes is tested based on the concepts of social-ecological fit and bonding/bridging ties, which are both assumed to influence governance outcomes. The underlying assumption is that actor collaboration on common environmental issues and exchanging knowledge with other actors across governance networks positively impact governance outcomes. The results reveal that network patterns and governance outcomes are indeed dependent on each other. Paper 3 shows how actors can leverage bonding ties in particular (but not so much bridging ties) as a source of power to shape governance outcomes. The directionality of causality between network patterns and governance outcomes is, however, more complex, as Paper 4, which analyzes the link between social-ecological fit and governance outcomes, demonstrates. Contrary to what was hypothesized initially, the results of Paper 4 indicate that the level of social-ecological fit is particularly high in settings of unsatisfying governance outcomes. While this does not mean that social-ecological fit is counterproductive for governance efficiency, this might be an indicator that governance systems react with higher levels of social-ecological fit to difficult governance situations. For further studies building on social-ecological fit, it is therefore highly relevant to be cautious when interpreting the link between fit and governance outcomes – particularly when they build on temporal datasets.

Overall, those results on social-ecological fit and bonding/bridging ties show that network patterns and governance outcomes are indeed interdependent. However, making a strong statement about how those two influence each other can be difficult. Furthermore, the results show that the ability of actors to be successful in shaping governance outcomes goes further than mere collaboration to increase social-ecological fit. Rather, being successful in shaping governance outcomes also depends on the network context, for example, if the collaboration ties contribute to bonding structures in the actor networks.

Key contribution III: Integrative analysis of social-ecological systems and relevant case context [RQ1]

Not all characteristics of SES governance are equally suitable to be conceptualized as networks (Scott & Ulibarri, 2019). This thesis explores how SES characteristics, such as the institutional embedding of a case study that are not easily conceptualized based on nodes and ties, influence the perceived governance structures. The focus is on the integration of two network-external factors: 1) interdependencies across governance sectors [Paper 1] and 2) conditions shaping the complexity of governance settings [Paper 2]. While the importance of such network-external factors is generally acknowledged, the extent to which such factors shape structures in networks of SESs is rarely analyzed in network research on SES governance and collaborative governance (Bodin et al., 2019; Bodin & Tengö, 2012; Van Bommel et al., 2009; Vos et al., 2018).

The results of Papers 1 & 2 indicate that network-external factors are important to consider for analyzing and interpreting networks of SESs. Paper 1, for example, shows that actors share more contact ties with other actors in the same sector. The results of Paper 2 demonstrate how actors account differently for actor-issue path qualities characterizing social-ecological fit depending on the complexity of the governance setting. As such network external factors seem to influence actors' interaction behaviors, there is potentially also an impact on the efficiency of the associated governance settings. For example, a governance setting that spans across multiple sectors might result in a lack of bridging ties. For a meaningful integrative analysis of SESs, it is further important to have methods that can cope with different types of data, of which some are conceptualized as networks, and some are not. With the qualitative meta-regression analysis introduced in Paper 2, this thesis also offers a new methodological approach for how to combine such different data types.

Key contribution IV: Comparative study setting [RQ1]

Network-analytic approaches that analyze SESs based on multi-level networks (e.g., based on the SEN concept (Hamilton et al., 2019; Sayles & Baggio, 2017a)) tend to focus on single case studies (Bodin et al., 2019; Sayles et al., 2019). As comparative research of SES networks that employs multiple distinct types of nodes and ties within and across these different types of nodes is rarely done in network research of SESs (Kluger et al., 2020; Sayles et al., 2019), the dataset of the wetlands project (presented in the dataset Paper and analyzed in Papers 2 - 4) offers a unique opportunity to analyze multi-level networks of SESs in a comparative setting with multiple comparable cases.

The comparative dataset on ten wetlands systems helps to make the contributions of Papers 2 - 4 particularly noteworthy. Most importantly, the comparative setting helps leverage case-specific findings of social-ecological interdependencies that are context-sensitive yet generalizable. To ensure a robust generalization of the results, it is important that the underlying assumptions of causal interferences are comparable, and that the heterogeneity among the cases is controlled for. As this is difficult to achieve when combining separate case studies, it is crucial to have a coordinated approach to the data gathering for all cases that are compared. Thanks to such a robust network conceptualization of SESs based on a dataset of ten comparable cases, the power of the findings from Papers 2 - 4 is increased and is more likely to remain valid for other governance settings of SES. Furthermore, the results of those papers helped to further develop network-analytic methods and theories for multi-case settings (see also Further developments of conceptualizations of network-analytic approaches for SESs). In order to encourage further comparative network research on SESs, the dataset is made publicly available based on the dataset Paper.

Further developments of conceptualizations of network-analytic approaches for SESs

Elaborating on the four key contributions of this thesis reveals certain gaps and limitations of network-analytic approaches of SESs, such as the SEN concept this thesis builds on. Relevant gaps concern, for example, the conceptualization of cross-level ties that are equally meaningful for the social and ecological network levels. Equally meaningful implies that ties between social and ecological nodes represent cause-and-effect relationships where social and ecological nodes influence and are influenced by each other equally. Another example of a limiting factor is the facilitation of network topologies with different types of nodes and ties that also account for governance outcomes of SESs. Further, developing network-analytic approaches for SESs should also support comparing results across cases. To improve the comparability of research results across cases, it is important to standardize terms (e.g., the conceptualization of nodes and ties that remains robust across SESs) to facilitate the accumulation of knowledge across cases (Kimmich et al., 2022). To account for these gaps and limitations of network-analytic approaches of SESs I propose a new network approach to conceptualize and analyze the governance of SESs. This is particularly relevant for RQ1 and the issue of what type of elements of an SES governance system should be integrated into networks of SES based on different types of nodes and ties. But also RQ2 and RQ3 might benefit from it, as cross-system dependencies are often under-defined in network approaches of SESs, as well as because governance outcomes are often not even accounted for in networks of SESs.

To develop a new network-analytic approach for SESs governance research, this thesis builds on 1) experiences made working on the PhD papers and particularly regarding the four key contributions, and 2) related literature with a network-analytic focus on the governance of SESs. While some related literature is presented, the aim is not to provide a holistic literature review but to highlight a few interesting perspectives on network-analytic approaches. In line with an increase in the popularity of network-analytic approaches, network concepts are rapidly developing (Felipe-Lucia et al., 2022b; Jasny et al., 2021; Schlüter et al., 2019). Due to this rapid development of network concepts, different network-analytic approaches for SES governance exist that are often not fully coordinated (Sayles et al., 2019). Therefore, the identified gaps do not necessarily reflect all network studies of SESs. The benefit of the existence of many network-analytic approaches in parallel is that it is possible to learn from other network studies of SESs.

Here some aspects from the literature on networks of action situations are used to account for the meaningfulness of cross-level network ties and the integration of outcomes. Action situations (e.g., venues, governance sectors, or biophysically interdependent units of decision-making) gain traction for analyzing SESs governance settings (Kimmich et al., 2022). As these action situations are often interdependent, they can be conceptualized as networks of interdependent action situations (McGinnis, 2011; Sendzimir et al., 2010). One example of such an action situation centered approach is the social-ecological action situations framework by Schlüter et al. (2019). The social-ecological action situations framework takes up multiple elements from the SES framework by Ostrom (2009), such as social and ecological elements of SESs as well as the action situation concept. Based on the social-ecological action situations framework, actors and ecological entities are connected through different action situations, while outcomes emerge from these action situations. One benefit of such action situation centered approaches is for systematically exploring how actors' activities influence SES governance outcomes given a specific set of rules and institutions. Besides, action situations centered approaches can help to connect otherwise disconnected entities of complex SESs, such as social and ecological nodes (Kimmich et al., 2022).

While I also use action situations for the development of a new network analytic approach for SESs, the development additionally focuses on 1) how action situations are embedded between the social and the ecological network levels and 2) how outcomes are influenced by interdependencies between the social entities, ecological entities, and action situations. The underlying system perspective for the integration of these two steps builds on the literature of polycentric sustainability governance, which assumes an ecology of games (EoG) with many centers of decision-making, multiple actors, and interdependent venues (Lubell, 2013; Lubell & Morrison, 2021a). The challenge for actors is to decide which of these interdependent venues in polycentric sustainability governance they will participate in. The assumption here is that those venues are conceptually similar to action situations. Both can be described as a collective action problem defined by rules and regulations based on which actors interact to achieve certain governance outcomes.

The idea of interdependent venues or action situations based on a set of rules and regulations is linked to the SES framework by Ostrom (2009). I use the SES framework as a system perspective and language to integrate those different approaches and to developpe the new network approach for SES governance proposed in this thesis. Building on the terminology of the SES framework helps to develop a robust network conceptualization where dependencies between network levels are made explicit based on clearly defined terms. Further, a robust network conceptualization grounded on clearly defined terms and a language familiar to the broader research on SES governance helps to communicate and compare results across cases and research projects. Using the example of the case study of wetland governance, I outline how network-analytic concepts of SESs could be developed to reveal the interdependencies of SESs more nuanced. To clearly distinguish between other network concepts of SESs and my recommendations for a new network-analytic approach and to highlight the connection to the SES framework, I call the emergent network "resource-governance network" (see Figure 5).

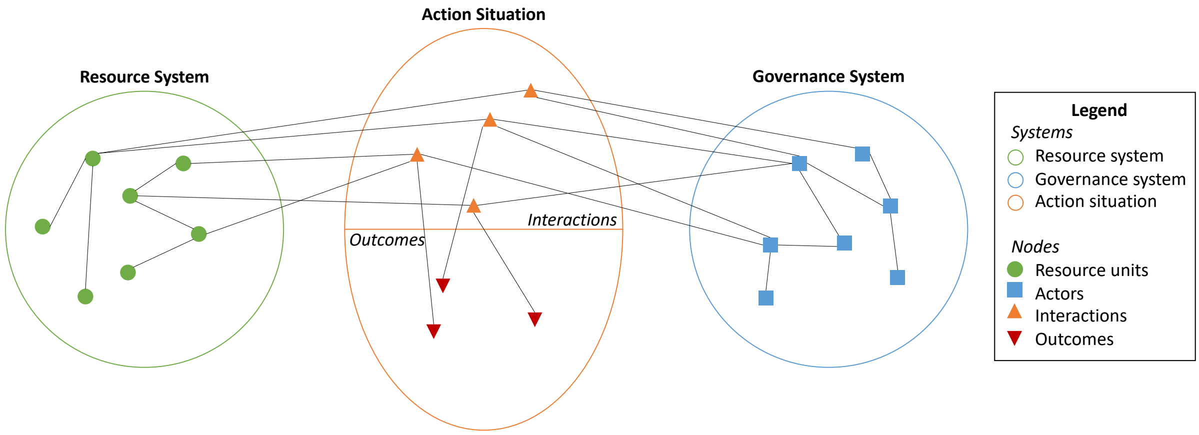

Figure 5: Resource-governance network with three network levels based on the resource system, the governance system, and action situations. The nodes of the resource system are resource units, the nodes of the governance system are actors, and the nodes of the action situations are outcomes and interactions as well as ties within and across the different nodes of the three network levels.

Based on the terminology of the SES framework, a resource system can be a protected area or any other kind of ecosystem that entails different resource units (e.g., resources such as gravel or populations of different species) that are the nodes of the resource network. Ties between the nodes of the resource system exist if there is some movement of biophysical elements or trophic interactions between the resource units. On the other side, the governance system is characterized by present governmental agencies and other organizations that set the rules under which private and public actors – the nodes of the governance network – cooperate. Cooperation between actors exists when actors have some common or dependent activities (e.g., collaboration or exchange of resources). Unlike in other network concepts of SESs, such as the SEN concept, no direct ties exist between the governance and resource network levels exist (similar to the social and ecological network levels in the SEN concept). Instead, similar as in the social-ecological action situations framework by Schlüter et al. (2019), the governance and resource network levels are connected through action situations. The action situation network is a two-mode network with interactions and outcomes as nodes and ties between interactions and outcomes but no ties within interactions and outcomes. Each interaction (e.g., management actions or policies) is connected to a set of resource units on which it depends on and a set of actors involved in executing or managing the interaction. Further, the interactions are connected to emergent governance outcomes. The quality of the governance outcomes (e.g., ecosystem services or performance measures of the governance system) depends on the set of dependent nodes of the governance and resource network levels. Outcomes and interactions together build the action situation network. While all conceptualizations of systems, as well as nodes and ties within and between the systems, have their origin in the SES framework by Ostrom (2007b), they are adapted to fit the network conceptualization. For further details on the definition of nodes and ties, including examples, see Tables 1 & 2.

Table 1: Definition of all node types of the resource-governance network (see Figure 5), including examples thereof. The node types are partially adapted from Bodin et al. (2019); McGinnis and Ostrom (2014); Sayles et al. (2019).

System(s)	**Node types**	**Definition**	**Qualities**	**Examples**
governance system 	actors 	Any type of agency that has a direct or indirect impact on the resource system (no need to impact other agencies present in the governance system).	organizations individuals households	Organizations that set the rules for how resources in a wetland can be utilized or individuals that are actively engaged in the management of wetlands.
resource system 	resource units 	Any type of resource unit that can be directly or indirectly used or conceptualizations of such resource units.	living organisms habitat patches natural resources	Plants that can be harvested or wetland areas that can be utilized for fishing or recreational uses.
action situation 	interactions 	An interaction consists of one or multiple action fields that are dependent on resource units and agencies.	management actions policies resource extraction	Managing the water quality in a wetland or policies that define the rules on how the water quality should be addressed.
	outcomes 	Outcomes can be anything that describes the state of the resources and/or governance system and is dependent on interactions.	ecosystem services performance measures of governance system performance measures of resource system	The recreational value of a river defined by how the available resources are governed, based on multiple management actions or the size of a beaver population in a wetland influenced by the policies in place.

Table 2: Definition of all tie types of the resource-governance networks (see Figure 5), and examples thereof. The tie types are partially adapted from Bodin et al. (2019); McGinnis and Ostrom (2014); Sayles et al. (2019).

System(s)	**Tie tpypes between nodes**	**Qualities**	**Description**
governance system	actor – actor	relationship	Any kind of relationship between nodes of the governance system, such as collaboration between actors.
		exchange	Any kind of exchange between nodes of the governance systems, such as sharing of knowledge or transfer of resources.
resource system	resource unit– resource unit	movement of biophysical elements	Movement of species between habitat patches or the flow of water and the biophysical materials therein.
		trophic interactions	Movement of energy along the food chains of animals across different species.
		concepts of environmental dependencies	Causal dependencies that can connect different kinds of resource units such as microplastic, water quality, or fish population.
governance system / action situation	actor – interaction	ownership	Organizations that are responsible for the implementation of policies or are affected by certain policies.
		influence (management)	Execution of activities by governance actors such as a park ranger responsible for visitor guidance in a protected wetland.
resource system / action situation	resource unit – interaction	exploitation	Ecosystem management activities that require specific resources (e.g., harvesting of crops).
		regulation	Ecosystem management activities that want to maintain specific resources (e.g., enforcing hunting bans) or policies that regulate the use of resources, such as the minimum water flow in the river that a hydropower plant must maintain.
action situation	interaction – outcome	environmental link	The flow of resources or ecological processes that affect/are required to maintain ecosystem services, such as insect pollination activities.
		causal dependency	Cause-effect relationships describe, for example, how ecosystem management activities affect the achievement of social or ecological performance measures (e.g., the impact of the maintenance of paths on the recreational value of a protected area).

The resource-governance network can be illustrated based on the governance of wetlands. In such an example, the governance network level has nodes like farmers or the cantonal office for agriculture that share a common tie as both collaborate together for the governance of the wetland. One specific area of collaboration between farmers and the cantonal office for agriculture is the policy area of agriculture which is conceptualized as an interaction node in the action situation network. Due to their involvement in agriculture, both actors have a tie to the interaction node of agriculture. The interaction node of agriculture additionally has ties to different nodes of the resource network level as the water quality or the amount of nutrients. Nodes of the resource-governance network level have ties with each other when a causal effect exists, such as for the nutrient amount on the water quality. The actors and resource units of the resource and governance network levels influence each other based on their connecting ties across the action situation network level. Based on the mutual interaction node, actors and resource units are responsible for the quality of emergent governance outcomes such as biodiversity or agricultural productivity that are linked to the interaction node of agriculture.

Compared to other network concepts of SESs, one advantage of the newly proposed resource-governance network approach is that it clarifies the connection between the relevant network levels in the resource-governance network, building on clearly defined concepts of nodes and ties. Besides, the terms used in the resource-governance network approach are identical to the SES framework, which supports a translation between the SES framework and the resource-governance network approach. Further, the resource-governance network approach more explicitly accounts for emergent governance outcomes than other network concepts of SESs, such as the SEN concept supporting a more holistic perspective on SES governance.

Still, some questions remain open. On the technical side, this is particularly true with regard to appropriate tools for analyzing such complex multi-level networks. Even though some advancements are happening, for example, regarding the implementation of multi-level (Wang et al., 2016) or bipartite (Kevork & Kauermann, 2022) ERGMs, it still remains challenging to meaningfully model, analyze, and interpret social and ecological network dynamics in combination with each other. Therefore, there is still a need for further methodological developments to fully exploit the potential of network conceptualizations of SESs, such as the here introduced resource-governance network. On the applied side, the challenge is about identifying the appropriate definitions of the network levels, as well as nodes and ties between them, which is particularly difficult for multiple combined case studies. While the provided list of examples (see tables 1 & 2) supports the identification of relevant network levels, as well as nodes and ties between them, the selection process still largely depends on the case context and focus of analysis. Depending on the analysis's focus, it is also possible to exclude certain network levels from the analysis. For example, suppose the focus is only on how actor collaboration produces specific governance outcomes based on joint action situations regardless of available resources. In such a case, interdependencies within the resource system could be excluded from the analysis. It is, however, important that researchers document why which elements are included or excluded from the analysis. Such documentation supports research transparency and helps to find a balance between case sensitivity and comparability that contributes to the development of the resource governance approach and helps to avoid panacea traps.

Finally, given the complexity of SESs and the diversity of governance problems, hardly any single concept or framework will be able to resolve all governance problems of SES governance (Bousquet et al., 2015; Schlüter et al., 2019). Rather, solving governance problems should draw from different concepts and frameworks combining different knowledge sets. With the resource-governance network, I want to enable the exchange of information and research results between frameworks and concepts analyzing SESs by providing a common language that makes relevant system dependencies explicit and helps grasp SES governance issues more holistically. A common language that builds up on long-standing theoretical frameworks, such as the SES framework, supports the transfer and communication of qualitative and quantitative research findings. Additionally, clear language enables the thoroughly consideration of ways to operationalize SES governance problems, with the particulars depending on the research focus.

Conclusion

To sum up, this thesis shows the potential of highly detailed network conceptualizations of SESs but also the limitation of such detailed conceptualizations, as they sometimes demonstrate a level of detail that is not practical in daily management decisions [Paper 2]. However, such complex networks are not always needed to identify collaboration patterns. Paper 1 shows, for example, how an actor network without any additional ecosystem information can be used to identify differences in interaction patterns within and across governance sectors. In addition, the results show how important it is to include empirical data on governance outcomes when analyzing the link between network patterns and governance efficiency of SESs, as interpretations are often not straightforward, as the results of Paper 4 on social-ecological fit revealed. Further, Papers 2 - 4 demonstrate the power of comparative study settings to reveal trends across cases and generally increase the power of network analyzes of SESs. Finally. The experiences made working on the PhD Papers resulted in the here proposed resource-governance network approach, which helps to improve the conceptualization of relevant characteristics of SES governance.

The findings and conclusions presented in this thesis are subject to certain limitations. First, even though Papers 2 - 4 are based on up to ten combined case study areas, the number and size of the cases included are limited. The small number and size of the cases limit the possibilities of statistical analysis. Nevertheless, even with this limited number and size of the cases, it is possible to use qualitative (e.g., qualitative comparative analysis (QCA)) and/or quantitative (e.g., social network analysis (SNA)) methods for analyzing the results. Furthermore, experiences made based on the small number and size of the cases can help increase the number and size of cases for future research projects. For example, the qualitative meta-regression analysis from Paper 2 could be used as a starting point to further developpe the comparative analysis of network analytic approaches. Single elements of the qualitative meta-regression analysis, such as heterogeneity of case area structure or network characteristics, such as the number of closed network motifs of social-ecological fit, can be used to identify necessary and sufficient conditions for beneficial governance outcomes using QCA. By doing so, not only the comparative analysis of networks of SESs could be improved, but also a new application field for QCA studies could be developed (Mello, 2020).

The second practical limitation is the case selection, which is restricted to water bodies and associated ecosystems located in Switzerland. This is particularly relevant with regard to RQ1, as the identified social and ecological units might not be transferable to any other issue of SES governance. However, while the focus is on water bodies and associated ecosystems, the governance issues can likely be transferred to other types of ecosystems facing issues coordinating social, ecological, and economic needs. While the governance issues, such as the overexploitation of resources, are likely to be similar also in other world regions, the institutional structure of Switzerland is rather unique. Therefore, responsibilities and power are likely to be distributed differently among the relevant actors in other regions of the world. While this might impact the ego-networks of specific actors, the overall network structure and present governance issues are likely to remain similar as the underlying issue of efficient allocation and distribution of scarce resources remains similar also in other world regions.

Third, all papers presented in the thesis strongly build on the literature on natural resource governance [Paper 1], collaborative governance [Paper 2], polycentric sustainability governance [Paper 3 & 4], and more generally on the SES framework, and network conceptualization of SESs, such as the SEN concept. Other frameworks, concepts, or methods could also be used to analyze the governance of SESs. QCA could, for example, be used to compare the ten cases of wetland governance in Switzerland. The benefit of QCA is to be able to identify specific network characteristics (e.g., bonding vs. bridging ties) or factors shaping the networker structures that influence governance outcomes across multiple cases of SES governance (Mello, 2020; Ragin, 2014). The integration of additional contextual factors would also benefit RQ2, where the number of contextual factors is still limited. Furthermore, many results build on the assumption that actor interaction, such as collaboration, is beneficial and that social and ecological units of analysis should be aligned. Results of Papers 2 & 4 show, however, that the link between collaboration or social-ecological fit and governance outcomes is more complex. The four papers' focus on concepts and theories related SES governance shows a lack of diversification in the underlying theoretical assumptions of this PhD, especially as some of the theoretical assumptions (e.g., the positive impact of social-ecological fit on governance outcomes) still remain uncertain [see results Paper 4]. To strengthen the theoretical foundation of future research, additional data is needed to better specify the conditions under which actor interactions and social-ecological fit are beneficial for the governance of SESs.

Future research should build on and test the newly proposed resource-governance network concept to validate it based on additional case studies in different settings. Among other things, the resource-governance network could help analyze network structures' impact on governance outcomes in a more standardized way, making results related to RQ3 more accessible. However, it is important to mention that in the case of the resource-governance network, some network-based methodological limitations pertain as well, such as the difficulty of capturing process-related variables based on nodes and ties. Nevertheless, it would be interesting to investigate to what degree the proposed conceptualization of nodes and ties of the resource-governance network applies to different case settings. While the network conceptualization is assumed to hold for cases other than wetland governance, this assumption needs to be further tested with cases that differ from these cases of wetlands governance, for example, using other cases primarily defined by resource extraction, such as mining. Additionally, it would also be interesting to see if the resource-governance network concept improves the comparability of research results across case studies. In a first step, comparability could focus on network data gathered in a coordinated approach. However, it could later be extended to combine multiple separate papers analyzing SES governance using resource-governance networks in a meta-study. Finally, it would also be interesting to see whether the language used for the resource-governance network concept supports the communication of research findings to different kinds of actors within and outside academia.

Communication of the research findings to different types of actors working in the governance of SESs could contribute to increasing the impact of the research findings on practice. One recommendation for SES governance is to increase the alignment of actor interactions with ecological and environmental system structures. Aligning actor interactions with ecological and environmental structures requires interactions across governance sectors and institutional borders, such as district borders that often cut across ecosystems, such as the catchment areas of rivers and lakes. The responses from actors active in the Engadin [Paper 1] or wetland governance [Papers 2 - 4] show that even though actors generally want to be integrated into governance decisions, they tend to struggle to account for complex interdependencies, and often focus on limited but apparent interdependencies. However, these apparent social-ecological interdependencies are not always the most important ones for deciding on governance strategies and interaction partners. Therefore active support of actors to identify relevant interdependencies and to act on them is important for increasing the alignment for the governance of SESs (see PlaNet for an example of how to support actors in identifying collaboration partners). When supporting actors to identify interaction partners, it is important to be aware that a small group of experts (often cantonal agencies) are highly interesting interaction partners for many others. Those central actors often feel overexploited by others, so they should only be contacted when other actors cannot provide similar services to distribute the load of SES governance to a diverse set of actors.

More generally, accounting for ecological and environmental system structures helps efficiently distribute the limited resources for SES governance, particularly for nature protection projects. Furthermore, limited resources for nature protection also require allocation, distribution, and prioritization among different revitalization projects. Allocation and distribution of scarce resources for the governance of SESs are important for achieving the goals formulated in the new Swiss water protection act. In the same vein, prioritization is essential, as the number of Swiss wetlands in poor conditions – targeted by the water protection act – is too large to simultaneously install projects in all wetlands needing revitalization measures. Rather revitalization projects should focus on areas where the potential for improvements is particularly high. While the FOEN (Federal Office for the Environment) has already started evaluating wetlands areas on their potential for revitalization measures, they struggle to have up-to-date information that accounts for the areas' social, ecological, and economic potentials for improvements. The newly proposed resource-governance network here can help to holistically analyze and evaluate wetlands, and to identify hot spots favorable for future revitalization projects that also support adaptation to climate change.

Given the increasing speed in the development of climate change (Pörtner et al., 2022) and its impact on water bodies in Switzerland (more extended dry periods or more intense rain events (Volken, 2012; Weber, 2016)) paired with increased social and economic pressures, there is a high need for “good” governance solutions for SESs. The results of the papers included in this thesis on the governance of SESs paired with novel conceptualizations of SESs using networks such as the resource-governance network can support such a development. Still, it is essential to acknowledge that conceptualizing SESs as networks remains a “messy” task. This messiness often makes it challenging to have clear findings when analyzing single-case studies and particularly also when analyzing multi-case studies. Network concepts with network topology accounting for different archetypes for relevant nodes and ties, such as the resource-governance network, can help to manage such messines. The resource-governance network concept also helps as a theoretical lens to analyze and compare the governance of multiple SESs in parallels, strengthening the validity of network-based research in collaborative governance, environmental governance, or integrated resource management.

Cross-sectoral information and actors' contact networks in natural resource governance in the Swiss alps

Abstract

Governance of natural resources is challenging due to cross-sectoral dependencies across related sectors such as, e.g., water, agriculture, and energy. Actors involved in natural resource governance create network contacts with each other, in order to deal with specific governance issues. An important resource for actors is information, and actors act according to the amount of information they have about other related sectors. In this article, we study how the information actors possess about different sectors is related to their contact network across sectors. We empirically study a case of water management in the Swiss mountain valley of Engadin. We use descriptive and inferential network analysis to show that actors with more information about other sectors establish more contacts in general, as well as with actors from those other sectors. We conclude that successful natural resource governance hinges upon the information that actors have about other sectors related to their sector.

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Introduction

The governance of natural resources requires the integration of different actors with different sets of interests and information (Carpenter et al., 2006; McGee & Jones, 2019). Furthermore, actors involved in the governance of a natural resource often represent different but interlinked sectors (McGinnis & Ostrom, 2014; Ostrom, 2009). A sector consists of a distinct group of activities related to a given resource, such as, for example, agriculture, tourism, or energy. Activities in one sector can influence other sectors, and, more generally, the governance of the natural resource in question. Integrating actors representing different sectors and possessing different sets of information about interrelated sectors thus allows for a coordination of sector specific activities and demands, and, consequently, for achieving integrated and sustainable resource governance (Bodin, 2017; Edelenbos & van Meerkerk, 2015; Folke et al., 2007).

Integrated and sustainable governance of natural resources and the role of different interrelated sectors therein has been discussed across different bodies of literature. For example, in the social-ecological system (SES) framework, sectors are conceptualized as interdependent units in the governance system linked to the natural resource system (McGinnis & Ostrom, 2014; Ostrom, 2009). The governance of these sectors is influenced by the actors active in those sectors and the availability of resources. One crucial resource of actors that enables them to deal with interrelated sectors is information about these other interrelated sectors. Also, the literature on integrative environmental governance or environmental policy integration (Jordan & Lenschow, 2010; Runhaar et al., 2014; Visseren-Hamakers, 2015) has dealt with the integration of different policy sectors relevant to environmental issues, focusing on inconsistencies among sectoral policies, administrative reorganization, organizational challenges, policy outputs or outcomes, and implementation and monitoring (Persson et al., 2018; Tosun & Lang, 2017). However, there has been little focus on a broad set of actors involved in governance processes, their (informational) resource,s and their contact networks (for exceptions, see Baulenas et al. (2021); Metz et al. (2020); Wagner et al. (2021)).

The network perspective emphasizes the integration of different actors in a natural resource governance system, including the integration of actors across different sectors, through networks of contacts among those actors. Establishing and sustaining network contacts is generally costly and challenging to actors. Creating contacts across different sectors might even be more challenging. Differing sectoral logics related to different types of internal organization, different roles, as well as different values and interests can complicate interactions across sectors (Brion et al., 2012; Crona & Parker, 2012; Vangen et al., 2015). For example, while the fluctuations in the flow of rivers due to hydropeaking from hydropower plants are harmful to the local biodiversity that requires natural river dynamics, it is an important element of an efficient operation of hydropower plants. Before being able to establish cross-sectoral network contacts, actors might even face difficulties in recognizing cross-sectoral dependencies that would require cross-sectoral coordination (Bergsten et al., 2019; Edge & Eyles, 2014; Ingold & Fischer, 2014). Thus, a crucial resource for actors to create network contacts across sectors is information (Fischer et al., 2017; Hess & Ostrom, 2007; Peters, 2015) – more specifically, information about other, interrelated sectors. In this article, we explore *how actors' information about other sectors relates to their network contacts within and across sectors in natural resource governance.*

To answer this question, we focus on a case of water governance as an example of natural resource governance in a context of high autonomy of local political organizations. Our study site, the Engadin, is located in an exceptionally dry valley in the Swiss Alps with an urgent need to use the resource water efficiently. During the dry summer months the lack of water can only be compensated by water stored as snow and ice during the winter months, making up 50

% to 80 % of the annual water runoffs. However, the amount of water stored in this way during the winter months continuously decreases. To nevertheless maintain existing economic activities (e.g., energy production, agriculture, or drinking water supply) and sustain the unique alpine biodiversity in the Engadin, changes in water governance are needed (Lanz, 2016). Second, in cases of high autonomy of local actors such as municipalities or associations in Switzerland (e.g., Keuffer and Horber-Papazian (2020)), a focus on the networks among those organizations is especially relevant. We analyze the contact network of actors relying on descriptive network analysis as well as Exponential Random Graph Models (ERGMs). Data stem from a survey among all relevant actors in the case study area. Based on this data, we show that actors with higher levels of cross-sectoral information have more network contacts. Contact is therefore defined as some form of communication between actors to share information relevant to water management. While we can show that actors with higher levels of cross-sectoral information have more contact ties, the ERGMs do not allow us to make any statement on the directionality of the causal effects between the level of cross-sectoral information and the probability of contact ties.

With this study, we make several contributions to the literature. First, while it has been long suggested that cross-sectoral dependencies and related coordination among actors are important for understanding holistic and integrated natural resource governance, assessing how actors' contact networks contribute to dealing with these challenges is a much more recent endeavor (Bodin et al., 2019; Bodin & Tengö, 2012; Van Bommel et al., 2009; Vos et al., 2018). We thus contribute to the literatures on (cross-sectoral) natural resource governance, the governance of social-ecological systems (McGinnis & Ostrom, 2014), and environmental policy integration (Jordan & Lenschow, 2010; Runhaar et al., 2014) with an explicit focus on actors and their (cross-sectoral) network contacts. Second, by assessing the importance of actors' information about other sectors alongside other, traditional factors relevant for explaining networks contacts, we add to the literature on governance and policy networks that has aimed at identifying the factors that foster or hinder actors' network contacts (Fischer et al., 2016; Henry & Dietz, 2011; Leifeld & Schneider, 2012). More specifically, we identify cross-sectoral information as an important resource (Brenton et al., 2022; Fischer et al., 2017; Hess & Ostrom, 2007; Peters, 2015) that allows actors to create specific ties in their contact networks. Third, directly related to our study area, a lack of contact among local actors in water governance was recognized (Ferrand et al., 2018) despite strong competencies at the local level due to Swiss federalism. Our study suggests that increasing actors' access to cross-sectoral information is important for natural resource governance.

Theory

Natural resource governance and cross-sectoral networks

Responsibilities for different aspects related to the governance of a natural resource are usually organized within pre-defined geographical units and (resource) sectors. In fact, the challenges of natural resource governance most often transcend geographical, administrative, and sectoral boundaries that structure the governance system (Edelenbos & van Meerkerk, 2015; Folke et al., 2007). For example, rivers flow from one geographical territory to another, and their successful governance requires coordination between sectors of energy production, infrastructure, agriculture, nature conservation, and others. However, dealing separately with different elements of natural resource governance without considering systemic boundary-spanning characteristics can be detrimental to the successful governance of a given resource and, more generally, to natural resource governance (Bodin, 2017; McGee & Jones, 2019). By contrast, taking into account cross-sectoral dependencies is crucial for achieving integrated and sustainable resource governance (Bodin, 2017; Edelenbos & van Meerkerk, 2015; Folke et al., 2007). The SES framework emphasizes the different interdependent units of a natural resource system and the challenges of a fragmented governance system to successfully manage such natural resource systems (McGinnis & Ostrom, 2014; Ostrom, 2009). The specific challenge of governance across different sectors has also been addressed by the literature on environmental policy integration, suggesting the importance of re-organizing governance organizations and policies in order to take cross-sectoral dynamics into account (Jordan & Lenschow, 2010; Runhaar et al., 2014; Visseren-Hamakers, 2015).

In order to address the potential misfit between a natural resource system and a governance system and to account for cross-sectoral challenges, collaborative and network-based approaches have been suggested as more effective than hierarchical approaches, given their flexibility (Bressers et al., 1994; Carpenter et al., 2006; McGee & Jones, 2019). However, the networks among actors implied by collaborative and network-based approaches are shaped by different factors that are often not explicitly related to the cross-sectoral challenge at hand. Homophily, for example, describes the mechanisms that similar actors tend to have more network ties than dissimilar actors (Di Gregorio, 2012; Henry & Dietz, 2011; Scott & Ulibarri, 2019). Furthermore, understanding other factors such as decision-making power (Ingold & Fischer, 2014) and institutional venue participation are essential to understanding how networks among actors form (Fischer et al., 2016; Leifeld & Schneider, 2012).

Information as a resource for actors' cross-sectoral contacts

Creating cross-sectoral ties is likely more challenging to actors in comparison to establishing contact ties within a given sector. Differing sectoral logics can, for example, lead to higher levels of conflict or power imbalances across sectors, complicating the establishment and maintenance of cross-sectoral contact ties (Ansell & Gash, 2008; Crona & Parker, 2012; Emerson et al., 2012; Vangen et al., 2015). Still, some actors, depending on their personal attributes, knowledge, skills, and roles, are able to deal with this challenge better than others. Actors with skills that enable them to build support and understanding, as well as actors in roles where they can be autonomous but also inclusive of others from different sectors, are more likely to manage higher levels of conflict and to establish contact ties across sectors (Herzog, 2018; van Meerkerk & Edelenbos, 2018; Williams, 2013). While creating cross-sectoral network contacts is a challenge, it might also be beneficial to actors. For example, actors who manage to establish cross-sectoral ties and thus (partly) to address cross-sectoral dependencies can benefit from contributing to integrated and sustainable outcomes. Alternately, establishing cross-sectoral ties can help overcome structural holes and increase the connectivity between otherwise disconnected network clusters, potentially opening up venues for new and innovative ideas (Berardo & Scholz, 2010; Edge & Eyles, 2014; Granovetter, 1973). Occupying brokerage positions across different sectors can thus help actors strengthen their position in their sectoral network clusters (Bergsten et al., 2019; Burt, 2000).

Besides these roles and skills, information is a key resource to governance systems and actors therein (Hess & Ostrom, 2007; Peters, 2015). Literature has shown that actors in governance systems strive to gain and exchange information to increase their influence (Carpenter et al., 2004; Leifeld & Schneider, 2012). Information can be technical, about a policy issue or a resource system, or political, about potential policy instruments and preferences of other actors (Fischer et al., 2017). Peters (2015) emphasizes situational knowledge of agencies about the conditions of a specific policy domain. The famous principal-agent dilemma emphasizes information asymmetry between actors as a source for influence and power (Wood & Waterman, 1991). More specifically related to cross-sectoral natural resource governance challenges, actors can benefit from different amounts and qualities of information with respect to a specific natural resource governance system, the relevant issues therein, and other actors present in that system (Gray et al., 2013; Moon et al., 2019; Peters, 2015). literature on social-ecological networks (Bodin, 2017; Guerrero et al., 2015; Sayles & Baggio, 2017b) claims that limited information about the dependencies of ecological units in natural resource governance hinders collaboration among actors involved in the joint management of interdependent units (Hedlund et al., 2020). Furthermore, it has been shown that actors provided with information about dependencies in natural resources governance are often more willing to establish contact with others across sectors (Van Bommel et al., 2009; Vos et al., 2018).

Based on these arguments, we claim that actors that have more information about other sectors also have more contacts with other actors from this other sector than actors with less cross-sectoral information. An example of the impact of information about other sectors is the following: If the operator of a hydropower plant active in the sector of energy production is informed about other sectors (e.g., nature protection or tourism), this actor is likely to have more contact ties across sectors. In contrast, an actor with less information about other sectors is expected to have fewer network contacts with other sectors. We thus expect to see that actors well informed about other sectors are likely to have contact ties with other actors, and especially with other actors active in other sectors.

Case, data, and methods

Case description

We study the case of the Engadin located in a valley in the Alps in the southeast corner of Switzerland. Alpine regions are very sensitive ecosystems, which are regenerating only very slowly after natural disasters (Lanz, 2016). The Engadin is located in the upper catchment area of the river Inn[1]. The water from the river is an important resource in the sparse mountain valley. However, due to limited precipitation, the availability of water is also limited, posing a high pressure on the water coming from the Inn. The Inn is used for energy production, agriculture, tourism, and other activities, but can also produce dangerous flooding. Due to the multiplicity of uses, high problem pressure, and a lack of exchange across sectors, the case study of the Engadin allows us to analyze factors shaping cross-sectoral coordination in water governance. The lack of exchange across sectors in the Engadin was also a source of motivation for the Engadin to participate in a project[2] with the aim to increase collaboration within and across sectors. Since data gathering for this study was conducted the same year as the project was initiated (Ferrand et al., 2018), the project might have influenced the available information actors have on other sectors, but is unlikely to have yet affected the contact ties among the local actors. In the federalist Swiss system, many competencies related to the governance of water are located at lower (municipal or cantonal) levels. The implementation of federal law is often delegated to lower governance levels. Municipalities in collaboration with cantons (the constituent states of Switzerland) and private actors carry out concrete projects, benefitting from comparatively high local autonomy (e.g., Keuffer and Horber-Papazian (2020)). For long-lasting activities, municipalities and cantons jointly set up specialized institutions (e.g., management bodies of protected areas). Thus, water governance involves actors like

[1] While the biggest part of the Engadin is located within the catchment area of the Inn, some municipalities are located outside the catchment area. Those municipalities are excluded for this analysis even if they filled in the survey.

[2] The strategic Planning for Alpine River Ecosystems (SPARE) project aims to contribute to a harmonization of protection needs and human use requirements (Ferrand et al., 2018).

municipalities, cantonal and state agencies, as well as a diverse set of private actors such as associations or private companies.

Data gathering

Actor identification and survey

We identified relevant actors active in water governance in the Engadin using a combination of decisional, positional, and reputational approaches (Knoke, 1993). First, we identified actors with decisional power, that is, actors that participate in events relevant to water governance in the Engadin. The identification of these actors was based on web-based document analysis combined with lists of participants from public events on water governance in the Engadin. In line with the positional approach, we identified actors in formal decision-making positions where they make decisions pertaining to processes relevant to the governance of water in the Engadin. Those actors do not need to be present at events, but have the potential power to influence the decision-making process as a part of the government or parliament, for example. Finally, in line with the reputational approach, we validated the actors identified with local experts in the area. In addition, the participants of the survey had the chance to add additional actors to the actor list. Those actors were then also contacted and included in the analysis. The only difference is that they did not have any one-directional ties, but all their ties were assumed to be bi-directional since the other actors had no chance to specify whether they had a contact tie in the survey.

The survey was sent out to all 91 actors identified to be relevant to the water governance in the Engadin. The survey documents also included an accompanying letter specifying the focus of the survey on water management in the Engadin and explaining the importance of including various actors from different sectors. 55 actors answered the questionnaire, resulting in a response rate of 60.4 %. To reach such a response rate, actors who did not respond to the survey were reminded three times, and finally also contacted by telephone. While the overall response rate is satisfying, there exist some differences among actor groups[3]. The largest actor group of survey participants are municipal actors, for two reasons. First, the case study area is split up into many small administrative units, i.e., municipalities, so municipalities make up a large group of actors, to begin with. Second, the response rate among municipalities is also higher than for other actor groups. By contrast, cantonal authorities and private companies have a low response rate. Cantonal authorities mentioned that they were unwilling to participate in the survey because they did not want to threaten their neutral position as public actors. Tourism operators did often not participate in the survey, as they did not perceive themselves as relevant to water governance in the Engadin. Although we received sufficient responses from each actor group to be reasonably confident in our overall inferences, we have included an actor type variable in our model to account for differences in actor behavior varying with actor type.

Methods

We use Exponential Random Graph Models (ERGMs) to model how ties in general and cross-sector ties in particular depend on the actors' information about other sectors. ERGMs build on the idea of analyzing larger networks by studying smaller configurations that function as building blocks (Cranmer et al., 2017). The benefit of ERGMs is their support of statistical inference on processes influencing the tie formation process in networks and thus provide additional insights on how network patterns form. At the tie-level, the interpretation of estimated ERGM coefficients is similar to logistic regression models, indicating the ceteris

[3] The response rate is correlated with the actor type (Pearson-r = -0.32, $p < 0.00$).

paribus change in the likelihood of a tie given a change in a network-endogenous or exogenous node or dyad-level variable. Node-level variables in our case refer to variables measuring the attributes of actors. Dyad-level variables measure characteristics of actor pairs, for example, their similarity in an attribute or their geographic distance. We used the ERGM package (Handcock et al., 2019) in R (R Core Team, 2021) for the estimation of the models via Markov Chain Monte Carlo maximum likelihood estimation (MCMC MLE). Using the ERGM package, we model how the occurrence of ties in the contact network is associated with our independent variable (actors' information about other sectors), adjusting for several network-endogenous and -exogenous node-level, as well as dyad-level covariates. In an additional step, we then analyze how the impact of cross-sectoral information differs between contact ties among actors within the same sectors and across different sectors (our dependent variable).

Operationalization of the dependent variable (cross-sector ties)

In the survey[4], actors were presented with a list of all other actors active in water governance in the case study area. Using this list, the actors could specify with whom they had contact[5] while working on water-related topics. Data from this survey item draws up a directed contact network among actors active in water governance in the Engadin. "Being in contact" however, is a reciprocal activity involving two actors, and is thus best captured in an undirected network. We chose to symmetrize the directed contact network using a weak criterion; that is, we kept all ties that were mentioned by at least one of the actors. The use of a weak criterion is justified by our fundamental research interest in contact networks in this analysis, leading us to prioritize capturing a network as complete as possible, including weaker forms of interaction not necessarily remembered or judged as contact by both actors.

To measure the cross-sector nature of contact network ties, we used self-reported sector involvement by actors. Actors could specify in the survey which of five sectors they were involved in: politics/governance, tourism, ecology, energy, and agriculture. Each actor can be active in one or multiple sectors. Actors in the sector of politics/governance are mostly political parties and administrative organizations on different administrative levels (e.g., municipal, cantonal). Instead of considering the very general category of politics/governance as a sector, we attribute the respective actors to a more specific sector (e.g., the office for agriculture and geoinformation to the sector of agriculture), or if not possible, we assume that they are active in all the other sectors (e.g., the municipality of Scuol is assumed to be active in all sectors). If two contact partners are active in different sectors their contact tie is "cross-sectoral" or if the two contact partners are active in the same sector, they have a contact tie "within sectors".

Operationalization of the independent variable (cross-sectoral information)

The main independent variable is a node-level covariate. For each actor (representing a node in the contact network), we assess its overall level of cross-sectoral information (see Figure 6). We expect a higher level of cross-sectoral information to be associated with an increase in ties in general and cross-sector ties in particular. We use a two-step approach to operationalize the independent variable of cross-sectoral information. In the first step of the operationalization, we establish in which sectors each actor is active, and in which ones not (see above). In the second step, we use a survey item measuring actors' information on each sector. Survey participants were asked to indicate how informed they are about the different sectors (tourism, ecology, energy, and agriculture) on a four-point scale ranging from "very well informed" to

4 Exact survey questions appear in the Appendix A: Survey questions.

5 To elicit contact ties between actors we asked: Please mark all the actors with whom you had contact based on your activities in the Engadin regarding the management of water.

“very poorly informed”. We then create a variable that expresses the average level of cross-sectoral information for each individual actor. A value of 1 indicates that this actor is very well informed about other sectors, while a value of 0 indicates that this actor is very uninformed. This variable is then included in the model as the main effect measuring the association of actors’ information on contact ties.

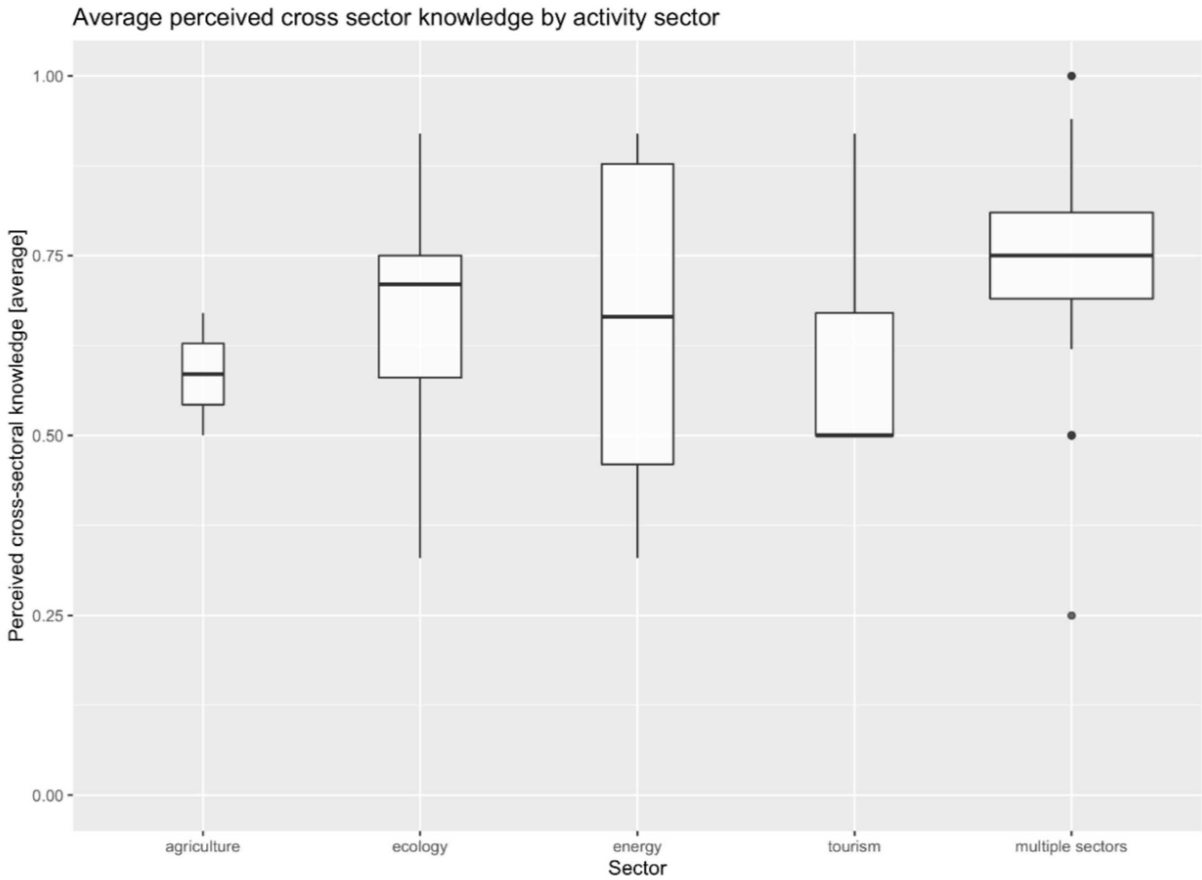

Figure 6: Actors’ level of cross-sectoral information by sectors. Next to the different sectors, an additional category exists for active actors in multiple sectors. Actors that are active in multiple sectors are, on average, more informed than actors active in one specific sector only. Further, all actors, regardless of which sector their active in, have at least some level of information about other sectors.

To assess the association of cross-sectoral information with the probability of cross-sectoral ties, we include a term specifying the interaction of the variable of cross-sectoral information with cross-sectoral ties. Based on this term, we can estimate separate slopes for the effect of cross-sectoral information on contact ties within and across sectors[6]. Further, we also include a dyad-level, binary variable measuring the main effect of a pair of actors active in the same sectors. Therefore, the interaction term of cross-sectoral information and cross-sectoral ties is

[6] Note that the information of what sectors actors are involved in (and, conversely, not involved in) is used to specify the main independent variable and is also underlying the interaction term. Related to the variable of the level of cross-sectoral information, knowing what sectors actors are involved in necessary for constructing a meaningful variable that expresses cross-sectoral information without taking into account information about the actor’s own sector. Related to the interaction term, knowing what sectors actors are involved in allows specifying the relevant contacts in the contact network that represent cross-sectoral contacts. Relying on the same information for both variables however does not bias our results, given that the level of information is theoretically independent of cross-sectoral contacts, i.e., the level of cross-sectoral information can theoretically range from 0 to 1 independently of whether an actor has many or few cross-sectoral ties.

not influenced by the increased probability for actors to share a contact tie with other actors from the same sector.

Control variables

We include several established explanatory factors for actors' network contacts as control variables (see, e.g., Berardo and Scholz (2010); Klijn et al. (2010); Prell et al. (2009)). The control variables are organized into five groups[7]: 1) variables directly related to the operationalization of the independent variable, 2) variables related to actors' perceptions of governance problems, 3) variables related to the geographical regions where the actors are active, 4) variables related to the type of actors, and 5) variables related to endogenous network-related factors.

First, we control for homophily effects for actors' level of cross-sectoral information used to operationalize the node-level covariate for the independent variable of cross-sectoral information. For the homophily of actors' cross-sectoral information, we use the Euclidean distance[8]. Controlling for homophily in actors' cross-sectoral information is necessary because we expect actors with similar features to cluster together, regardless of whether actors are more or less informed on other sectors.

Second, we control for homophily based on actors' general beliefs regarding different aspects of water governance in the Engadin. Clustering of actors along the lines of similar policy beliefs is an oft- observed phenomenon in networks (Henry et al., 2011; Zafonte & Sabatier, 1998). A survey question asked actors to indicate agreement or disagreement with a set of statements on four-point and, for some questions, three-point Likert scales[9]. We group the relevant questions into three categories: 1) Integrated governance (8 questions), 2) long-term orientation of governance (5 questions), and 3) multi-level governance (3 questions). First, the belief category integrated governance deals with actors' beliefs regarding the integration of different sectors (e.g., water or energy) relevant to water governance in the Engadin. The second category of the belief questions is about the long-term orientation of governance. The third category, multi-level governance, is about the distribution of responsibilities across several institutional levels (e.g., municipal or cantonal level). The separation of responsibilities across several institutional levels mostly concerns public actors but is also affecting any other actors. We construct an aggregated variable based on the mean tendency in each of the three categories per actor, ranging from 0 – 1, with higher values indicating that the actors are in favor of integrated governance processes, long-term oriented governance processes, and governance processes involving multiple levels. For each of the three belief categories, we include a dyad-level and a node-level control variable. The dyad-level level variable controls for similarity in beliefs between pairs of actors based on the Euclidean distance[10]. The node-level variable controls for the impact of differing levels of agreement of an actor in the respective belief category on the contact network.

Third, it is likely that actors that work within the same geographic spaces or administrative-political units are more likely to develop contact network ties. In the survey, actors were asked to indicate geographical areas in the Engadin where they were active in. We calculate the Cosine similarity distance (Nguyen & Bai, 2011)[11] to attribute a similarity coefficient to each

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[7] All control variables are listed in the Appendix A: Additional tables (Table A12).
[8] See Appendix A: Calculations of similarity matrices.
[9] Survey questions in the group "6. Belief questions" a) and c) are on a four-point Likert scale; the questions from the group b) are on a three-point Likert scale.
[10] See Appendix A: Calculations of similarity matrices.
[11] See Appendix A: Calculations of similarity matrices.

pair of actors based on matches in the resulting binary vectors of area choice. Cosine similarity is used here as many actors are active only in a few areas but inactive in many areas. However, such inactivity in the same areas does not make actors similar. Instead, we want to capture similarity in activity areas and therefore use the cosine similarity distance.

Fourth, the formation of contact ties is likely to follow different patterns for actors of the same organizational type and between actors of different organizational types. For example, actors of the same organizational type are likely to share more contact ties due to shared organizational logics (Ingold, 2011). Actors were asked in the survey to self-attribute an organizational type, namely, cantonal actor, municipal actor, political party, private actor, or NGO/association. We adjust for homophily in actor type by creating a dyad-level variable indicating a match or mismatch in type and a node-level variable to adjust for differences in contact network activity among type categories.

Fifth, we adjust for endogenous network processes as network data is interdependent and follows certain patterns (Handcock et al., 2019). Therefore, we include an edges term in our model, which is conceptually similar to an intercept in conventional regression models, establishing a baseline probability for a tie to occur in the network. Further, we control for triadic closure (the tendency of an actor pair with a common tie also to have a common partner in the network) by including a term accounting for edgewise shared partners (esp) (Hunter, 2007).

Results

Figure 7 illustrates the contact network under study. The size of the nodes illustrates the level of cross-sectoral information of actors. While only a few actors perceive to be very poorly informed on other sectors most actors are well informed on other sectors. This indicates that on average a certain level of information on other sectors is available still there is room for improvement as most actors did not indicate to be very well informed on other sectors. At the same time, actors that are very well informed show the highest average degree centralities (average out-degree = 21.1) compared to other actors that indicate to be less informed on other sectors. Therefore, actors that are over-proportionally informed play an important role in communication across otherwise disconnected network clusters and different sectors. Among the actors with high degree centralities, actors that are active in multiple sectors are overrepresented such as public actors. This is in line with previous research that has shown that public actors such as cantonal actors typically have high degree centralities in actor networks due to their formal roles and reputation (Angst et al., 2018).

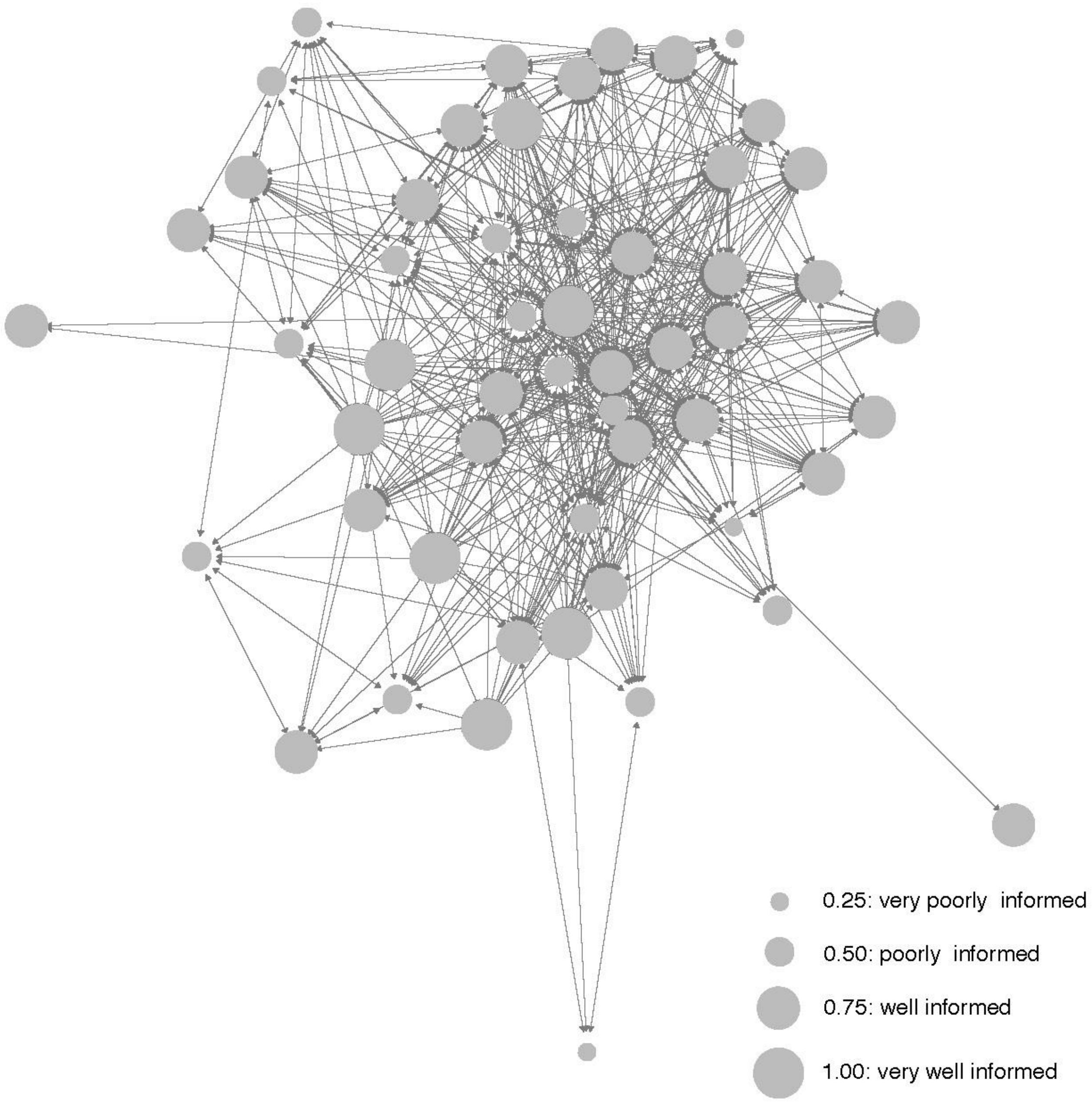

Figure 7: Illustration of the water governance contact network between actors in the Engadin.

Table 3: Results for the ERGM. The main variable related to actors' cross-sectoral information is highlighted in bold.

	Estimate (logged odds)	**Std. Error**	**P-Value**
edges	-2.92	1.45	0.04
esp (1)	-0.23	0.43	0.58
H: Cross-sectoral information (nodecov)	1.1	0.31	0
CV: Cross-sectoral information (edgecov)	0.67	1.63	0.68
CV: Interaction of cross-sectoral information x sector homophily (edgecov)	0.85	1.67	0.61
CV: Sector homophily (edgecov)	0.2	0.56	0.73
CV: Beliefs – Integrated gov. (nodecov)	-2.36	0.42	0
CV: Beliefs – Integrated gov. (edgecov)	-0.63	0.48	0.2
CV: Beliefs – Long-term orientation of gov. (nodecov)	0.98	0.47	0.04
CV: Beliefs – Long-term orientation of gov. (edgecov)	0.45	0.43	0.29
CV: Beliefs – Multi-level gov. (nodecov)	-0.58	0.3	0.06
CV: Beliefs – Multi-level gov. (edgecov)	0.11	0.4	0.78
CV: Location homophily (edgecov)	0.76	0.26	0
CV: Type homophily (nodematch)	0	0.18	0.98
CV: Municipal actor (nodefactor)	1.32	0.61	0.03
CV: Cantonal actor (nodefactor)	2.52	0.6	0
CV: Political party (nodefactor)	0.36	0.65	0.58
CV: Private company (nodefactor)	0.89	0.6	0.14
CV: Association/NGO (nodefactor)	1.77	0.6	0

Table 3 presents the results for the ERGM. Based on the analysis of the goodness of fit (GOF) statistics[12], the model provides a good fit to the data. The results for the independent variable[13] on actors' cross-sectoral information indicate that we can – with relative confidence – reject the null hypothesis of no effect of actors' level of information. The coefficient estimate shows a positive impact of actors' cross-sectoral information on the probability of actors having a higher number of contact ties. The same model run on a directed contact network yields the same results (see Appendix A, Robustness test for operationalization of the contact network), a model on an undirected network symmetrized with a strong criterion (a tie exists whenever both actors indicated contact) does not converge due to more isolates.

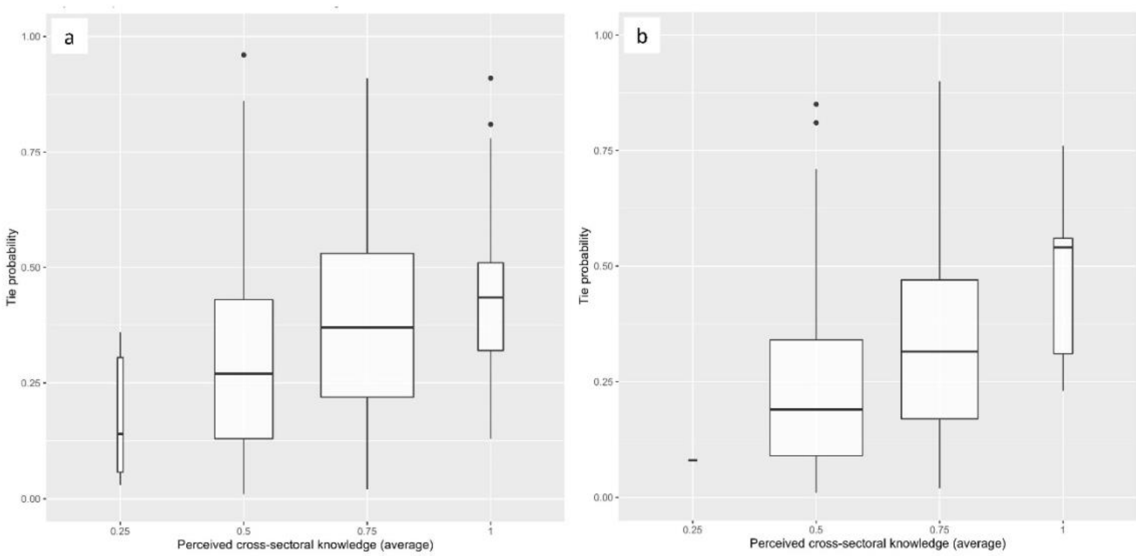

Figure 8: Illustration of the probability of contact ties dependent on the level of cross-sectoral information for actor pairs active in the same sector (a) and actor pairs active across different sectors (b). The level of cross-sectoral information is grouped into multiple categories of 0.2. A value of 1 stands for the highest possible level of cross-sectoral information of an actor pair.

While results from the ERGMs only indicate that actors' cross-sectoral information influences an actor's number of contact ties, Figure 8 illustrates how our independent variable is associated with the chance of within- and cross-sector contacts forming. The figure shows the predicted increase in the probability of an additional contact tie (vertical axis) given an increase in cross-sectoral information (horizontal axis). An increase from 0 to 1 in actors' cross-sectoral information increases the probability of a contact tie forming by 75 %. While the probabilities of ties always increase when actors have a higher level of cross-sectoral information, the increase is steeper for cross-sectoral ties. This finding further supports our expectation that actors with higher cross-sectoral information are more likely to establish contacts with actors active in other sectors.

Besides actors' information about other sectors, several control variables matter for understanding the observed contact network. For example, the presence of actors in the same regions seems to be an important factor explaining actors' decisions with whom to get in contact. However, other variables, such as the similarity in sectoral information, are associated with a high level of uncertainty. This is important to note as, at the same time, a high level of cross-sectoral information has a strong positive impact on the probability of contact ties in the

[12] The GOF statistics for the ERGM can be found in the Appendix A: Additional figures (Figure A22).

[13] The coefficients of the ERGMs are the logged odds of a tie forming in the network. The logged odd can be used to calculate the probability of a tie forming (exp(logged odds)/(1 + exp(logged odds))) or to calculate the multiplicative effect on the odds of tie (exp(logged odds)).

network. Further, the differences in the impact of the three belief categories are interesting. While, for example, the support for long-term orientation of governance has a positive effect on actors' contact ties, the support for integrated governance has a negative effect on contact ties. This difference between the belief categories shows the importance of distinguishing between different categories of actors' beliefs.

Discussion and conclusions

Our results offer support for the expectation that actors with higher levels of cross-sectoral information have more network contacts. While actors with higher levels of cross-sectoral information have a higher probability of establishing contact ties to other actors (as shown in the ERGM results in Table 3), the relation of cross-sectoral information is even stronger with actors' contact ties across sectors (as shown in Figure 8). While such results are not overly surprising, it still adds valuable empirical insights into how actors' preferences and capacities for establishing contact ties relates to their level of cross-sectoral information. Together with other research dealing with the challenges related to cross-sectoral dependencies (Bodin et al., 2019; Bodin & Tengö, 2012; Van Bommel et al., 2009; Vos et al., 2018) we show one possible way to achieve a stronger integration of cross-sectoral dependencies in natural resource governance, focusing on actors' information. The study thereby adds evidence to an area of research where (quantitative) empirical studies are still rare (Bodin et al., 2019).

Disposing of information about other sectors allows actors to set appropriate system boundaries when managing a resource. On the one hand, information about other, related sectors helps actors to coordinate with those other sectors that are directly relevant to the resources sector in question. On the other hand, based on information about other sectors, actors can also avoid including irrelevant other resource sectors (Bodin, 2017). Higher levels of cross-sectoral information, therefore, have the potential to increase the efficiency of actors' networking and, relatedly, the success of governance arrangements. This is crucial, especially since the success of sustainable and integrated natural resource governance is claimed to be dependent on the capacity to integrate relevant resource sectors (Bodin, 2017; Edelenbos & van Meerkerk, 2015; Folke et al., 2007). Fostering collaboration across sectors is also a fundamental principle in several fields of governance research. One important aspect that is particularly emphasized in polycentric governance is that decisions are made in different decision-making centers (Ostrom, 2010). In the context of this paper, such centers of decision-making relate to different sectors relevant to water governance. Our results are thus highly relevant for the achievement of Integrated Water Resources Management goals and the respective literature (Edelenbos & Teisman, 2013; Hofmann et al., 2010), as well as the more general literature on integrative environmental governance (Bodin, 2017; Edelenbos & van Meerkerk, 2015; Folke et al., 2007; Visseren-Hamakers, 2015). The latter body of literature in particular is lacking a strong focus on actors beyond public administrations, and their network contacts as ways of linking interrelated resources sectors (for exceptions, see Baulenas et al. (2021); Metz et al. (2020); Wagner et al. (2021)).

Along with others, we conceive information as a resource that actors can draw on and that allow them to establish network contacts (Fischer et al., 2017; Hess & Ostrom, 2007; Peters, 2015). A relevant related question is then of course how actors can gain access to the resource of information, and more specifically of cross-sectoral information. Projects fostering collaboration across sectors, as the recently initiated project in the Engadin (Ferrand et al., 2018), might help actors to increase actors' cross-sectoral information. Specific activities such as, e.g., discussions in workshops or forums (Fischer & Leifeld, 2015; Lubell, 2004) could help actors to improve their information about complex cross-sectoral dependencies. Often, forums have a cross-sectoral character and are specifically designed to bring together actors from different sectors (Fischer & Maag, 2019). Further, a focus on information as a resource also draws attention to other types of actor resources that might be relevant for gaining cross-sectoral information in the first place, and then establishing cross-sectoral network contacts in the second place. For example, the capacity of an actor for gaining relevant cross-sectoral information might often depend on the amount of personnel and further organizational resources that can be used to gain access and process cross-sectoral information. Finally, one could also further specify the type of cross-sectoral information, by, e.g., separating technical information (e.g. about the functioning of energy production based on hydropower plants or the role of water in agricultural production) from political information (e.g., about coalition structures, power relations and policies in other, related sectors) (e.g., Fischer et al. (2017).

Further, we add an important explanatory factor to the literature on governance and policy networks (Fischer & Sciarini, 2016; Henry & Dietz, 2011; Leifeld & Schneider, 2012). We show that actors' networks do not only depend on their power dependencies or policy beliefs and preferences, but on their level of information as well. While we do explicitly assess the level of information that actors have, information has implicitly been part of studies aiming at understanding how actors form network ties in governance and policy networks. For example, Leifeld and Schneider (2012) explain the effect of institutional opportunity structures by the fact that institutional co-participation allows actors to gain information about others that help them to choose the right network contacts. Also, explanations for actors' network contacts based on resource dependence theories assume that given actors (actors with high reputational power, or state actors) dispose of information that others want to have access to, and therefore try to establish contacts with these resourceful actors (Fischer & Sciarini, 2016; Henry & Dietz, 2011; Leifeld & Schneider, 2012).

Several caveats apply. First, the analysis is based on a case study for water governance in the Engadin, a Swiss mountain valley. We cannot make strong claims that results also hold for other regions with other governance problems. However, we propose that the underlying governance challenge for actors to establish cross-sectoral contacts, and how they can deal with it based on cross-sectoral information, is likely also relevant to other cases. We do not see strong arguments for why actors' cross-sectoral information would not be related to their cross-sectoral contacts in other situations. The case of water governance in the Engadin is characterized by the challenge of potential water scarcity and related multi-functional water use in a highly vulnerable alpine landscape. In such a context, cross-sectoral information is likely to be useful for actors to establish cross-sectoral contacts. These cross-sectoral contacts again are relevant for establishing holistic, integrated systems of natural resource governance. In the specific case of a Swiss region of limited size, obtaining cross-sectoral information and being able to establish cross-sectoral contacts might be simpler than in other cases. For example, in governance systems with less local autonomy than the Swiss case, actors might be more constrained by formal hierarchies, and consequently less free to establish network contacts across sectoral boundaries. Also, in larger governance systems such as entire countries or even world regions, actors are likely to have a harder time gaining information about other sectors. Second, our case study might be influenced by the region's project aiming at improving collaboration in water governance across sectors. Given that data gathering happened in the same year as the project started, the project might have already affected the local actors' awareness that water governance can benefit from collaboration across sectors. However, actors are unlikely to have had time to establish contact ties according to their updated awareness. While consequently our study might underestimate the influence of actors' cross-sectoral information on contact ties, the identified trends remain robust. Third, we assume that water governance (including the sectors of agriculture, energy environment, and tourism) is an appropriate system boundary for the management problem of the Engadin. Further, as the chance of actors being active in multiple sectors is higher in such a tightly interdependent setting and actors active in multiple sectors are on average more informed than others (as shown in Figure 6), this additionally increases the actors' overall level of cross-sectoral information. Actors' level of cross-sectoral information would likely be lower if the case study's boundaries would be wider and included additional sectors, as then the actors from these more distant sectors would have fewer commonalities (Bergsten et al., 2019). Fourth, the influence of actors' level of cross-sectoral information and influence on actors' contact networks should be further analyzed, especially within dynamic networks. Only observing networks over time will allow for understanding how cross-sectoral information dynamically co-evolves. With our cross-sectional setting, we cannot exclude that causality partly works in the opposite direction, that is, that existing network contacts (across sectors) influence actors' cross-sectoral information. Still, with this study, we have added one piece of evidence to the growing set of studies of actors' cross-sectoral information and their consequences on different aspects of natural resource governance and beyond.

How the qualities of actor-issue interdependencies influence collaboration patterns

Abstract

Environmental governance is complex because it addresses challenges anchored in different sectors and concern multiple interdependent issues. Managing those complex interdependencies through collaboration is vital for efficient long-term environmental governance. However, since interdependencies between environmental issues are challenging to unravel and vastly complex, it is challenging for actors to account for them when deciding with whom to collaborate. I use the concept of Social-Ecological Networks to study interdependencies among actors and environmental issues and ask how the quality of actor-issue interdependencies influences collaboration patterns. Based on the actor-issue network, I account for interdependencies based on three distinct qualities of actor-issue paths, i.e., i) Length of actor-issue paths: how closely actors are connected by environmental issues, ii) Multiplexity of actor-issue paths: if actors have multiple parallel paths connecting them through environmental issues, and iii) Similarity of actor-issue paths: whether actors' environmental impact is similar to one of their potential collaboration partners. Using Exponential Random Graph Models and data on eight Swiss wetlands, a qualitative meta-regression analysis of the results reveals that the three qualities of actor-issue interdependencies influence collaboration patterns between actors. Whether the impact of actor-issue interdependencies on the probability of collaboration ties is positive or negative largely depends on the complexity of the governance situations. Only in situations with homogenous case areas and under the absence of borders (low network exogenous governance complexity) as well as in the presence of many actors do the length, multiplexity, and similarity of actor-issue interdependencies have a clear, positive impact on the formation of collaboration ties. While the comparative setting helps identify specific governance settings where the hypotheses are supported, it also reveals the importance of multi-case studies to compare contextual differences between cases.

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Introduction

Collaboration among actors is seemingly imperative for the successful governance of environmental systems (Bodin & Crona, 2009; Lubell, 2013; Prell et al., 2009). Still, we have only a partial understanding of how actors decide to collaborate for the purpose of governing environmental systems. This research analyzes the impact of interdependent environmental issues on actor collaboration. In order to advance the body of knowledge pertaining to environmental issues influencing actor collaboration, I adopt a governance perspective of complex Social-Ecological Systems (SESs).

The governance of SESs can be complex due to external conditions influencing the structure of SESs or based on different types of internal complexity of the SESs themselves. External conditions that influence the structure of SESs can be the fragmentation of the geographical or administrative settings. In itself, the governance of SESs can be complex due to the number of interdependent actors and environmental issues (Adkin et al., 2017; Brandenberger et al., 2020). The environmental issues and actors are interdependent as they can be influenced by activities of actors or other environmental issues. For example, water quality is an environmental issue affected by the operation of wastewater treatment plants. Since interdependencies between environmental issues are often vastly complex, it may be challenging for actors to understand their activities' full impact on specific environmental issues (Bergsten et al., 2019; Bodin & Crona, 2009). Additionally, interdependencies between environmental issues are complex as they are not binary – either present or absent – but rather can have different qualities (Jasny et al., 2021; Sayles et al., 2019). For wastewater treatment plants it is, for example, not enough to state that they influence the water quality but it is important to specify that they potentially improve water quality.

For studying how the quality of interdependencies among environmental issues influences actors' choices of collaboration partners, I adopt a Social-Ecological Network (SEN) perspective based on SES theory (Bodin et al., 2019; Bodin & Tengö, 2012). The concept of SEN emerged more than a decade ago to describe and analyze SESs using multilevel networks (Bodin & Tengö, 2012; Cumming et al., 2006; Janssen et al., 2006). SEN studies often focus on collaboration among resource users and the resilience of interdependent SESs (Bodin et al., 2014; Dakos et al., 2015; Guerrero et al., 2015; Janssen et al., 2006). While I generally refer to the literature on SEN, I characterize the network under study as an actor-issue network. This is as I apply the SEN logic not to ecological elements but rather to environmental issues and the ways in which actors collaborate to manage those interdependent environmental issues (Bergsten et al., 2019; Hedlund et al., 2020).Further, I use the term actor-issue paths to refer to interdependencies between the two levels of the actor-issue network and different qualities thereof. Conceptualizations of SENs using different concepts of nodes are common and can include social entities, such as institutions or practices, and ecological entities, such as resources, species, or environmental issues. Environmental issues are often used for SEN studies that operate on an intermediate level of aggregation where a clear definition of ecological nodes is difficult (Bodin et al., 2019). Further, I analyze how the impact of different qualities of actor-issue paths on collaboration ties in the SENs changes depending on the overall complexity of the governance setting.

With this research, I contribute to the SEN literature in two ways. First, I increase the understanding of the governance of environmental systems and the network paths between environmental issues by acknowledging these systems' inherent complexity. When the concept of SEN is applied to study ecological or environmental systems, the network ties are often binary and do not include any information about the quality of ties (Jasny et al., 2021; Sayles et al., 2019; Vasudeva et al., 2020). Accounting for the quality of dependencies can help explain why many environmental problems entail conflicts of interest (Bodin et al., 2020; Herzog & Ingold, 2019). While complex environmental and ecosystem networks are established in natural science fields, for example, to analyze cross-ecosystem fluxes in biology (Altermatt et al., 2020; Harvey et al., 2020), this is often not the case for networks used for analyzing and informing environmental governance decisions (Bodin et al., 2019).

Second, a more detailed perspective of the qualities of network paths between environmental issues is essential for understanding collaboration patterns. Within the field of SEN research, the concept of (social-ecological) fit is prevalent for explaining which collaboration patterns are beneficial for the governance of ecosystems (Enqvist et al., 2020; Guerrero et al., 2015; Sayles & Baggio, 2017a; Treml et al., 2015). The literature on fit claims that the alignment of collaboration patterns with the structure of the ecosystem enhances governance effectiveness (Epstein et al., 2015a; Ostrom, 2007a; Widmer et al., 2019). By contrast, a poor fit can cause non-efficient resource use resulting in exhaustive or non-productive consumption. However, current discussions on fit often do not account for different qualities of network paths between environmental issues when assessing collaboration patterns among actors. This gap limits the power of the concept of fit since the achievement of fit depends not only on the existence but also on the quality of actor-issue paths. While the quality of actor-issue paths is often not accounted for in studies on fit, the general importance of different qualities of network paths for the study of social-ecological systems using networks is recognized (Debortoli et al., 2018).

The methodological approach of this study combines qualitative expert interviews and quantitative survey data of eight Swiss wetlands with statistical modeling of networks using Exponential Random Graph Models (ERGMs). The ERGMs are then further compared using a qualitative meta-regression analysis that combines the results across the cases of wetland governance. Wetlands are among the ecosystems with the richest biodiversity in Europe and worldwide. However, 90 % of the wetlands existing in 1850 in Switzerland have disappeared due to intensive use and various demands of societal, political, and economic actors (Müller-Wenk et al., 2003; Verhoeven, 2014). The research setting is based on eight separated yet comparable case study areas with around 500 actors active in the local governance across these wetlands. The cases differ in their level of governance complexity characterized using four conditions: 1) Number of actors in actor network, 2) Number of ties in issue network, 3) Case area structure, and 4) Existence of cantonal borders. The four conditions are used in a qualitative meta-regression analysis to compare how actors' ability to account for actor-issue paths influences the achievement of fit in different contexts. By using SEN in a comparative study setting, I additionally answer the call from the field of SEN studies to move beyond single case studies and provide an exciting opportunity to evaluate and compare SEN in a comparative setting across cases (Bodin et al., 2019; Sayles et al., 2019), contributing to a more general understanding of collaboration patterns in SEN.

Theory

The governance of Social-Ecological Systems (SES)

Previous research in ecosystem governance established the importance of governing ecological and social systems in an integrated manner (Berkes & Folke, 1998; Bodin & Crona, 2009; Lubell, 2013; Ostrom, 2007a; Prell et al., 2009). The integration of social and ecological aspects is important as processes in SESs are often entangled within and across the levels of the SESs. Further, the governance of SESs does not take place in isolation but is influenced by exogenous governance complexities, given, e.g., by the geographical as well as the administrative setting. Consequently, ecosystem governance often faces the challenge of managing the high inherent complexity of intertwined social and ecological systems in relation to larger system dependencies (McGinnis & Ostrom, 2014)

I build on the SES framework by Ostrom (2007a) that holistically conceptualizes and analyzes governance structures of ecosystems (Gerber et al., 2009; McGee & Jones, 2019; Ostrom, 2009). The SES framework emphasizes the importance of aligned social and ecological systems to resolve policy issues and achieve sustainability of SESs (Epstein et al., 2015a; Lubell et al., 2014; Ostrom, 2009). To achieve an alignment of social and ecological systems and manage SESs successfully, the importance of actor collaboration is often stressed in research building on the SES framework (Hedlund et al., 2020; Ingold et al., 2018; Pittman & Armitage, 2017). I define collaboration here as an interaction between two actors to govern environmental issues. While collaboration is generally assumed to be beneficial, it is also associated with certain costs (Hileman & Bodin, 2019b). The costs of collaboration ties are also a matter of interest in the Ecology of Games framework (EoG) (Berardo & Lubell, 2019b; Lubell et al., 2014). The EoG analyzes how actors' capacities to collaborate are constrained by the availability of physical and cognitive resources, and how constraints on collaboration influence governance outcomes. In addition to interdependencies between actors, interdependencies between issues within the environmental/ecological systems are also relevant for understanding collaboration but tend to remain understudied (Bodin & Tengö, 2012).

The role of Social-Ecological Networks (SEN) for the governance of ecosystems

One approach to structure complex interdependencies within and across systems focuses on networks. In networks, social and ecological systems are both conceptualized based on nodes and ties. Networks play an increasingly important role in analyzing the governance of SESs and exploring different forms of dependencies (e.g., collaboration) between actors (Dragicevic & Shogren, 2017; Robins et al., 2012). However, the concept of networks is not limited to actor interactions (Janssen et al., 2006; Scott & Ulibarri, 2019) but can equally include other forms of dependencies between any units of analysis (Bentley et al., 2019). The concept of SEN has gained popularity for its combined analysis of social and ecological systems. The concept of SEN builds on two parallel network levels – the social and the ecological – with ties within and across those levels (Barnes et al., 2017). Since the SEN concept is still relatively new, only a few attempts exist to standardize the conceptualization of SENs (Bodin et al., 2019; Felipe-Lucia et al., 2022a; Sayles et al., 2019). Research using SENs often focuses on analyzing the governance of ecosystems based on single case (Bodin et al., 2019; Sayles et al., 2019)

To analyze the governance of SESs using networks, the concept of fit gives particular emphasis to social-ecological paths illustrating interdependencies between the two network levels (Sayles & Baggio, 2017a; Widmer et al., 2019). The concept of social-ecological fit implies that the social systems should be aligned with the ecosystems (Epstein et al., 2015a; Ostrom, 2007a; Widmer et al., 2019). The ecological and social network structures in SENs are aligned when actors managing dependent environmental issues collaborate. Different concepts of fit have emerged (Bodin et al., 2014; Folke et al., 2007; Lebel et al., 2013; Widmer et al., 2019) that can be categorized as ecological fit, social fit, and social-ecological system fit (Epstein et al., 2015a). I refer to the latter one when identifying structures in SENs that are potentially influencing the governance of SESs. The benefit of social-ecological fit is that it accounts for the full SES and not only one component of inextricably interlinked SESs as social fit and ecological fit concepts do (Epstein et al., 2015a; Moss, 2003). The challenge with social-ecological fit is, however, to properly conceptualize the complex interdependencies of SESs. In this paper, I use networks to conceptualize actor-issue interdependencies. Fit in those networks exists when the interdependencies represented by actor-issue paths are aligned with collaboration ties.

The importance of the quality of actor-issue paths for collaboration patterns

I define actor-issue paths as a combination of two or more ties that connect the social and ecological levels of SENs – in contrast to general network paths that connect any two nodes in a network. Using actor-issue paths, it is possible to characterize how actors are connected at the issue network level. When actor-issue paths connect two actors that collaborate, a network motif of fit is created where the management of environmental issues is aligned. However, unlike other scholars analyzing fit based on networks, I do not differentiate between different network motifs of fit (e.g., triangle vs. four-cycles (Bodin et al., 2016; Lubell et al., 2014)) but rather focus on how different actor-issue paths contribute to network motifs of social-ecological fit. The three hypotheses that focus on different qualities of actor-issue paths and thus describe different situations of fit, are illustrated in Figure 9. The top row presents the configuration with the highest probability of observing a collaboration tie, and the further rows show additional configurations with lower expected probabilities for collaboration ties. Additional configurations that can be more or less complex are also taken into account in the analysis as such configurations potentially influence the probability of observing a collaboration tie. The three hypotheses illustrated in Figure 9 are assessed for a diversity of cases with different levels of governance complexity. I assume that the support of the hypotheses varies depending on the level of governance complexity, as governance complexity likely influences actors' perception of the qualities of actor-issue paths. The analysis of the relation between governance complexity and the three hypotheses has a hypotheses generating character in this article.

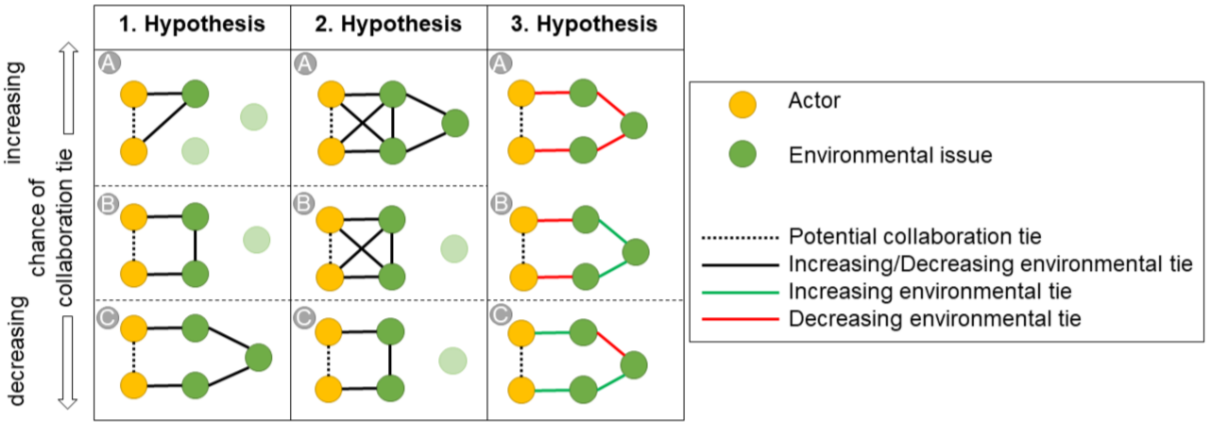

Figure 9: Illustration of simplified network motifs for the three hypotheses; different motifs that include more/less environmental issues are possible. Motifs with an A always have the greatest chance to cause a collaboration tie from all the motifs presented, and motifs with a C have the lowest chance of causing a collaboration tie. For the third hypothesis, motifs A and B have the same chance to cause a collaboration tie. For the first hypothesis, actors are more likely to collaborate in the triangle motif because the connecting actor-issue path is shorter. For the second hypothesis, the actors are more likely to collaborate in the top motif because the number of connecting actor-issue paths is higher. Finally, for the third hypothesis, actors are more likely to have a collaboration tie in motif A or B because they impact the state of an environmental issue in the same direction based on their actor-issue path, given by the multiplication of the increasing (+1)/decreasing (-1).

When the probability of a collaboration tie forming is assessed, this is often done based on the shortest network connection between two actors (Berardo & Scholz, 2010; Moon et al., 2019). In the literature on fit, the path length plays a minor role, as only very limited motifs of fit with only a small number of nodes are analyzed (Enqvist et al., 2020; Guerrero et al., 2015; Pittman

& Armitage, 2017). I include the path length connecting pairs of actors in the first hypothesis to analyze how proximity across actor-issue networks influences actors' decisions to collaborate. The assumption is that the shorter the actor-issue path connecting two actors, the stronger the connection between them, and the more likely actors are to collaborate. This assumption is based on the idea of bounded rationality, where actors make decisions based on a limited perception of the underlying problem (Simon, 1991). The concept of bounded rationality serves to limit the cognitive load to a manageable level for everyday decisions. The cognitive load essentially addresses the amount of information that needs to be processed to make a decision (Renkl et al., 2009) – in this case, with whom to collaborate. In complex governance settings reducing the cognitive load is essential, as actors only have limited resources they can invest in collaboration ties (Hileman & Bodin, 2019b; Lubell et al., 2014). Therefore, actors might focus on short actor-issue paths when choosing collaborators.

1. **Hypothesis** – *Length of actor-issue paths: Actors are more likely to collaborate if the actor-issue path connecting them is shorter.*

Furthermore, only one actor-issue path (that connects two actors based on their impact on a common issue) is usually included when the alignment of collaboration patterns with an ecosystem's ecological or environmental structure is analyzed (Epstein et al., 2015a; Guerrero et al., 2015). This is in contrast to the frequent existence of multiple alternative paths in SENs. Multiple alternative paths are typical for complex networks (Guimarães, 2020; Widmer et al., 2019). Therefore, the second path quality accounts for multiple parallel actor-issue paths connecting pairs of actors. The assumption is that the more alternative paths exist, the more likely it is that those actors are aware of each other (Huang, 2014; Siciliano et al., 2020). Therefore, I assume that the multiplexity of actor-issue paths increases the chance of actors sharing a collaboration tie because those actors manage multiple common environmental issues together. Similarly, as with shorter path lengths, higher multiplexity also has the potential to increase the mutual awareness between actors (Dörner, 1980; Renkl et al., 2009) and increase the probability that actors share a collaboration tie.

2. **Hypothesis** – *Multiplexity of actor-issue paths: Actors are more likely to collaborate the more alternative actor-issue paths are connecting them.*

Finally, actor-issue paths are often not neutral – i.e., simply describing an influence – but rather can be specified as having an increasing or decreasing effect on the state of dependent environmental issues. If two actors influence the state of an environmental issue in the same direction – increasing or decreasing the state of the issue – their management practices tend to be aligned. The alignment of management practices has the potential to facilitate collaboration between actors. This does not mean that actors should not collaborate when they influence environmental issues differently. However, differences in actors' influence on environmental issues are likely to increase the cost of establishing collaboration ties. Therefore, the third hypothesis assumes that actors are more likely to collaborate if they have a similar influence on the state of an environmental issue. Similarity of actors with respect to different characteristics is commonly used to explain why actors collaborate (Siciliano et al., 2020). Typical applications of similarity explaining actor collaboration are based on shared beliefs (Calanni et al., 2015) or occupational similarity (Cepić & Tonković, 2020). Here I investigate actor similarity in terms of the direction in which they impact environmental issues (e.g., decreased/increased state of an environmental issue).

3. **Hypothesis** – *Similarity of actor-issue paths: Actors are more likely to collaborate if they influence the state of an environmental issue in the same direction.*

Case, methods and data

Case description

In this paper, I study the governance of eight wetlands across Switzerland. Wetlands comprise various habitats that are characterized by high biodiversity. However, many wetlands are also located in areas that are economically utilized as farmland or for recreational purposes. Therefore, while the importance of wetlands to sustain rich biodiversity is recognized, the size and number of wetlands have continuously decreased to the point where they only make up 0.7 % of Switzerland's area (Müller-Wenk et al., 2003; Verhoeven, 2014). In the revised Water Protection Act, the poor condition of wetlands is recognized, as one-quarter of Swiss water bodies have been designated as being in need of active restoration measures (Weber, 2016). However, ten years later, the restoration of the water bodies is proceeding slowly, and the status of most wetlands does still not satisfy the requirements of the law (Bonnard et al., 2020).

While the water protection act is initiated and funded on the federal level, cantons and municipalities (the constituent states and sub-states of Switzerland) are responsible for its implementation. Thus, when analyzing the governance of wetlands in Switzerland, I primarily focus on actors on the regional and local levels, such as cantonal agencies and municipalities, as well as a diverse set of private actors (NGOs, associations, or private companies).

When I selected the cases of Switzerland's wetlands, I considered multiple criteria. First, only the wetlands that are listed in the inventory for alluvial wetlands of national importance were considered (Bundesamt für Umwelt, 2014). The inventory of alluvial wetlands is managed by the federal office for the environment to improve the protection and maintenance of wetlands and ensures that all the areas identified for this article show characteristic features of Swiss wetlands. Second, the case selection covers different regions and cantonal administrations across Switzerland to account for geographical and socio-cultural diversity, including the German, French, and Italian-speaking regions. While some cases are located within one canton's administration area, other cases cut across cantonal borders, and are governed by multiple cantons. Third, wetlands were selected that represent goal conflicts between societal, economic, and ecological interests. Therefore, the focus is on river wetlands and wetlands along lakes, which are often located in densely populated areas. Finally, the wetlands' size was also a factor when deciding on the case selection of the wetlands. Small wetlands (< 0.6 km^2) were excluded from the study to avoid cases with only a few actors, as those would have complicated a meaningful statistical analysis. However, purely geographic case boundaries cannot fully demonstrate the multiple dimensions of governance issues (Moss, 2012). Therefore, I also account for socio-economic aspects relevant to the management of wetlands (e.g., close by farming land or upstream hydropower plants) to include further surrounding areas that form one functional unit (for further details, see Appendix B, Location of selected wetlands).

From the wetlands that fulfill all criteria, I selected eight cases across Switzerland that are included in the analysis of this paper (for detailed information on the data gathering approach, see Appendix B, Data gathering). For each of the eight cases, I then chose key actors deeply involved in managing the respective wetlands representing the public and private sectors. In expert interviews with those key actors, I identified environmental issues and interdependencies between them using a conceptual mapping approach inspired by the Open Standards (OS) framework (Schwartz et al., 2012) (for examples of the data gathered in the expert interviews, see Appendix B, Conceptual maps). Subsequently, I sent out a survey to 395 of the total number of 499 actors identified to be relevant. The number of contacted actors is lower, as some actors present in multiple areas (mostly the ones active on the national level with no local presence in the wetlands) could not be contacted for all surveys. Of the actors that I contacted, 276 actors filled out the survey (response rate: 70 %). The two most important survey questions for this paper are "*Which of the activities below has your organization been involved in over the past three years in the [case area]?" and "*Which of the organizations listed below have you regularly collaborated with in the past three years as part of your activities in the [case area]?" (for further details on survey structure and questions, see Appendix B, Survey text)

For the analysis of the cases, collaboration ties are the dependent variable, and different qualities of actor-issue paths are the independent variables. The characterization of collaboration ties and different qualities of actor-issue paths is identical for all cases and dependent on the set of actors and the relevant environmental issues for each case. Where the cases differ is regarding their level of governance complexity. The level of governance complexity increases actors' cognitive load and influences their ability to account for the length, multiplexity, and similarity of actor-issue paths (Dörner, 1980; Jones, 2003; Widmer et al., 2019). Governance complexity has a hypotheses generating character for this paper, as it potentially influences the actors' decision to collaborate based on actor-issue paths.

Table 4: All cases, categorized based on the four conditions of governance complexity: (1) number of actors in actor network, (2) number of ties in issue network, (3) case area structure, and (4) existence of cantonal borders. The conditions are grouped into endogenous network conditions directly integrated into the actor-issue networks (the number of actors and environmental issue ties) and exogenous network conditions that influence the structure of the actor-issue networks (case structure and cantonal borders).

Cases	**Network endogenous**		**Network exogenous**	
	Number of actors in actor network	*Number of ties in issue network*	*Case area structure*	*Existence of cantonal borders*
Alte Aare	59	105	0.7	No
Bolle	74	80	-0.2	No
Sense	67	103	-0.1	Yes
Murtensee	59	92	-0.7	Yes
Reussebene	72	111	0.4	Yes
Untere Saane	61	85	-1.6	No
Rhone	44	74	-0.6	Yes
Neuchatel	63	70	2.2	Yes

The governance complexity is characterized using four conditions (see Table 4): 1) Number of actors in actor network, 2) Number of ties in issue network, 3) Structure of case area, and 4) Existence of cantonal borders. The conditions can be grouped based on their integration in the actor-issue network. The number of actors and ties between environmental issues are elements of the actor-issue network and, therefore, indicators of the endogenous network complexity. The case structure and presence of borders are not part of the actor-issue network but influence the network structure and, therefore, are measures for exogenous network complexity. The index for the case area structure includes the size of the case area as well as the number of separately protected wetlands within one case and is zero-centered. The condition of cantonal borders separates the cases into two categories: 1) cases that cut across cantonal borders, and 2) cases located within one single canton. I use this differentiation as a measure representing the institutional fragmentation of the cases. A high index for the case area structure and the presence of cantonal borders indicates a high governance complexity and increases the cognitive load of actors.

Methods

The survey data of the wetlands is analyzed using ERGMs. I use ERGMs to test the three hypotheses individually for each of the cases' specific network structures. ERGMs build on the idea of analyzing networks by studying smaller structures that function as building blocks (Robins, Pattison, et al., 2007; Snijders, 2011). They have their origin in spatial statistics, and were first introduced as Markov graph models but have been extended in various ways (Cranmer et al., 2017). At the tie-level, the interpretation of ERGM coefficients is similar to logistic regression models, indicating the ceteris paribus change in the likelihood of a tie given a change in a node or dyadic attribute. To estimate the models, ERGMs build on the Markov Chain Monte Carlo maximum likelihood estimation (MCMC MLE). I used the ERGM package (Handcock et al., 2019) in R (R Core Team, 2021) to estimate the models for each case and hypothesis. All exogenous variables of the ERGM models are operationalized as either node-level or dyad-level covariates to explain the occurrence of collaboration ties (dependent variable).

To compare the ERGM results related to the hypotheses across cases and to recognize trends related to the four conditions of governance complexity, I use a qualitative meta-regression analysis. The qualitative meta-regression analysis helps compensate for the small sample size of the individual cases by pooling together the results across all cases. The qualitative meta-regression analysis is based on separate regressions for each case and each of the three hypotheses. The individual ERGM results used to calculate the regression lines are associated with different variances. As an indicator of the variances of the ERGM results, I use the associated p-values with smaller p-values indicating smaller variances of the results. The p-values are used as the weights (weight = |1 - p-value|) for the weighted least squares regressions. Consequently, results associated with a lower p-value have a stronger influence on the qualitative meta-regression analysis.

Conceptualization of the actor-issue network

To analyze the case data from the qualitative interviews and quantitative surveys using ERGMs, I conceptualize the data as actor-issue networks (for further details, see Appendix B, Detailed conceptualization of the actor-issue networks). More specifically, the actor network level is conceptualized as the dependent network in the ERGMs. The issue network as well ties across network levels are included as dyad-level covariates – one for each hypothesis. Since the same actor-issue paths can be relevant for the operationalization of the dyad-level covariates for all three separate hypotheses, I calculate separate ERGMs for each of the three hypotheses (for further details, see Appendix B, Aggregated covariance table for hypotheses). This is done in an effort to avoid interdependencies between the hypotheses and to distinguish between the effects of the hypotheses on collaboration ties in the actor-issue networks. The reason for possible interdependencies between the hypotheses is that the dyad-level covariates are all partially based on the same actor-issue paths but differ in how they are operationalized. The variables of path length and multiplexity, for example, both depend on the same shortest actor-issue path connecting an actor pair. While the operationalization of the variable of path length only relies on the shortest actor-issue path connecting an actor pair, the operationalization of the variable path multiplexity also takes into account longer parallel paths connecting an actor pair.

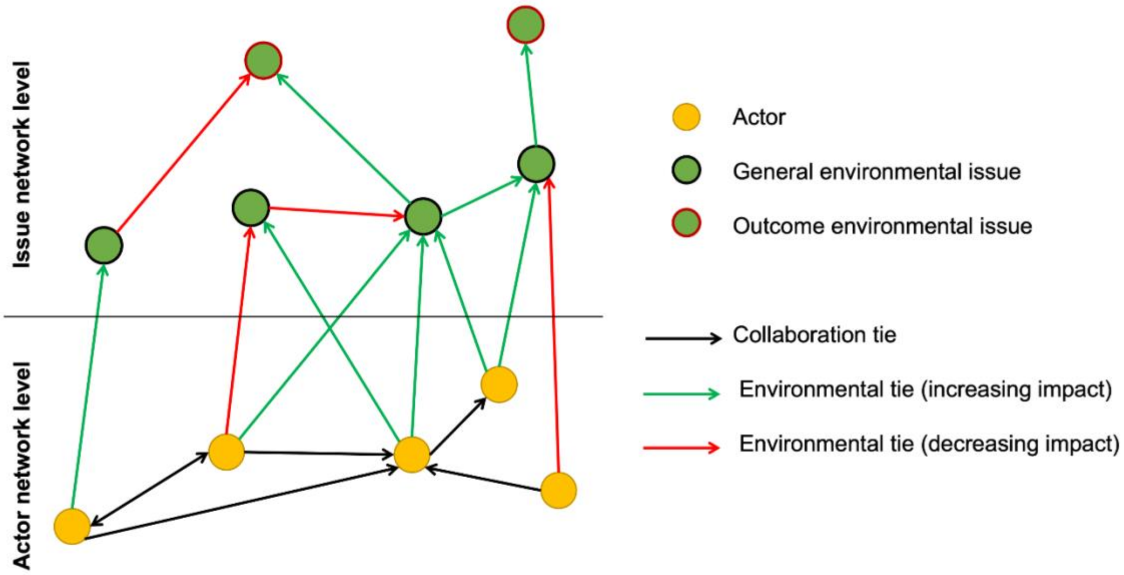

Figure 10: This illustration highlights the characteristic features of the actor-issue networks used for the analysis of this paper. The illustration is split into two dimensions: (1) The actor network with actors as nodes (yellow) and directed collaboration ties. (2) The issue network consists of environmental issues (green) and directed ties based on the impact of environmental issues. The environmental issues are split into general environmental issues (e.g., water quality) and outcome environmental issues (e.g., biodiversity). Both types of environmental issues are based on environmental interdependencies, but outcome environmental issues are aggregated stronger than general environmental issues and can not be directly influenced across network levels by actors. Ties between network levels exist when actors directly impact general environmental issues based on their environmental management activities. The color of the environmental ties illustrates if environmental issues or actors have an increasing (green)/decreasing (red) impact on the state of other environmental issues.

The actor-issue network consists of two interdependent network levels that characterize the interdependencies between actors, between issues, and between actors and issues (see Figure 10). The nodes of the actor network are actors, and the directed ties represent a collaboration between those actors. The nodes in the issue network are environmental issues. Environmental issues are aggregated features of ecosystems (e.g., water quality or population of beavers) or issues that have an impact on them (e.g., amount of trash). Directed, increasing/decreasing ties between environmental issues exist if one can increase/decrease the state of another environmental issue. The "amount of trash", for example, decreases the "water quality" as the state of the environmental issues of "water quality" is worsened due to the higher "amount of trash". The issue network can also be described as a network of cause and effect relationships between multiple interdependent environmental issues. Finally, also ties between the two network levels are possible. Similar to ties between environmental issues, such ties that connect the two network levels are also directed and have either an increasing or decreasing impact. A tie between the two network levels exists if actors directly impact the state of an environmental issue by executing their activities or if environmental issues influence the execution of the activities of actors. A "park ranger" that is responsible for the cleaning of the area, for example, has a decreasing impact on the "amount of trash"; therefore, a decreasing tie from the "park ranger" to the issue "amount of trash" exists. Environmental issues are additionally grouped into two categories of nodes: 1) general environmental issues and 2) outcome environmental issues. The difference between the two categories of nodes is that outcome environmental issues represent more aggregated goals, and are not directly influenced by actors but only by incoming ties from general environmental issues. Outcome environmental issues allow assessing the similarity of actors' impact on the actor-issue network relevant for hypothesis three on a system level.

Operationalization of network variables

The first hypothesis is based on information on the length of the actor-issue paths (see Figure 9). A triangle network motif of two actors and one environmental issue indicates a shorter actor-issue path than, for example, a square or hexagon motif with two actors and multiple environmental issues. The second hypothesis relies on information on the multiplexity of the actor-issue paths. The focus here is on the amount of parallel actor-issue paths between actors. The shortest of those actor-issue paths connecting two actors have the strongest weight; the longest actor-issue paths have the smallest weight for calculating the multiplexity index.

The operationalization of the third hypothesis is based on the increasing or decreasing impact of actors on the two outcome environmental issues: local biodiversity and recreational value. Both are selected as they were mentioned as most relevant in the expert interviews across all cases. Actors' influence on outcome environmental issues is based on actors' actor-issue paths. In this particular case, actor-issue paths are not used to directly assess the connection between a pair of actors (as in the operationalization of H1 and H2) but to assess the connections between an actor and outcome environmental issues. For example, the presence of a "ranger" responsible for the "maintenance of a wetland area" decreases the "amount of trash". Further, the "amount of thrash" decreases "habitat quality" and consequently also the "biodiversity". Therefore the presence of a "ranger" has overall a positive impact on the "biodiversity" based on the actor-issue path. Each actor has multiple such paths connecting them with outcome environmental issues. The aggregated impact of actors on outcome environmental issues based on their actor-issue paths is used to construct a similarity coefficient for each pair of actors using the Euclidean similarity metric (Liberti et al., 2014). Actors with a high similarity index have a similar – whether positive or negative – effect on the biodiversity and recreational value of the wetlands, and are more likely to collaborate (for further details, including examples for the operationalization of all hypotheses, see Appendix B, Detailed examples for the operationalization of the independent variables).

I also include several established explanatory factors for actor networks as control variables for the tie formation process (Bodin & Crona, 2009; Prell et al., 2009). First, I control for the power of actors as actors perceived to be powerful are attractive collaboration partners (Fischer & Sciarini, 2015). Second, I control for homophily among actors based on their type of organization (state actors, cantonal actors, municipal actors, NGOs and associations, and others) and their activity area (on the spatial level of cantons). Actors with the same organization type and activity area are more likely to collaborate as they share organizational logics and are active within the same functional areas (Ingold, 2011). Third, also actors who did not respond to the survey are included in the analysis. Therefore, controlling for the response of individual actors is needed as the information available to construct the actor-issue network is less complete for actors that did not respond to the survey. Non-response also has an impact on their ego network, which is sparser compared to other actors. Fourth, I adjust for endogenous network processes (Handcock et al., 2019). Therefore, I include an edges term in the model, which is conceptually similar to an intercept in conventional regression models, establishing a baseline probability for a tie to occur in the network. Additionally, I control for triadic closure (the tendency of an actor pair with a common tie also to have a common partner in the network) by including ergm terms for edgewise and/or dyadwise shared partners (Hunter, 2007).

Results

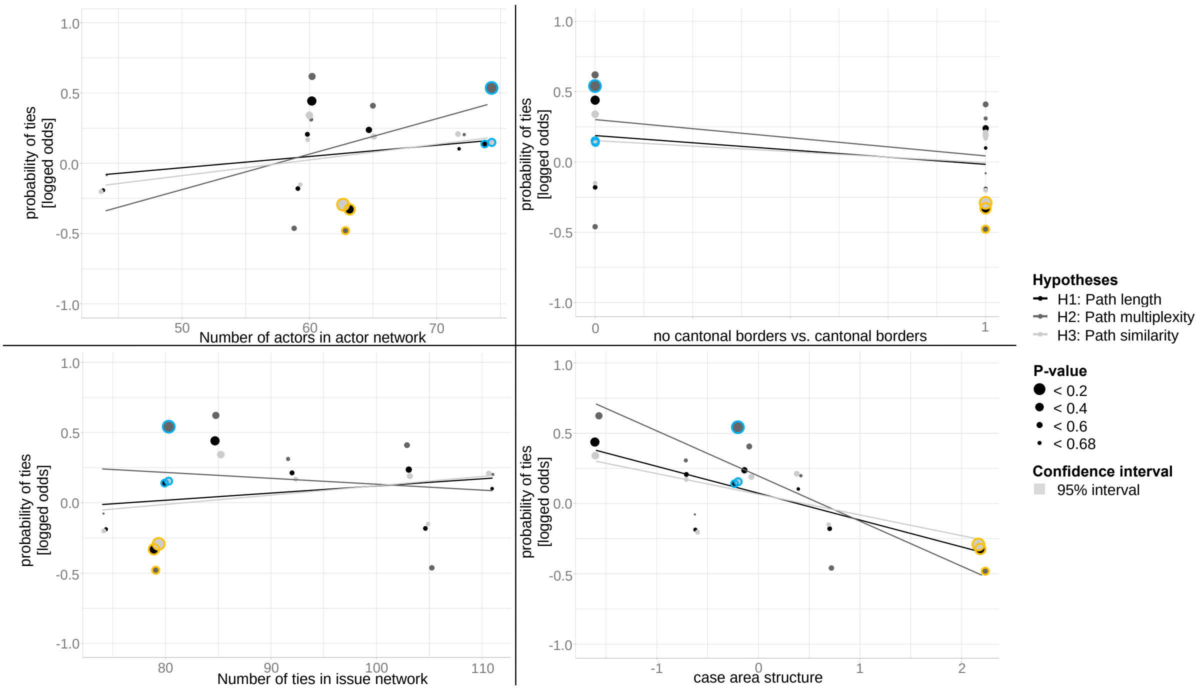

Figure 11: Qualitative meta-regression analysis with the logged odds of the Exponential Random Graph Models (ERGM) for the three hypotheses (y-axis) plotted against the four indicators of governance complexity (x-axis): number of actors, ties in the issue network, the existence of cantonal borders, and structure of case area. The size of the dots indicates the p-value of the corresponding logged odds of the hypotheses, with the largest points having the lowest p-values. The slopes represent the linear regression lines weighted based on the p-values for all the logged odds for each separate hypothesis. The grey area represents the 95% confidence interval for the combined regression lines of the three hypotheses. Finally, the minor blue and yellow points refer to the cases of Neuchatel (yellow) and Bolle (blue) that are discussed in-depth in the Discussion section in order to highlight the importance of contextual differences between the cases.

I calculate separate ERGMs for each case and each hypothesis. Based on the goodness of fit (GOF) statistics analysis, ERGMs of all cases provide a relatively good fit to the data given the limited sample size of the individual case studies (for result tables and GOF statistics as well as an additional discussion of limited sample size, see Appendix B, ERGM results and GOF statistics). Two cases that I have data on are not included in the analysis due to poor GOF statistics.

Overall, the results (see Table 5) indicate a certain effect for all three hypotheses. However, while only a positive effect of the variables of path length, multiplexity, and similarity on collaboration ties was hypothesized, the effect of the variables on collaboration ties ranges from positive to negative. Further, many of the results of the ERGMs are associated with relatively high levels of uncertainties as the sample sizes of the individual cases are relatively small (for further information on the influence of sample sizes on statistical tests, see Foulley (2019); Wasserstein et al. (2019)). To overcome this uncertainty on the case level and to characterize the cases where the hypotheses are supported, I rely on a qualitative meta-regression analysis (see Figure 11). The qualitative meta-regression analysis pools together the results across cases, which helps to compensate for the small sample size of the individual cases.

Trends for the influence of the three hypotheses of path length, multiplexity, and similarity on actor collaboration appear in the qualitative meta-regression analysis presented in Figure 6.

The four scatter plots of the qualitative meta-regression analysis plot the logged odds of tie probability against the four conditions of governance complexity (number of actors, number of ties in issue network, case area structure, and existence of cantonal borders). An increase in the size of the dots symbolizes higher confidence in the results (lower p-value), and the regression lines represent the trends weighted based on the p-values for the three hypotheses across cases. While the trends differ between the four conditions of governance complexity, they are mostly similar for all of the three hypotheses of actor-issue path length, multiplexity, and similarity.

Table 5: Exponential Random Graph Model (ERGM) results for the three hypotheses for each of the eight cases. The estimate values are the logged odds of the hypotheses on the probability of a collaboration tie. The estimates and p-value presented in the table are again illustrated in Figure 3. Full ERGM results, including all control variables, can be found in Appendix B, ERGM results and GOF statistics.

Case	**Model**	**estimate**	**Std error**	**p-value**
Alte Aare	H1-path length	-0.18	0.24	0.45
Alte Aare	H2-path multiplexity	-0.46	0.50	0.36
Alte Aare	H3-path similarity	-0.15	0.21	0.48
Bolle	H1-path length	0.14	0.15	0.35
Bolle	H2-path multiplexity	0.54	0.27	0.05
Bolle	H3-path similarity	0.15	0.12	0.20
Sense	H1-path length	0.24	0.22	0.26
Sense	H2-path multiplexity	0.41	0.40	0.31
Sense	H3-path similarity	0.19	0.17	0.28
Murtensee	H1-path length	0.21	0.25	0.42
Murtensee	H2-path multiplexity	0.31	0.51	0.54
Murtensee	H3-path similarity	0.17	0.22	0.44
Reussebene	H1-path length	0.10	0.21	0.63
Reussebene	H2-path multiplexity	0.20	0.46	0.66
Reussebene	H3-path similarity	0.21	0.21	0.32
Untere Saane	H1-path length	0.44	0.24	0.07
Untere Saane	H2-path multiplexity	0.62	0.47	0.18
Untere Saane	H3-path similarity	0.34	0.24	0.15
Rhone	H1-path length	-0.19	0.32	0.54
Rhone	H2-path multiplexity	-0.08	0.49	0.87
Rhone	H3-path similarity	-0.20	0.25	0.42
Neuchatel	H1-path length	-0.33	0.20	0.09
Neuchatel	H2-path multiplexity	-0.48	0.39	0.21
Neuchatel	H3-path similarity	-0.29	0.14	0.05

The most robust trend for the influence of the independent variables – and in particular the variable of the multiplexity of actor-issue paths – on the probability of collaboration ties appears for the exogenous condition of governance complexity related to the case area structure. For the case area structure, the influence of the three qualities of actor-issue paths is on average positive for homogenous cases and negative for more heterogeneous and complex cases. A similar but less accentuated trend appears for the second exogenous complexity condition based on the existence of cantonal borders. Further, the regression lines slopes are positive for the endogenous condition of governance complexity based on the number of actors. Therefore, unlike for the exogenous conditions, the probability of path length, multiplexity, and similarity to cause a collaboration tie is on average higher in situations of high complexity. Finally, the number of ties in the issue network does not influence the relationship between any of the three independent variables and the probability of collaboration ties.

Discussion

The results of the ERGMs presented in the qualitative meta-regression analysis show the importance of exogenous and endogenous governance complexity to identify general trends for the effect of the three independent variables on the probability of collaboration ties. The exogenous governance complexity, based on the case area structure and the existence of cantonal borders, has a negative effect on the independent variables' influence on the probability of collaboration ties. Therefore the hypotheses are, on average, only supported when the exogenous governance complexity is low. This might be explained as in cases with a low exogenous governance complexity, the cognitive load of actors to perceive actor-issue path qualities is also low (Jones, 2003; Renkl et al., 2009). Therefore a low exogenous governance complexity increases the chance that actors account for actor-issue path qualities when deciding with whom to collaborate. However, also other mechanisms need to be in place as in cases of high exogenous governance complexity, the effect on the probability of path length even turns negative. The negative effect on collaboration ties is particularly distinct in cases with complex case area structures. One mechanism that might explain this negative effect is that in such cases, environmental issues can be tightly connected to actors based on the actor-issue path but at the same time, those environmental issues are geographically distant from those actors. Actors might, therefore, not collaborate based on the quality of their actor-issue paths but based on their geographical proximity.

For the endogenous network complexity based on the number of actors, a positive trend can be recognized. This indicates that the more actors are present in the governance of wetlands, the more likely actor-issue paths positively influence the tie formation process. The positive slope of the regression line might be explained as actors using the quality of actor-issue paths as a coping strategy to reduce the cognitive load when selecting from a large set of actors a few which might be favorable to collaborate with (Dörner, 1980; Renkl et al., 2009). The quality of actor-issue paths reduces the complexity as it provides additional criteria for actors to decide on a promising collaboration partner. The condition of endogenous governance complexity based on the number of ties in the issue network does not affect any of the three hypothesized relations. Very likely, the number of issue ties does not affect the shortest actor-issues paths that are the most important ones for the operationalization. The reason why there is hardly any effect of number on issues ties on the shortest path lengths is that already with fewer ties in the issue network the path lengths of connecting actor-issue paths are relatively short. A higher number of issue ties increases the number of longer parallel actor-issue paths. These longer actor-issue paths are, however, weighted less for the operationalization of the three hypotheses.

Consequently, hardly any effect can be identified based on the complexity condition of the number of issue ties.

Case insights

To go beyond analyzing general trends across cases, I analyze two of the cases in depth – one where the hypotheses are supported and another case where the results do not support the hypotheses. The two selected cases do not reflect the proportions of cases that support or reject the hypotheses but rather illustrate how different local governance situations influence the results.

The first case is a wetland system along the shore of the lake Neuchatel (see green dots in Figure 6). Results for this case do not provide support for the hypotheses. The area of the case of Neuchatel is rather large and split across the administration areas of three cantons. The large size and the administrative heterogeneity of the area likely make it more difficult for actors to perceive the qualities of actor-issue paths. In such a situation, other factors explaining actor collaboration than the quality of actor-issue paths might be more important. For the case of Neuchatel, such mechanisms might relate to two distinct case characteristics. First, the case area's high complexity might favor collaboration based on geographical proximity instead of common environmental issues. Second, most actors have been active in the case area for quite some time, as the wetland has already been protected for multiple decades. Therefore, it might be easier for actors to rely on their personal contacts as they already know most potential collaboration partners and do not need to account for actor-issue path qualities when deciding whom to collaborate with. However, in the case of Neuchatel, instead of having no impact of the actor-issue path qualities on collaboration ties, we even see a negative impact on collaboration ties. This unexpected result might be due to two factors. First, actors might have problems in perceiving actor-issue path qualities due to the high exogenous governance complexity of this case. By contrast, in other cases with lower exogenous governance complexity, it is likely easier for actors to perceive the quality of actors-issue paths. Second, in cases with high exogenous governance complexity like the case of Neuchatel, alternative, more dominant mechanisms that correlate with actor-issue path qualities might influence the probability of actor collaboration.

The second case, which offers relative support for the three hypotheses, is the case of Bolle (see red dots in Figure 6) – a river delta that includes the river mouths of the river Ticino and Verzasca into the Lago Maggiore. On one side, the wetlands in the Bolle are among the most popular tourism destinations in Switzerland in Switzerland, but they are also surrounded by large industrial areas and attract many visitors. As a consequence, several actors with different goals influence the governance of the wetland. The high number of actors makes it challenging for actors to recognize relevant collaboration partners. In such situations, the quality of actor-issue paths can help to identify relevant collaboration partners. Besides, the exogenous governance complexity of the Bolle is rather low as the case is quite homogenous and located in one single canton. This makes it easier for the actors to perceive qualities of relevant actor-issue paths. Together, the high number of actors and low exogenous governance complexity increase the chance that actors depend on the length, multiplexity, and similarity of actor-issue paths when deciding with whom to collaborate.

Conclusion

Analyzing the governance of eight Swiss wetlands based on a qualitative meta-regression analysis of the ERGM results, I can make three key statements on the influence of the quality of actor-issue paths on the probability of collaboration ties. 1) Overall, the three hypotheses have a meaningful effect – positive or negative – in most cases. If a positive effect can be identified and therefore, the hypotheses are supported depends however strongly on the characteristics of the individual cases. 2) In cases where the endogenous network complexity is high due to many involved actors, the qualities of the actor-issue paths have a positive influence on the formation of collaboration ties. Therefore, the qualities of the actor-issue paths can potentially help actors identify fitting collaboration partners. 3) When the exogenous network complexity is low, particularly due to a simple case area structure but also due to the absence of cantonal borders, actor-issue path qualities play an essential role in identifying collaboration partners. The second and third statements illustrate the importance of differentiating between network endogenous and exogenous governance complexity. Depending on the combination of endogenous and exogenous forms of complexity, the hypotheses' chance to be supported or rejected varies. The strongest support exists when actors can easily perceive actor-issue paths, and at the same time, strongly benefit from actor-issue paths in their decision process with whom to collaborate. Further, the three key statements illustrate that it is important to account for the context sensitivity of results of SEN studies based on a diverse set of multiple cases. A diverse set of cases is important as results are often not generally applicable but rather depend on multiple contextual factors. A direct consequence of this is that hypotheses are likely not to be supported by all cases. However, mixed support of the hypotheses is a sign that the cases are selected based on meaningful contextual differences across cases.

Overall, the results show that the quality of actor-issue paths have generally an influence on collaboration patterns in the actor network. However, there are no large differences between most of the three qualities of the actor-issue paths; the differences that exist largely depend on the governance complexity. This is in line with other research findings (e.g., Widmer et al. (2019)), which also identified complexity as a factor that influences the tie formation process in actor networks. The reason for such influence of complexity is that in complex governance situations, actors can often not take all actor-issue paths into account (Bergsten et al., 2019; Crona & Bodin, 2006). Here I additionally show the importance of distinguishing between different forms of complexity – network endogenous and exogenous complexity – when analyzing the influence of complexity on the formation process of collaboration ties. Similarly, (Bergsten et al., 2014) have shown that not only the number of paths between issues (endogenous complexity) but also the existence of cross-sectoral issues (exogenous complexity) influence the capacity of actors to achieve fit. One reason for the differences between exogenous and endogenous complexity is that exogenous complexity increases the cognitive load of actors to perceive actor-issue path qualities. In contrast, actor-issue path qualities can help actors identify potential collaboration partners and, therefore, reduce the cognitive load in situations of high endogenous complexity.

Since the support for most of the hypotheses heavily depends on contextual factors influencing the governance complexity, the approach of this paper highlights the importance that SEN case studies are combined in comparative settings. Only then is it possible to meaningfully account for varying contextual factors in the analysis (Bodin et al., 2019; Sayles et al., 2019; Siciliano et al., 2020). Using single-case studies only, it would not be possible to identify trends across cases for different qualities of actor-issue paths. However, the comparative analysis of SENs in general and applying a qualitative meta-regression analysis to the ERGM results in particular also poses new challenges. First of all, the same ERGM-terms need to be applied to all models.

But even if the same ERGM-terms are used, significant differences can exist due to the uneven distribution of input values to the ERGM-terms. When I control for the activity area of actors, for example, the diversity is consistently higher for cases that cut across cantonal borders than for such located in one single canton. Further, there is a lack of robust measures for network comparisons tailored to SEN approaches (Bodin et al., 2019; Sayles et al., 2019). With this paper's approach of comparing different qualities of actor-issue paths across cases based on the concept of governance complexity, I take the first step towards advancing the comparative analysis of multiple SEN using the hypotheses-generating character of governance complexity in a qualitative meta-regression analysis.

By comparing the cases, I show that collaboration patterns in cases with high network endogenous and low exogenous governance complexity are, on average, better aligned with the issue network. While the impact of complexity on the achievement of fit has been discussed in some articles (Bergsten et al., 2014; Epstein et al., 2015a; Widmer et al., 2019), the impact of endogenous complexity based on the number of involved actors brings in a new perspective. While the level of fit generally increases when the actor-issue paths are easier to perceive – as is also shown in other literature on fit (Enqvist et al., 2020; Guerrero et al., 2015; Sayles & Baggio, 2017a; Treml et al., 2015) – this is not necessarily true for cases with only a few involved actors. However, this behavior might not necessarily have a negative impact on the governance outcomes, as in a situation of low endogenous complexity actors might be perfectly capable of identifying relevant actors for collaboration. Regardless, different qualities of actor-issue paths correlate with the probability of collaboration ties and therefore impact the achievement of fit. This is why I recommend including them in further analyses of fit, particularly in settings of low exogenous governance complexity. Furthermore, it would also be interesting to analyze how contextual factors influence the role of fit for deciding with whom to collaborate. Additionally, it would be worth looking more in depth at specific qualities of actor-issue paths and elaborate limits where actors stop perceiving actor-issue path qualities. Finally, whether the governance outcome benefits from a higher fit achieved in governance settings of lower complexity would also be an issue for future research.

It is also important to note that the results of this study are limited by several factors. First, the analysis is based on cases studies that are limited to Switzerland. Whether the results are transferable to other kinds of ecosystems and regions remains an open question. However, the underlying concept of fit has been applied in different contexts. Therefore, it can be assumed that the quality of actor-issue paths is generally also important for other cases. Second, the number of actors in the networks is rather low, which is likely to increase the uncertainties associated with the ERGM results (Foulley, 2019; Wasserstein et al., 2019). This can be compensated for to some degree by the qualitative meta-regression analysis that combines the eight cases of wetland governance. However, to further reduce the uncertainties associated with the ERGM results, larger networks with more actors would be needed. This again would have consequences for the issue networks that would become more complicated to conceptualize in larger case areas. Third, in this research, I do not account for the evolution of networks over time, and it should be acknowledged that only the observation of networks over longer time periods allows advancing the understanding of how the quality of actor-issue ties and collaboration patterns among actors dynamically co-evolve. Fourth, even though the study compares different cases of wetland governance, a statistical analysis of the differences among the cases is not possible without strongly increasing the number of cases. Still, the value of this study lies in it contributing evidence to the growing set of SEN studies and showing that different qualities of actor-issue paths can influence collaboration patterns among actors, and should therefore be included in further analyses of fit.

Who is satisfied with their inclusion in polycentric sustainability governance? Network embedding, power and procedural justice in Swiss wetlands

Abstract

Sustainability governance in polycentric systems needs to ensure both effectiveness and procedural justice. Effectiveness and procedural justice are intricately linked to power dynamics in governance. To assess polycentric sustainability governance, understanding different types, sources and effects of power is key. Here, we investigate network embedding of actors as a specific source of power in polycentric sustainability governance. Actors are embedded in networks they create through various types of interactions. Networks can be sources of power. Networks are also shaped by power relations. We ask two questions: How does network embedding translate into power? And: How is power associated with satisfaction with inclusion? We relate network embedding to power and satisfaction with inclusion in governance processes for 299 actors in ten cases of Swiss wetlands governance. Using a Bayesian multi-level regression model, we find that network embedding is a source of pragmatic and framing power for actors. In our cases, this is especially true for bonding social capital in networks. Further, network-derived power but also power sourced outside network embedding clearly translate into satisfaction with inclusion. Research and practice of sustainability governance need to be careful to account for power in nuanced ways, acknowledging its sources and relation to procedural justice.

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Introduction

One of the key challenges for humanity in the 21st century is effective and inclusive sustainability governance (Burch et al., 2019). Sustainability governance includes all action on common affairs of any collectivity (Clark & Harley, 2020) on issues related to sustainability related outcomes. Examples range from natural resource governance to urban mobility transformations or energy provision.

Sustainability governance often takes place within polycentric governance systems. In a polycentric governance system, governance activity is distributed across the system (Ostrom, 2010). A key contribution of the policy studies literature to sustainability governance has been to develop an understanding of structures and processes in polycentric governance systems and how effective these are in impacting sustainability related outcomes (Lubell & Morrison, 2021b). Next to evaluating effectiveness, research on sustainability governance is also paying increasing attention to questions of inclusion and procedural justice in polycentric sustainability governance (Okereke, 2018; York & Yazar, 2022).

In this article, we follow recent calls for unraveling the impact and function of power dynamics within polycentric governance systems (Berardo & Lubell, 2019b; Morrison et al., 2019a) in relation to inclusion and procedural justice. A key entrance point to study questions of inclusion are the individual actors who make up a polycentric governance system (Scott & Thomas, 2017). These actors are embedded within organizational networks including actors from all societal sectors (Bodin et al., 2019; Rhodes, 1996; Scott & Ulibarri, 2019) within an ecology of games, a larger environment of interconnected issues, venues and institutions (Lubell, 2013).

Our specific contribution in this article is to disentangle interrelations between *network embedding, power and inclusion* of individual actors in polycentric sustainability governance. Network embedding has often been conceptualized as a source of power for actors that exists next to openly authoritative sources of power (Mancilla García & Bodin, 2019a). In the context of the nuanced typology of power in polycentric governance systems developed in Morrison et al. (2019a), we propose that social capital derived from the position of an actor in a governance network (Berardo, 2014a) is relevant as a source of pragmatic and framing power.

More generally, the proposition that networks or relations (Lubell & Morrison, 2021b) somehow matter for outcomes on both the individual and system level is at the heart of why the literature on polycentric governance even cares about networks in the first place. The proposition of a link between network embedding and outcomes has however seldom been put into the context of a nuanced typology of power in polycentric governance and empirical tests for it are rare. We therefore see value in asking a first, fundamental question on the connection between network embedding and power:

1. **Research Question**: *How does network embedding translate into power in polycentric governance systems?*

We recognize that network embedding is both a source, but also a consequence of power. Governance networks are shaped by power by design (Héritier & Lehmkuhl, 2008), for example because governmental actors with formal authority are preferred collaboration targets (Leifeld & Schneider, 2012). However, networks are not exclusively shaped by power by design. Especially in highly polycentric systems, governance networks can open up additional avenues to attain network embedding derived power for actors both high and low in power by design (Mancilla García & Bodin, 2019a).

When it comes to questions of inclusion and procedural justice, understanding sources of power in polycentric governance is only a first step. The realization of actors' preferences for inclusion is not fully determined by power and different types of power may not translate into inclusion in the same way. In order to advance understanding on how power creates winners and losers (Morrison et al., 2019a; Scott & Thomas, 2017) in polycentric sustainability governance, we therefore go one step further and ask:

2. **Research Question**: *How does network embedding derived power influence satisfaction with inclusion in polycentric sustainability governance, compared to other sources of power?*

In a rare multi-case study of governance networks and outcomes on the actor level, we relate individual level satisfaction with inclusion in the governance process and measurements of power to governance network embedding for 299 organizational actors across ten cases of Swiss wetlands governance in a Bayesian multi-level, multivariate regression model. With regard to network embedding, we specifically distinguish the impact of bridging and bonding ties as two key features of social capital derived from network embedding (Berardo, 2014a).

Wetlands are prime examples for complex, polycentric sustainability governance settings. They are places where multiple, at times competing societal demands on a natural resource concentrate in space, including issues as diverse as flood protection, recreational use, hydropower production or biodiversity. Our governance networks include state, civil society and private sector actors engaging with these issues related to a given wetland.

Theory

Inclusion and effectiveness in polycentric sustainability governance

At this point in time, there is hardly any discussion of sustainability governance, which does not refer to the normative ideal that governance for sustainability must combine both inclusion and effectiveness. This is evident in high-level agenda setting activities in governance frameworks such as the United Nations 2030 Sustainable Development Goals (United Nations General Assembly, 2015) reports by large funding agencies like the American National Science Foundation (National Academies of Sciences Engineering and Medicine, 2021) or academic literature reviews (Burch et al., 2019; Clark & Harley, 2020).

Accordingly, questions of effectiveness and inclusion have been key topics of investigation in polycentric governance systems specifically. Actors in polycentric governance systems interact with each other across multiple decision-making venues (Lubell, 2013) characterized by a multitude of formal and informal institutional rules. Lubell and Morrison (2021b) recently introduced the concept of *institutional navigation* to study polycentric sustainability governance from the viewpoint of individual actors. Institutional navigation emphasizes individual agency. It provides an overarching framework under which to study how actors in polycentric governance system act and interact in order to achieve individual and collective goals.

Institutional navigation happens within complex systems composed of a large sum of interacting parts (Lubell, 2013) characterized by profound uncertainty (Burch et al., 2019). It is not surprising that Lubell and Morrison (2021b, p. 664) speak of an “art” that there is to such navigation. Many actors in polycentric governance systems engage seemingly effortlessly in institutional navigation, much as artists we admire practicing their craft. Institutional navigation entails that actors take a large number of conscious and unconscious, recurring decisions on how they engage in polycentric governance systems. Key among these decisions are which issues to tackle and which stance to take regarding them; which venues for policy-making to join (Angst et al., 2022); and which actors to interact with and in which fashion (Scott & Ulibarri, 2019). The outcome of these choices determines how effective an actor can be in reaching their goals. The combined choices of all actors in the governance system shape the system and produce overall collective outcomes.

The institutional navigation framework challenges the existing literature on sustainability governance to develop an understanding of effective institutional navigation. In our understanding, an actor is ultimately effective in navigating a polycentric governance system when they achieve their individual goals, according to their specific organizational interests, mandates and logics. However, as (Lubell & Morrison, 2021b) acknowledge, not all actors have access to the same portfolio of strategies to employ to achieve their goals. This brings questions of inclusion and procedural justice to the forefront, both as a subject of study as fundamental normative goals of sustainability governance (Okereke, 2018), as well as in relation to effectiveness.

Analytically, inclusion and power in institutional navigation can be approached from an individual and a collective perspective. On the individual level, the study of inclusion in institutional navigation covers the strategies actors can employ and constraints they face when it comes to both attaining power and increasing their likelihood for achieving their own preferences for inclusion in polycentric governance systems. On the collective level, the interest with regard to inclusion lies in systemic conditions and common patterns in actor behaviour that are associated with an increased likelihood for the realization of procedural justice as a systemic property. From this perspective, questions of trade-offs between inclusion and effectiveness might also become more apparent (Morrison et al., 2019a).

There is an important distinction between individual and collective perspectives in terms of the normative orientation of research questions related to institutional navigation. Questions of collectively effective and inclusive navigation are very much tied to normative goals of a governance system that manages to produce sustainable outcomes, including procedural justice, and how individual actors can contribute to this. Inclusion and effectiveness on the individual level however is in principle only tied to how actors achieve their own, specific goals. These may include goals seen as producing unsustainable outcomes by a majority of stakeholders or scientific consensus. In our understanding, research on institutional navigation in polycentric sustainability governance must study both levels in order to gain an understanding about institutional navigation on a general level. In other words, the study of determinants and the distribution of inclusion on the individual actor level is a crucial precondition to discussions of procedural justice but procedural justice can ultimately not be resolved on the individual level.

Power and its relation to inclusion in polycentric governance systems

Power is one of the richest concepts in social science and the nuances to which it has been explored are hard to do justice in an encompassing manner. Here, we follow Morrison et al. (2019a), who offer a helpful typology of power specifically in the context of polycentric governance. They broadly define power as the "the uneven capacity of different actors to influence the goals, process, and outcomes of polycentric governance" (Morrison et al., 2019a, p. 2) and distinguish between three main types of power. First, *power by design* is authoritative power, combining power and legitimacy, which is "written, legislated and visible" (Morrison et al., 2019a, p. 3). In governance networks, state actors with formal competencies to enforce existing legislation are an example of actors we usually expect to hold such power (Angst et al., 2018). Second, *pragmatic power* is tied to the discretion actors enjoy in the application or non-application of existing formal or informal rules in governance. For example, local organizational actors, such as municipalities, in governance networks often need to translate higher-level policies in cooperation with other local actors into action and can shape how a policy plays out on the ground decisively (Mancilla García & Bodin, 2019a). Third, *framing power* is a softer, less visible type of power, related to ideological framing of governance issues and related agendas by actors. For example, civil society organisations might exercise framing power by engaging in campaigns to portray certain social practices, like driving cars or supporting coal power plants, as literally dirty.

In polycentric governance systems, power asymmetries between actors for different types of power are the norm. Power asymmetries often lead to differences in inclusion on the actor level (Mancilla García & Bodin, 2019a; Morrison et al., 2019a).

A key theoretical framework to study the structural signatures of power and inclusion compatible with the actor-centred focus of the institutional navigation framework has been the ecology of games (EoG) framework (Lubell, 2013). Taking stock in 2019, Berardo and Lubell (2019b, p. 18) stressed how some EoG research (Mancilla García & Bodin, 2019a; Mewhirter & Berardo, 2019; Scott & Thomas, 2017) had started to illustrate how power imbalances can lead to unequal resource access in polycentric governance systems, which may perpetuate or deepen existing power asymmetries. On the system level, this may contribute to sub-optimal outcomes.

It is worth noting that Berardo and Lubell (2019b, p. 19) approach inclusion from an instrumental perspective in this context, calling mainly for further EoG studies that illuminate the causal chain running from power imbalances over system fragmentation to reduced capacity for collective problem solving. Properties of inclusion are not explicitly approached as non-negotiable normative goals in their own right, as they commonly are in procedural justice approaches.

Still, even in cases where properties of inclusion are seen as goals in their own right, power asymmetries need to be approached in a nuanced way and are not per se undesirable. Traditionally underrepresented actors may also make use of power asymmetries as alternative sources of power (Morrison et al., 2019a) within complex ecologies of games. In the case of the Paraíba do Sul river basin committee in Brazil, Mancilla García and Bodin (2019a) find that participation in a larger number of policy forums is related to increased perceived influence for a diverse number of actors beyond traditionally powerful actors with power by design.

Network embedding as a source actor power

We investigate a specific, but key actor-level feature of institutional navigation, which is network embedding as a source of power, and its relation with inclusion. We therefore focus on the relationships that actors build with other actors in governance networks (Bodin & Crona, 2009; Scott & Ulibarri, 2019). Put differently, we ask how features of the individual governance networks of organizational actors (their network embedding) translate into inclusion.

Table 6: Network embedding as a source of power (with examples in parentheses) in polycentric governance systems compared to power sourced outside network embedding by type (Morrison et al., 2019a) of power.

type of power	**source of power**		
	network embedding derived		**sourced outside network embedding**
	bridging social capital	**bonding social capita**	
by design no no yes (formal authority)	no	no	yes (formal authority)
pragmatic	yes (control over information flow)	yes (risk reduction in discretionary implementation through	yes (discretion in implementation)
framing	yes (information brokerage in shadow networks)	yes (trusted information source)	yes (control of one-to-many information distribution systems)

Table 7: Overview over hypotheses and associated processes developed and tested.

Hypothesis	**Process tested**
1	Network embedding (bridging) -> Power
2	Network embedding (bridging) -> Power -> Inclusion
3	Network embedding (bonding) -> Power
4	Network embedding (bonding) -> Power -> Inclusion
5	Network embedding (bridging x bonding) -> Power

We posit that network embedding is a source of pragmatic and framing power in polycentric governance systems and is a complement to power sourced in other ways. As a general differentiation in terms of mechanisms through which power is derived, we focus on bridging and bonding social capital (Putnam et al., 1992) generated through network embedding. We suggest that both bridging and bonding social capital derived from network embedding are sources of pragmatic and framing power (summarized in Table 6). Both pragmatic and framing power can however also originate from other sources. Power by design, by definition, is not sourced from network embedding.

The differentiation between bridging and bonding ties in social networks has a long tradition in social network analysis in general (Burt, 2000) and in environmental governance networks specifically (Angst et al., 2018; Berardo, 2014a; Bodin & Crona, 2009; Scott & Ulibarri, 2019). They describe two conceptually opposite ways in which individual actors in a social network can derive advantages from the way they are embedded in a network. We test a number of hypotheses about the influence of bridging and bonding along an assumed process running from network embedding as a source of power to its translation into inclusion. All hypotheses introduced in detail below are summarized in Table 7.

Bridging ties, akin to the "weak ties" made famous in (Granovetter, 1973) are ties that "bridge" different parts of a network. An actor with many bridging ties can use these to assume a broker role (Everett & Valente, 2016; Gould & Fernandez, 1989; Granovetter, 1973). Actors in brokerage positions are often hypothesized to gain an advantage in governance networks by being able to control information flows (Jasny & Lubell, 2015) and strategically influence policy processes (Ingold & Varone, 2012). As such, bridging social capital is an avenue for actors to pragmatic power. Bridging ties are also a likely avenue for actors to gain framing power, for example by brokering information in informal shadow networks (York & Yazar, 2022). Empirical tests relating bridging or brokerage positions to actor level outcomes in governance networks have however been relatively rare (Scott & Thomas, 2017). We therefore see value in testing the following two hypotheses, related to our overall research questions. The first bridging hypothesis tests the assumed link between bridging ties and increases in the two specific types of power we link to network embedding:

1. **Hypothesis**: *Network embedding characterized by high amounts of bridging ties is associated with increased pragmatic and framing power of an actor.*

The second bridging hypothesis is set up to test the degree to which power sourced from bridging ties is translated into inclusion.

2. **Hypothesis**: *Network embedding characterized by high amounts of bridging ties is translated via increased pragmatic and framing power into increased satisfaction with inclusion in the governance process.*

Bonding ties describe relations of trust and reciprocity within cohesive subgroups. The literature on civic engagement has long placed an emphasis on bonding social capital derived from bonding ties (Putnam et al., 1992). Bonding social capital, in its relation to trust, is therefore likely to be a source of framing power. Actors with high bonding social capital are likely to be trusted information sources, enabling them to frame governance issues more authoritatively within their subgroups.

As a source of pragmatic power, in governance networks, the importance of bonding ties has been emphasized for situations where actors need to rely on cooperation of others to solve governance problems but there is a high risk of non-cooperation or defection by other actors. The potential for gaining control in these situations through transitive structures associated with bonding ties has prominently been hypothesized in the so-called risk hypothesis as especially important in such contexts (Berardo & Scholz, 2010). Conversely, the risk hypothesis suggests that in situations of low risk or long established collaborations, bridging ties gain in prominence. There have been empirical results broadly supporting the risk hypothesis in different contexts (McAllister et al., 2015; Olivier & Berardo, 2022), although it is probably fair to say that many empirical settings are characterized by degrees of mixtures of high-risk and low-risk, as well as variance in bridging and bonding ties within networks. In terms of the role that bonding social capital may play as a source of actor power, the theoretical framework drawn up by the risk hypothesis would thus suggest that bonding social capital would be sought after by actors in high-risk situations.

Similarly to the bonding hypotheses, we draw up to hypotheses along the causal chain running from network embedding over power to inclusion. The first bonding hypothesis tests the assumed link between bonding ties and increases in the two specific types of power we link to network embedding:

3. **Hypothesis**: *Network embedding characterized by high amounts of bonding ties is associated with increased pragmatic and framing power of an actor.*

The second bonding hypothesis is set up to test the degree to which power sourced from bonding ties is translated into inclusion.

4. **Hypothesis**: *Network embedding characterized by high amounts of bonding ties is translated via increased pragmatic and framing power into increased satisfaction with inclusion in the governance process.*

Bridging and bonding ties are conceptually opposite, but they are not mutually exclusive. The social network of an actor can contain both bonding and bridging ties. The two types of ties may also interact. Actors combining both bridging and bonding have analogies in network science more broadly, for example in the concept of network hubs or super generalists in ecological networks (Olesen et al., 2007). Burt (2000) made the argument that social capital is indeed created by bridging ties that span structural holes but that it is local closure and bonding ties that make it possible to leverage this capital. Given this, we would expect actors combining bonding and bridging (without necessarily excelling in each) to be able to derive power from their network embedding:

5. **Hypothesis**: *Network embedding characterized by a mixture of bonding and bridging ties is associated with increased pragmatic and framing power of an actor.*

Network embedding as a consequence actor power

Both theory used to understand governance networks as a concept of governance and their actual manifestations are often strongly tied to notions of hierarchy (Wachhaus, 2012). As such, processes in governance networks often take place under a ``shadow of hierarchy'' (Héritier & Lehmkuhl, 2008). For example, strong governmental organizations have been shown to take key positions in network governance approaches supposedly marking a shift from top-down control to collaborative governance (Fliervoet et al., 2016), resource-rich actors participate above average in key venues of polycentric governance systems, such as policy forums (Angst

& Brandenberger, 2021), and the possibility of hierarchical interventions by higher-level actors shapes collaborative government arrangements (Zhou & Dai, 2023)

The recognition that networks are shaped by power is crucially important for analytical reasons. To analyze network embedding as a source of power as well as its influence on inclusion, it is necessary to adjust for power by design, given its influence on the shape of networks. Power by design is a clear case of confounding when analyzing the impact of network embedding on inclusion and power. Without taking into account power by design when analyzing the impact of network embedding, we cannot be sure if an association between network embedding and power or inclusion is actually a case of eg. high levels of power by design of an actor shaping their network embedding and in turn their potential for realizing their preferences for inclusion.

Methods

Cases

We selected ten cases of Swiss wetlands governance (see Figure 12) based on a four-step approach to ensure both comparability of governance systems within our sample and representativeness of the sample at the country level. Each case study includes one or more wetlands listed in the inventory for alluvial wetlands of national importance[14], which lists 326 areas in Switzerland that have outstanding importance for the protection of wetland systems.

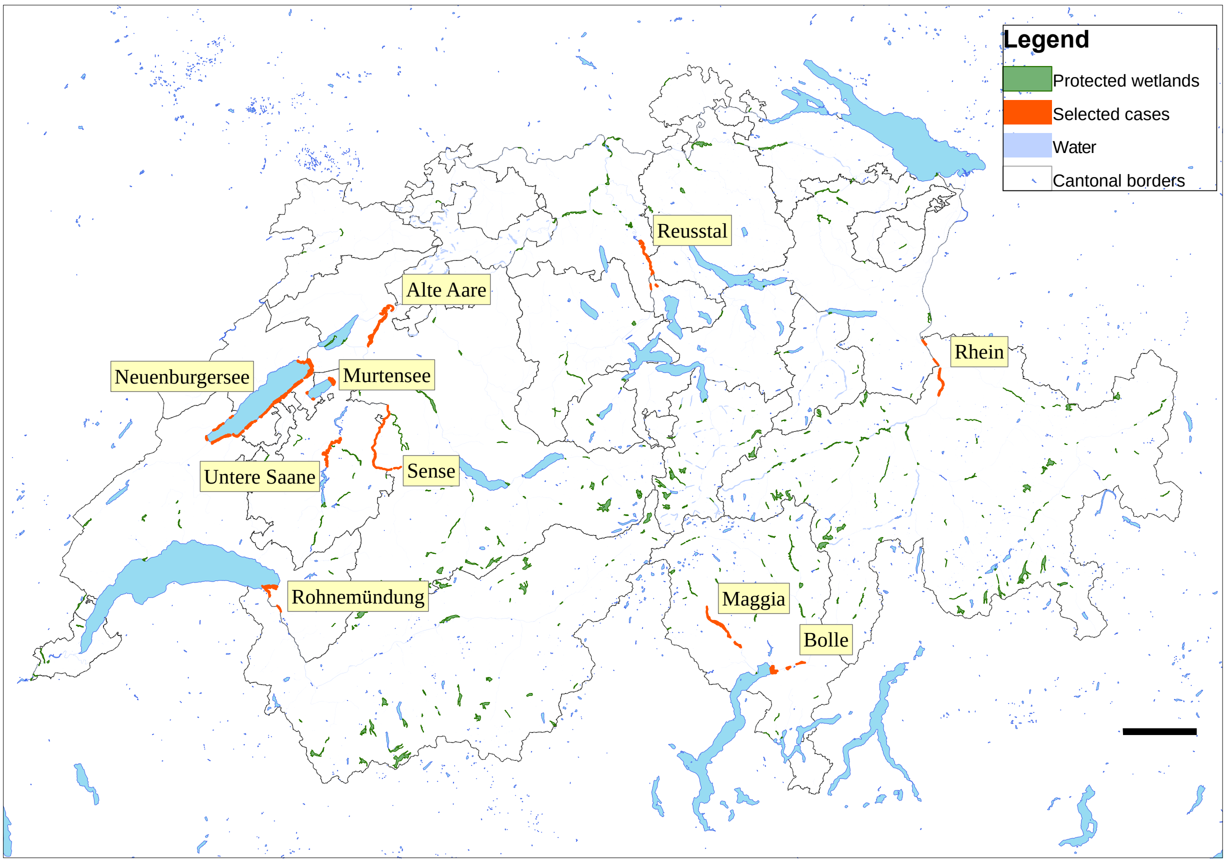

Figure 12: Overview over cases included in analysis across Switzerland.

[14] Dataset: https://opendata.swiss/de/dataset/bundesinventar-der-auengebiete-von-nationaler-bedeutung, last accessed 26.10.2022

First, we excluded wetlands located in remote areas such as the high alpine regions and only kept wetlands along rivers and lakes. Excluding wetlands in high alpine regions makes the remaining wetlands more comparable regarding relevant social, economic, and ecological management issues. Second, we grouped single wetlands into larger wetland systems based on their presence in river catchment areas and spatial proximity to other wetlands. Therefore, multiple separate wetland systems within one catchment area can exist. However, purely geographic case boundaries do not adequately cover the multi-dimensional nature of governance issues in wetlands (Moss, 2012). Therefore, we also included socioeconomic aspects (adjacent farming or upstream hydropower plants) to include further surrounding areas that form one functional unit for the governance of the respective wetlands. Third, the cases were selected to cover three of the four linguistic regions of Switzerland (German, French and Italian) and different cantons across Switzerland to account for geographical and socio-cultural diversity. Fourth, while half the cases are located entirely within one canton's territory (cantons are the constituent states and sub-states of Switzerland), the other half of cases cut across cantonal borders and are governed by multiple cantons. This reflects an important feature of governance in a federalist systems such as Switzerland.

From the wetlands that fulfilled these four criteria, we selected ten cases that are included in the analysis of this paper. Within those ten cases, we sent out online surveys (in German, French or Italian) to 521 actors that were identified to be relevant for wetlands governance through expert interviews and document analysis. 349 actors filled out the survey leading to a response rate of 67 %. Respondents per case ranged from a min = 26 to max =52 per case with a median of 32, which is broadly in line with many studies of other small to medium sized natural resource governance networks (Bodin et al., 2019).

Variables and measurement

Distributions and pairwise relations among all variables used in modeling are shown in Figure A27 in Appendix C.

Satisfaction with inclusion in the governance process

We use a straight-forward survey item to measure satisfaction with inclusion in the governance process for individual actors. Actors were asked on a four-point Likert scale whether they strongly agreed, agreed, disagreed or strongly disagreed with the statement “my organization is involved in decisions that have an impact on [name of the case] to a satisfactory degree” (exact German wording: “Stimmen Sie den folgenden Aussagen zu? a) Meine Organisation ist in Entscheidungen, die die [Name Fallstudie] betreffen, genügend einbezogen”).

Bonding and bridging

We collected fine-grained data of collaboration networks among actors involved in wetlands governance in each case. This network data forms the basis for our measurements of network embedding of individual actors, specifically their bonding and bridging social capital.

We asked survey respondents to choose from a roster of all actors per case the actors they collaborated with in wetland governance. Given this initial list of general collaboration, actors were then asked to qualify their relationships with their collaboration partners in two dimensions. They were asked in which specific issues (see section on priority issue status) the collaboration occurred, as well as whether the collaboration was positive (constructive), negative (difficult) or both. For the computation of bridging and bonding ties per actor, we symmetrized all networks using a weak criterion, therefore establishing an undirected collaboration tie for every dyad if at least one of the actors in the dyad indicated that the actors collaborated. We chose to do so primarily because it enabled us to take into account collaboration ties to non-respondents, leading to a more complete representation of the overall network structure in place, which is crucial for a valid computation of network embedding metrics. Network size including non-respondents in this way ranged from min = 44 to max =92 with a median of 64. All collaboration networks are plotted in Figure A28 in Appendix C.

To measure bonding social capital per actor, we use the number of closed triads an actor is involved in their positive, undirected collaboration network. A closed triad is a network constellation where three actors are all connected to each other. For an individual actor, a count of closed triads indicates the number of times their network contacts are themselves connected. This so-called transitive closure is a often used measurement for local density and bonding ties (Berardo & Scholz, 2010). For an individual actor, it indicates that the actor is part of a closely connected collaboration network of other actors with whom they have productive relations.

To measure bridging social capital per actor, we rely on a local measurement of betweenness centrality in each actor's collaboration network. Betweenness centrality is a classic measure of bridging potential for an actor and measures the amount to which an actor exclusively lies between other actors (Everett & Valente, 2016). Betweenness centrality for an actor is the sum of the fraction of shortest paths between every other pair of actors in the network that the actor lies on. As such, actors with high betweenness centrality provide efficient connections in a network, putting them in likely brokerage positions. We calculate betweenness for each actor based on their so-called ego network of order two (thus based on a network subset including all network contacts and their connections up to two contacts removed - collaborators of collaborators), as we argue that brokerage loses a lot of substantive meaning for connections that extend further (Angst et al., 2018). We used both positive and negative collaboration ties to construct our measure of bridging to reflect the fact that brokerage positions might also involve providing bridges among actors with conflicting views or in difficult collaborative settings.

We normalize bonding and bridging by case. This accounts for the fact that absolute numbers of triad counts and local betweenness are not directly comparable between cases as they may depend on the size and properties of the collaboration networks in each case. As essentially both measures are counts and strictly non-negative, we also log-transform them, as the log transformation in this case ensures a more natural scaling.

Ascribed general power

We measured an actor's general power over the governance process in each case by relying on the assessment of all other surveyed actors in the case. As such, we use an aggregate of dyadic influence attributions as a proxy (Ingold & Leifeld, 2016) for a generalized, relatively diffuse assessment of power.

Actors were asked to indicate for all other actors in the case (including actors they did not collaborate with) whether they considered them especially important for goal achievement in their priority governance issue (see below). We used the number of times an actor was indicated as influential by others to generate an individual score for ascribed power for each actor.

This diffuse measure of power potentially contains assessment of framing power, pragmatic power and power by design of actors. As such, put into relation with network embedding and inclusion, the measure on its own does not make it possible to make nuanced statements about how specific types of power are derived from network embedding nor how they influence inclusion. However, as we will outline in the causal model section, we will be able to approximate such statements by adjusting for a proxy for power by design.

Actor type as a proxy for power for design

Previous research on governance networks has shown repeatedly that actors with different institutional standing and on different jurisdictional levels face different opportunities and constraints in their ability to influence outcomes and processes of governance (Fliervoet et al., 2016; Héritier & Lehmkuhl, 2008; Kininmonth et al., 2015). In Swiss water governance contexts, especially higher-level state actors on the cantonal and federal levels are a key type of actor with generally high power by design (Angst et al., 2018), followed by local municipalities whose formal competencies in wetlands governance vary by issue area.

Given this, we included actor type as an actor attribute manually coded by the researchers involved in data gathering, combining the jurisdictional level and societal sector of an actor to approximate power by design of an actor. This leads to four main types of actors relevant for wetlands governance in our case. In order of decreasing average power by design, these were higher-level governmental agencies, local-level municipalities, local and higher-level non-governmental organizations, as well as an "other" category including mostly local companies and service provider

Priority issue status

It is likely that satisfaction with inclusion in the governance process varies by case, as some cases of wetlands governance, for example, face more pronounced levels of conflicts such as use conflicts. Beyond this, we suggest that satisfaction also varies across groups of actors based on the status of specific governance issues actors are interested in.

Natural resource governance systems, such as the wetlands we study, usually revolve around multiple, at times competing issues (Hedlund et al., 2021). Across all ten cases, we identified a total of 89 wetlands governance issues through exploratory expert interviews with 2-3 experts per case. Over a series of iterative coding rounds, these issues were grouped into 12 overarching wetlands governance issues, which formed the basis of the actor surveys in each case. Not all issues were relevant for each case, given bio-physical differences and differing usage patterns. For example, forestry and timber harvesting were only relevant in one specific case. Thus, not all issues appeared in every survey. Expert interviews were conducted several weeks before survey administration in each case. Experts were chosen to be representative of a wide variety of viewpoints in wetlands management and depending on the cases included state actors, private actors and NGOs.

Actors are likely to be more satisfied with their inclusion if they deem the status of issues they most care about to be positive. Many actors are specifically involved in wetlands governance in order to champion a specific issue and other issues are of secondary interest to them or do not concern them. This is especially relevant for the organizational actors we study, as many organizations, such as energy production companies, flood prevention agencies or local nature protection groups have a relatively well-defined single issue focus and follow associated organizational logics.

We focus on the top priority goals for each actor based on a survey question, where respondents were asked to rate how important issues were to them in a survey item that asked them to rank issues in order based on the question: "which goals in [case study name] are most important to your organization?" (exact German wording: "Welche Ziele an der [Name Fallstudie] sind für Ihre Organisation besonders wichtig?").

In order to assess how actors evaluate the status of their top priority issue we utilize information form a survey item that asked respondents to indicate how they rated the current state of goal achievement for each wetlands governance issue present in a given case on a three point scale ranging from “goal achieved”, over “neutral” to “goal not achieved” (exact German wording: “Unten sehen Sie mögliche Ziele für die Auengebiete an der [Name Fallstudie]. Wie gut werden diese Ziele Ihrer Meinung nach erreicht?”)

Causal model

We formalize the causal assumptions informing our modeling introduced in our theoretical framework in a directed acyclic graph (DAG) (Pearl, 2000; Shrier & Platt, 2008; Tennant et al., 2021). The DAG serves two purposes. First, to guide our model building by highlighting variables that need to be adjusted for confounding and second, to expose our assumptions to scrutiny. Figure 13, produced using *dagitty* (Textor et al., 2016) displays this graphically. To simplify the illustration bridging and bonding are subsumed under network embedding.

First, the DAG formalizes the two-step approach we take in our research design to disentangle the relation among network embedding, power and inclusion. The causal path running from network embedding to inclusion runs via power, illustrating that we need to model power both as an outcome (of network embedding) and a predictor (for inclusion).

Second, a crucial assumption we introduced in our theoretical framework exposed in the DAG is that network embedding can be a source of pragmatic and framing power, while power by design can only originate outside network embedding. Further, network embedding is both a source and consequence of power by design. As such, to isolate the total effect of social capital derived from network embedding for both power and on inclusion, we need to adjust for power by design, which we do by adjusting for actor type as a proxy.

Third, the DAG exposes how our measure of ascribed general actor power is diffuse and all three types of power load on it. Adjusting for power by design allows us to isolate the total effect of network embedding, but we cannot differentiate how much ascribed power sourced from network embedding is derived from framing power relative to pragmatic power.

Fourth, we assume that the priority issue of an actor has an effect on their satisfaction with inclusion in the governance process, given that in some issues, actors active in them have a higher (or lower) likelihood of being satisfied on average as the status of the issue starts from higher (or lower) baseline. One example for this are long-established, strictly regulated flood protection measures, where we generally expect higher levels of satisfaction than in more contested issues such as biodiversity protection. The same applies for the distribution of satisfaction with inclusion in the governance process across cases (eg. if procedural justice is higher on the case level). Given our DAG, these assumptions mostly matter in making it necessary to adjust for the priority issue of an actor in modeling satisfaction with inclusion as we also assume that the issue an actor prioritizes has influence on power (as some issue may for example be prioritized in legal frameworks). Not adjusting for priority issue opens a backdoor path from network embedding to satisfaction via ascribed power.

Fifth, beyond which issue an actor prioritizes, how an actor individually evaluates the status of the issues they prioritize matters for our causal model. We assume that priority issue status influences both an actor's satisfaction with inclusion in the governance process as well as, based on the risk hypothesis introduced in the theory section, their preferences for bonding or bridging social capital. This makes it necessary to adjust for priority issue status of an actor in addition to which issue an actor prioritizes per se.

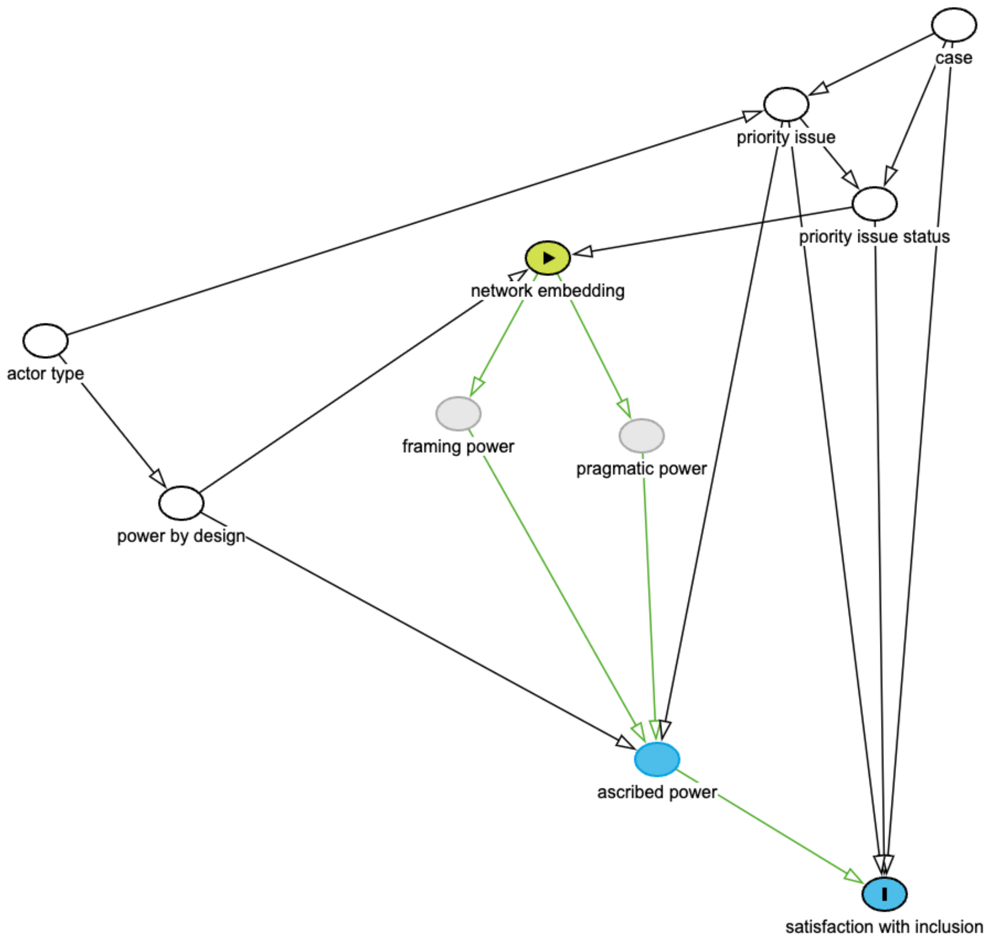

Figure 13: Directed acyclic graph illustrating the causal model assumed for analysis. For illustrative purposes, bridging social capital is set as exposure (green) and satisfaction with inclusion in the governance process as the outcome (blue). The green path illustrates the total effect of bridging social capital, given all variable with circles outlined in black are adjusted for. Grey variables are unobserved constructs.

Model specification

As we model power as both an outcome of network embedding and a predictor for inclusion, we utilize a multivariate model, combining two generalized linear models.

In the first part of the model, our outcome variable is ascribed power of an actor as a count of nominations as influential. As a count variable, we model it using a (zero-inflated) Poisson regression model. In the second part of the model, our outcome variable is satisfaction with inclusion in the governance process. It is an ordinal variable on a four-point Likert scale. In order to adequately model how it is associated with our predictors of interest we therefore use an ordinal regression model. Specifically, we use a cumulative ordinal regression model, which is a natural choice for the Likert or Likert-style variables we analyze (Bürkner & Vuorre, 2019).

Our analysis is a prime candidate for multi-level modeling: We analyze actors distributed across ten cases, while also taking into account that satisfaction may vary depending on the top priority issue of actors. Issues are nested in cases, but not all issues occur in every case.

Combining all of this, we use a Bayesian multivariate, multi-level regression model (Bürkner & Vuorre, 2019). In reporting the model in the following, we follow the recently proposed Bayesian Analysis Reporting Guidelines (BARG) (Kruschke, 2021). Table A14 in Appendix

C mirrors the list of key reporting points for the BARG in Kruschke (2021) and provides quick access to where the relevant points can be found within this article.

Returning to our multivariate model, in its first part we model ascribed power $y_{ascribed\ power_i}$ an actor i using a zero-inflated Poisson regression. We use a zero inflated model with a specific zero inflation parameter p_i for the chance of a zero outcome in addition to the λ_i for the shape, because we expect a high number of actors not to be nominated as powerful, given often concentrated power distributions in governance systems. The model is of the form:

$$
\begin{aligned}
&y_{ascribed\ power_i} \sim \text{zero} - \text{inflated} - \text{Poisson}(\lambda_i, p_i) \\
&\lambda_i\ = \\
&\alpha_{1[case]}\ +\ \alpha_{2[issue]}\ +\ \alpha_{3[case,issue]} + \alpha_{4[actortype]}\ +\ \alpha_{2[case,actortype]}\ + \\
&\beta_1 x_{bridgin}\ +\ \beta_2 x_{bonding}\ +\ \beta_3 x_{bridgin}\ *\ x_{bridgin}
\end{aligned}
\tag{1}
$$

For the second part of our multivariate model, we model satisfaction with inclusion in the governance process in a cumulative ordinal regression model. The model takes the following form to model the probability of each of our outcomes Y for an actor taking the ordered category value κ, given a linear predictor η,

$$
Pr(Y\ =\ \kappa|\eta)\ =\ F(\tau_\kappa\ -\ \eta)\ -\ F(\tau_{\kappa 1}\ -\ \eta) \tag{2}
$$

where F is the cumulative distribution function and τ indicates one of $K = 3$ thresholds, which split the assumed latent distribution of the outcome into the four measured categories. The linear predictor η encodes our hypotheses about the influence of ascribed power and power by design in the β parameters of the model. For our outcome of interest in this part of the model, satisfaction of an actor with their inclusion in the governance process, the linear predictor $\eta_{inclusion}$ is of the form:

$$
\begin{aligned}
\eta_{inclusion}\ =\ &\alpha_{6[case]}\ +\ \alpha_{7[issue]}\ +\ \alpha_{8[case,issue]} + \alpha_{9[actortype]} + \\
&\beta_4 x_{ascribed\ power}\ +\ \beta_5 x_{priority\ issues\ status}
\end{aligned}
\tag{3}
$$

The α parameters in both regression models stand in for a number of multi-level parameters of the model. We modelled varying intercepts for all multi-level blocks. We also modelled varying slopes between actor types for all main effects. We chose our final multi-level specification mainly based on comparing goodness of fit based on leave-on-out cross-validation (LOO) statistics between models with different degrees of varying effects. Generally, model fit improved in our models with the inclusion of varying effects, except for the zero-inflation parameter for the poisson model, which we did not model to vary for this reason. Varying zero-inflation (eg. across cases) did lead to a decrease in model fit, indicating that the variance from the baseline probability for zero inflation was already captured in the rest of the model.

The linear model in (3) does not contain a standard intercept parameter. In the ordinal regression model, the thresholds parameters τ_κ replace the intercept parameter and are estimated separately from the linear model. β_5 accounts for the effect of how actors assess the status of their top priority issue. As such, it models the effect of an ordered categorical variable and we use a monotonic effect to account for this (Bürkner & Charpentier, 2020).

Prior distributions and predictive checks

We use weakly informative normal(0,5) priors for all β parameters and normal(0,10) parameters for the α parameters of the model for ordinal regression model for inclusion. For the monotonic effect used in β_6, we relied on the *brms* default dirichlet(1) prior, assuming equal probability of increases in categories for all categories.

For the zero-inflated poisson model for ascribed power, all β parameters are estimated for variables on a log scale. In this context, setting weakly informative priors roughly translated to normal(0,0.25) priors. For the non-varying zero inflation parameter p_i we set a Beta(1,3) prior.

Figure A29 in Appendix C contains prior and posterior predictive checks of the model. These show that the priors used are indeed weakly (if even) informative. Before being updated with empirical data, the model does not predict the empirically observed outcome distribution well, but does stay within a sensible range. Prior predictions from the ordinal model overemphasizes the lowest and highest categories for satsisfaction with inclusion, while prior predictions from the poisson model overestimate zero inflation and occasionally predict nonsensically large values for power. After being updated, both parts of the model achieve high predictive performance, indicating that the data contains enough information to overwhelm the prior.

Two variables we use contained missing values. First, 14.3% of respondents (n = 50) did not provide an answer with regard to our main outcome variable, satisfaction with inclusion in the governance process. We excluded these respondents from the analysis (row-wise deletion). Additionally, 23.4% did either not choose a top priority issue or not assess the status of the issue. We imputed values for these respondents (if they were not deleted in the first step, leading to n = 56 imputed values) before model fitting using 20 multiple imputations in *mice* (van Buuren & Groothuis-Oudshoorn, 2011) In comparison to a model where row-wise deletion was applied instead, results did not change in any substantial way (the posterior distributions of of main parameters are compared for a model with and without imputation in Appendix C Figure A34 and Figure A35). As such we report the model without imputation for easier computational reproducibility.

Computation

We fit all models in the R (R Core Team, 2021) package *brms* (Bürkner, 2017, 2018). All modeling steps can be replicated using data and code provided in the open online repository.

We fit models using Markov Chain Monte Carlo (MCMC) to derive the posterior distribution, using 4 chains with 2000 iterations and a burn-in of 1000. $\hat{R}$ values were consistently one for all parameters, indicating that chains converged successfully. Tail effective sample size (ESS) was well above the recommended 400 (Vehtari et al., 2021) for all parameters and is reported for main parameters in Table A15 in Appendix C.

Posterior distribution

Figure A30 and Figure A31 in Appendix C show posterior distributions of the primary parameters of the model (parameter groups τ and β

Sensitivity checks
The posterior is not sensitive to alternative prior specifications. Introducing variation in prior settings by both making weakly informative priors broader or more restrictive, as well as for introducing variation to default prior settings does not fundamentally alter the posterior distribution of parameters (Figure A32 and Figure A33 in Appendix C). However, especially for broader prior distributions entailing a priori likely ranges of possible values well beyond what would make any substantive sense (such as ascribed power scores orders of magnitudes higher than what is possible for an actor to achieve), some alternative prior settings do lead to model fitting issues indicating non-convergence.

Results

Network embedding and power

Figure 14.a and Figure 14.b display the marginal and conditional effects (as posterior predictions) of bonding and bridging on pragmatic and framing power. Effects are illustrated stratified across different levels of power by design (approximated by actor type) and are generally robust in their trends across these levels. For bonding, a likely positive and substantial effect on pragmatic and framing power can be recognized. Bridging, however, has no discernible effect on actors' pragmatic and framing power.

Further, Figure 14.c illustrates a strong association of actors' levels of power by design with our measurement of ascribed power. Public actors and particularly higher level administration public actors, are assigned higher levels of ascribed power compared to other types of actors. However, the associated insecurity (captured in the 88% credible interval) is relatively high, indicating a clear trend but uncertain magnitude of the trend. Figure 14.c thus lends credence to our approach of controlling for power by design via actor type to estimate the effect of network embedding on pragmatic and framing power, as a testable assumption of our DAG.

Figure 14.d displays the results regarding hypothesis 5 about actors combining both high amounts of bonding and bridging social capital. We find indications that the interaction of both elements of network embedding is likely positive. However, the magnitude of the effects is so small, that it does hardly matter, which is especially visible on the outcome scale (as plotted in Figure 14.d).

Combined, the figure elements a, b, c and d show strong support for our hypothesis 3 on the importance of bonding ties as a conduit for pragmatic and framing power. For bridging ties, no clear effect on pragmatic and framing power can be recognized. As such, the hypothesis 1 is not supported by the results. Hypothesis 5 is also not supported by our results.

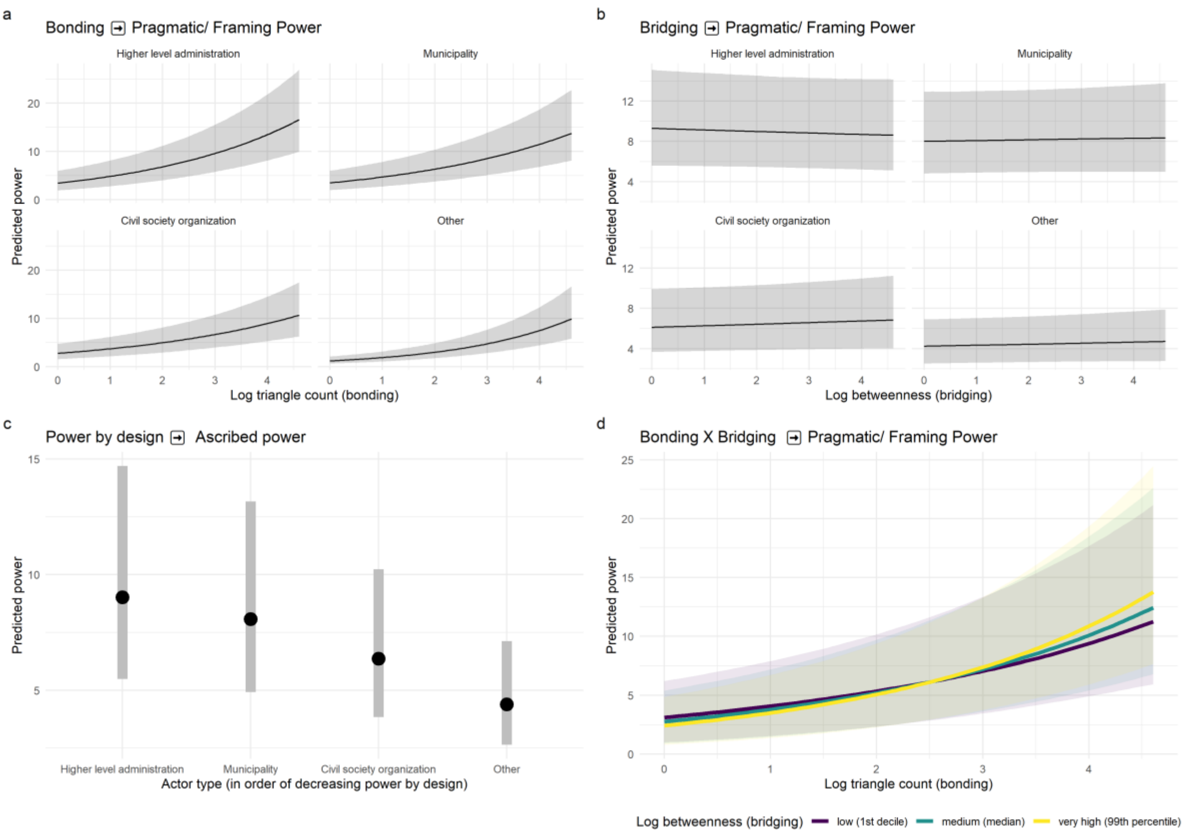

Figure 14: Bonding (a) and bridging (b) social capital as sources of pragmatic and framing power and association of power by design of actors with ascribed power (c). Grey areas denote 88% credible intervals.
a) Marginal effect of bonding, measured as log triangle count on pragmatic and framing power, by actor type.
b) Marginal effect of bridging, measured as log betweenness within an actor's ego network of order 2 on pragmatic and framing power, by actor type.
c) Conditional effect of power by design, approximated by actor type, on ascribed power.
d) Marginal effect of bonding by different levels of bridging in sample distribution (main effect plus interaction).

Translation of network embedding into inclusion via power

Figure 15.a shows the marginal effect of ascribed power on actors' satisfaction with inclusion in the governance process. The figure shows one vector of k of probabilities for every ordinal category modelled. These probabilities sum to one for every single configuration of inputs. k_i is then the probability of the i-th category, given the inputs. To interpret the figure, comparing the likelihood of an actor's satisfaction falling within the highest versus the lowest category with increasing ascribed power is illustrative. Our results quite clearly show that satisfaction with inclusion is a function of power.

The link established between network embedding and power can now be combined with the link established between power and satisfaction with inclusion to assess how network embedding translates into satisfaction with inclusion.

The Figure 15.b and Figure 15.c illustrate how bonding and bridging ties contribute to increasing the level of satisfaction with inclusion in the governance process through pragmatic and framing power. The figures show differences in the predicted distributions of satisfaction with inclusion for a comparison of two average, fictive actors with either low or high levels of bonding, respectively bridging ties, who are otherwise identical. Our result indicate that bonding ties translate markedly into satisfaction via power. For bridging, however, no effect can be found. We thus find support for hypothesis 4 and do not find support for hypothesis 2.

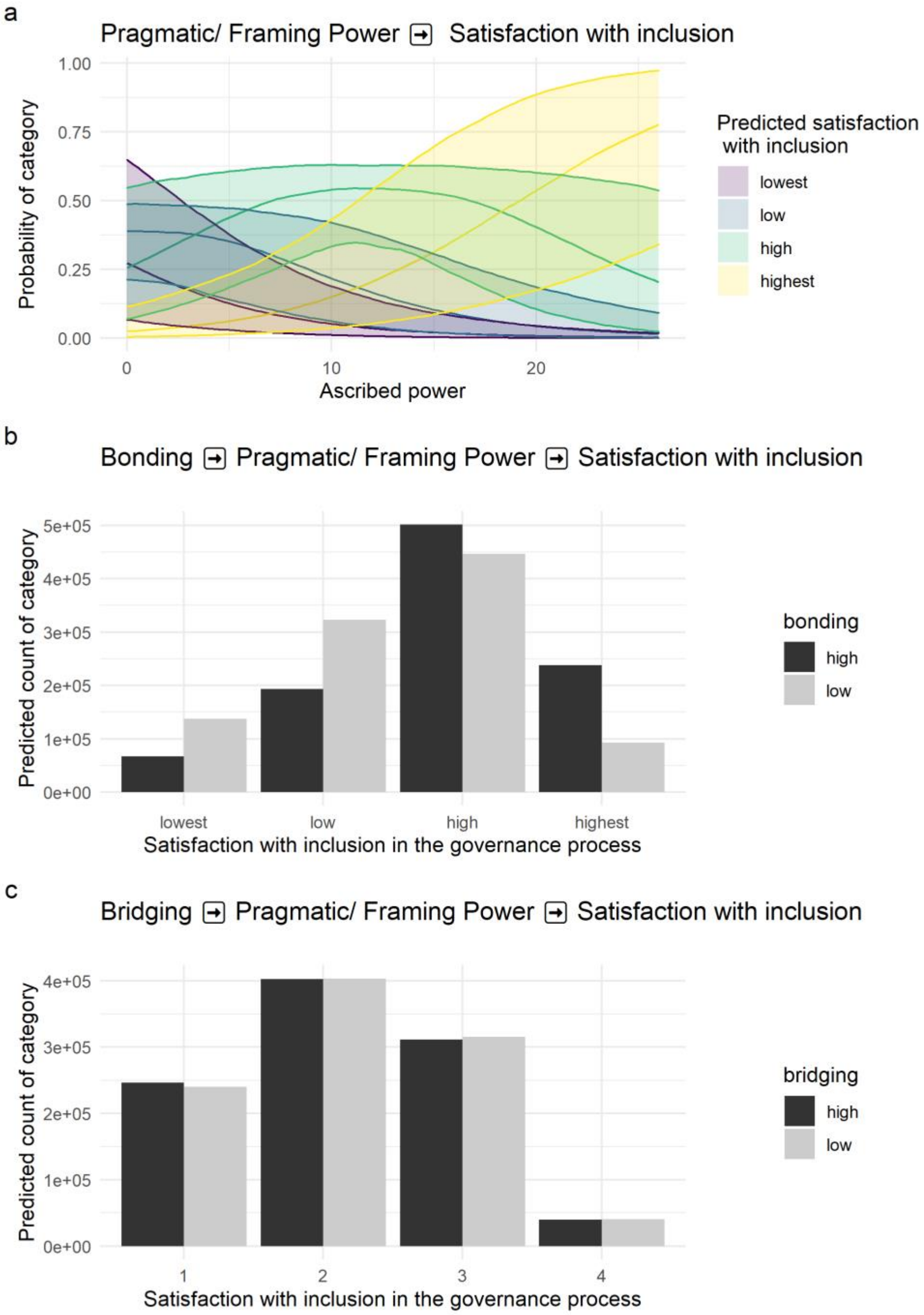

Figure 15: Effects (posterior predictions) of pragmatic and framing power (a) as well as bonding (b) and bridging (c) on satisfaction with inclusion in the governance process.
a) Marginal effect of ascribed power on satisfaction with inclusion in the governance process for an actor. Solid lines within ribbons show the median posterior density. Ribbons indicate the 88% credibility interval.
b) Translation of bonding, measured as log triangle count into satisfaction with inclusion in the governance process, via ascribed power. Example actor: Municipality in Reussebene case, priority issue biodiversity, all other characteristics at sample means. First differences between bonding at 2nd and 8th decile of sample distribution are shown. Predictions based on forward propagating predictions in the multivariate model based on 1000 draws from the posterior for the link between bonding and power.
c) Translation of bridging, measured as log betweenness within an actor's ego network of order 2, via ascribed power. Procedure analogous to b).

Discussion and Conclusion

Scientific knowledge of network governance processes and their relation to outcomes on a systemic level in sustainability and natural resource governance has been continuously growing (Bodin et al., 2019). There is considerably less evidence for how individual governance network embedding relates to actor-level outcomes (Lubell & Morrison, 2021b; Scott & Thomas, 2017). Our study adds valuable evidence about the relation between network embedding, power and satisfaction with inclusion in sustainability governance from a rare multi-case study design.

We have explored network embedding as a specific source and consequence of power in polycentric sustainability governance in this study. To sum it up, network relations matter as a source of power for actors in polycentric sustainability governance. We can clearly see effects of network embedding - independent of non-network derived power by design - across our ten cases.

Only particular types of network ties have a meaningful impact on power in our cases. Based on the results, actors who wish to maximize their power in polycentric sustainability governance in situations such as the ones we studied should benefit from focusing on bonding ties in networks. Bridging ties did not increase or decrease actors' power and neither is there clear evidence of an interaction effect where hub or super-generalist (Olesen et al., 2007) actors with many bridging ties would benefit dis-proportionally from them to leverage their bonding ties, as suggested in some network theories of social capital (Burt, 2000).

We should however be very careful in generalizing these insights. The importance of bonding compared to bridging ties could be a consequence of the high complexity of polycentric sustainability governance of Swiss wetlands, which entails associated risk for actors, shaping network structures and conditions under which actors operate (Berardo & Scholz, 2010). High complexity is commonly reported in polycentric sustainability governance settings and as such, the importance of bonding ties seems a credible result that might hold beyond our cases. However, it is important to keep in mind that our cases might simply be too small for actors to benefit from bridging ties. Our cases are all small to medium-sized cases of wetland governance where actors in brokerage positions might not enjoy the same leverage they enjoy in settings where actors are more socially distant from each other. As such, our results might just as well suggest that there is a likely scale dependency to how network embedding translates into power, which is an interesting avenue for further research on this topic.

In addition, the relevance of bonding might be particularly high in the Swiss context. Traditions of direct democracy and Vernehmlassungsverfahren (formalized consultation procedures) traditionally lead to many veto points in Swiss governance processes (Papadopoulos & Maggetti, 2018). In such situations, actors might have a natural incentive to form bonding ties to keep control over the decision-making process. In other case settings, this effect is likely to be less pronounced. In addition to a scale dependency, this also opens up a further dimension for research on the translation of network embedding into power that takes into account the influence of institutional settings or political systems more broadly (Metz & Brandenberger, 2022).

A key limitation of our study design is that we were unable to investigate the exact processes of how network embedding translates into pragmatic and framing power more deeply. We develop a theoretical understanding of the link between network embedding and power in this study. Combining this understanding with our ability to control for power by design, we are relatively sure, within the confines of our theoretical model, that we can demonstrate that network embedding is a specific source of framing and/ or pragmatic power. We are also relatively sure that bonding social capital plays a big role in generating power and satisfaction with inclusion in our cases.

Given our design, we could not distinguish the relative impact of network embedding on pragmatic versus framing power. Investigations into this link in complex governance system would be a welcome next step in assessing trade-offs involved regarding effective and inclusive polycentric sustainability governance systems on the collective level (Lubell & Morrison, 2021b; Scott & Thomas, 2017). We also could not investigate how exactly bonding social capital led to power for actors that was attributed to them by others in our cases. Further research should consider mixed methods or qualitative designs to investigate these questions.

Our findings provide relatively robust evidence that power, its type and source notwithstanding, is a key determinant of satisfaction with inclusion in the governance process. In light of questions of procedural justice, this is another illustration of a crucial normative challenge for polycentric governance systems. Recognizing that power asymmetries are the norm in such systems (Morrison et al., 2019a; Sayles et al., 2019), we need to balance effectiveness and procedural justice while taking into account the effect of power asymmetries on both.

For future research on the effect of network embedding on outcomes in governance systems, our study illustrates that it is crucial that we do not ignore power when assessing the effects of network embedding both for individual actors and at the system level. Governance networks are sources and results of power distributions.

For the practice of sustainability governance, the theoretical benefits of collaborative, polycentric, and networked governance arrangements at the systemic level are often argued to be increased legitimacy, effectiveness, and adaptiveness by including a diversity of actors. Given the role of governance networks as sources and results of power, our study shows, these benefits should not be taken for granted.

The link between social-ecological network fit and outcomes: a rare empirical assessment of a prominent hypothesis

Abstract

It is often claimed that the structure of governance networks influences governance outcomes. For environmental outcomes, network motifs of social-ecological fit have been linked to increased sustainability, but empirical tests of this link are rare. Social-ecological fit represents a situation in which different actors involved in the governance and management of linked ecological elements coordinate. Here, we test how motifs of social-ecological fit are associated with outcome assessments in ten cases of Swiss wetlands governance. To do so, we combine collaborative networks among organizational actors, ecological issue networks, and peer assessments of outcomes. Results show that – contrary to the prominent hypothesis – more fit is linked to worse outcomes. Drawing on the risk hypothesis, we argue that our surprising results likely highlight a complicated causal process between performance and adjustment to risk at play in the relationship between network structures and outcomes.

This is an original article submitted to Taylor & Francis in the Review of Society & Natural Resources.

This article was co-authored by: Mario Angst and Manuel Fischer. Martin Nicola Huber was the lead author.

Introduction

Societies have been facing the destruction of ecosystems around the world, which, among other consequences, also threatens human well-being (Reid et al., 2005). The concept of social-ecological systems (SES) emphasizes the crucial interactions of social and ecological systems, not only in terms of societal influences on ecological systems and vice-versa, but also in relation to the challenging management and governance of SES. Improving the governance of SES is key for sustainable development, in a broad sense, and the protection and restoration of ecosystems more narrowly. The governance of SESs can involve issues such as regulating the harvesting of fish stocks in rivers, lakes, or the sea, or managing the recreational use of forests, wetlands, or mountain areas.

SES governance often involves collaborative interactions among a large set of relevant actors. The literature on collaborative governance claims that the structures and types of collaborative interactions among actors influence outputs and outcomes (Lubell & Morrison, 2021b; Ostrom, 1990; Provan & Kenis, 2008). Networks are a way to operationalize and analyze collaborative interactions in SES governance (Kluger et al., 2020; Lubell et al., 2012). More specifically, multi-level networks that not only capture social interactions but also include ecological networks, as well as social-ecological interdependencies, have been proposed to study SES and sustainability governance (Barnes et al., 2019; Bodin et al., 2014; Felipe-Lucia et al., 2022a). Based on the theory of social-ecological fit (Bergsten et al., 2014; Epstein et al., 2015a) and similar to arguments in network and collaborative governance, collaborative interactions among actors that align with social-ecological interdependencies are expected to foster good outcomes.

Despite the increase in the number of studies dealing with fit in SESs and the governance of ecosystems, there are hardly any empirical studies on how different types or levels of fit influence governance outcomes (Bodin & Tengö, 2012; Guerrero et al., 2015; Widmer et al., 2019). Yet, it has been argued that specific structures of networks (for social-ecological networks motifs of social-ecological fit (Bodin et al., 2016)) have an influence on outcomes, either on the individual (e.g., actors success, (Scott & Thomas, 2017)) or the collective (better decisions, (Guerrero et al., 2015)) level. Given the prominence of the hypotheses of a link between network structures – and network fit in SESs more specifically – and outcomes, and the lack of empirical studies actually assessing that link, we ask:

> **Research Question**: *How do network motifs of social-ecological fit relate to governance outcomes?*

To answer this question, we rely on a multi-case study of ten cases of wetland governance in Switzerland. The networks include information on a) actors responsible for the governance of wetlands, b) ecosystem management activities of the present actors, c) issues representing social and ecological dimensions present in wetland governance, and d) governance outcomes characterizing the state of the wetlands. This information was gathered through a combination of document analysis, expert interviews, and online surveys. The ecosystem management activities represent the ecological nodes linked to each other by joint social and ecological dimensions. The availability of network data on SES governance that integrates social-ecological dependencies as well as governance outcomes offers a unique possibility to analyze the link between network motifs of fit and governance outcomes.

With this article, we contribute to the literatures on social-ecological systems, social-ecological networks, governance networks, collaborative governance, and ecosystem governance in four ways. First, we link data on governance processes to outcomes in a multi-level network, enabling us to empirically test the prominent hypothesis of the benefits of social-ecological fit. We thus propose a way to combine network motifs and outcomes. Second, the article provides new information for validating theories linking network patterns to governance outcomes (Lubell et al., 2012) based on the example of fit. Research on governance networks often claims governance efficiency or governance outcomes based on observed network patterns (Barnes et al., 2019; Bodin et al., 2016; Hamilton et al., 2019). Most of this research does not include empirical data that could be used to test for the theoretical link between network patterns and governance efficiency or governance outcomes (Bodin et al., 2019; Kluger et al., 2020) and particularly for network motifs of fit and governance outcomes (Epstein et al., 2015a; Guerrero et al., 2015; Widmer et al., 2019). Third, given this articles finding of a negative relation between network motifs of social-ecological fit and "good" outcomes, we link the arguments around social-ecological fit with arguments from the literature on collaborative governance. More specifically, the risk-hypothesis (Berardo & Scholz, 2010) suggests that actors form their networks depending on how they perceive the status of given issues they are dealing with, forming looser structures around low-risk and more closed structures around high-risk issues. Our results suggest that the causal pathway between network structure and governance outcomes is likely characterized by the simultaneous presence of adjusting to risk and forming performant structures. Fourth, our analysis goes beyond the study settings of most multi-level network studies of SESs, which focus on single case studies (Bodin et al., 2019; Kluger et al., 2020; Sayles et al., 2019) and accounts for differences across ten cases of SES governance.

Theory

The governance of interdependent environmental issues and multi-level networks

Complex governance settings such as those related to SES governance are characterized by multiple interdependent environmental issues (Hedlund et al., 2021), many parallel institutions and venues, and high levels of uncertainty (Burch et al., 2019). The SES framework by Ostrom (2007a) emphasizes collaborative, polycentric governance arrangements as a self-organizing system of many autonomous units that are in contact through processes such as collaboration, competition, or conflict (Ostrom, 2007c). Network theory provides conceptual and operationalizable background for analyzing SES governance and related actor interactions (Kluger et al., 2020; Lubell et al., 2012; Scott & Ulibarri, 2019; Wasserman & Faust, 1994a). Network approaches allow capturing the complex interdependencies among actors, as well as interdependencies between environmental issues or interdependent institutional rules. Multi-level networks in particular have grown in popularity for analyzing complex interdependencies of collaborative arrangements in SES governance.

In SES governance situations, actors collaborate across multiple venues to solve collective-action problems related to several issues at a time (Berardo & Lubell, 2019b; Lubell, 2013; Ostrom, 1990). Based on network thinking, the Ecology of Games (EoG) framework (Lubell, 2013) helps to identify relevant venues, institutions, and network structures relevant to SES governance (Berardo & Scholz, 2010; Hileman & Bodin, 2019b).

Furthermore, the successful governance of interdependent environmental issues requires actors to be able to identify the relevant environmental issues and their interdependencies and related network structures (Ostrom, 2007c). One approach utilizing multi-level networks to holistically analyze actor interactions and interdependent environmental issues in SES governance is the social-ecological networks (SEN) concept (Bodin et al., 2016; Felipe-Lucia et al., 2022a). The SEN concept builds on distinct social and environmental entities connected within and across network levels. Environmental entities can represent resources, ecosystem services, or biophysical characteristics of a SES. More recently, SEN analyses have started focusing on environmental issues (Bodin et al., 2019).

Social-ecological fit in social-ecological networks

The general theory (and terminology) of *fit* between ecosystems and the institutional arrangements set up for their governance (usually seen as normatively desirable) is well-established in the literature on natural resource governance (Folke et al., 2007). The main theoretical claim in the specific literature on social-ecological fit is that governance of SESs should be aligned across the social and ecological dimensions to improve governance outcomes. In a network conceptualization of such an alignment situation, two actors that both have a tie to the same or two connected entities of the ecological network levels would need to be connected in order to create fit (Bodin et al., 2016; Folke et al., 2007; Lebel et al., 2013; Widmer et al., 2019) (see Figure 16). An example of social-ecological fit for the wetland case study would be given by, e.g., two tourism operators that both provide river excursions and collaborate, as this can help distribute the visiting tourists better over one day and across different river parts, and thus prevent traffic jams during peak hours (see triangle motif on the top right of Figure 16). The interaction of actors related to one environmental issue supports the sharing of knowledge, facilitates learning from past governance mistakes, and consequently increases the resilience of the SESs (Lubell & Morrison, 2021b).

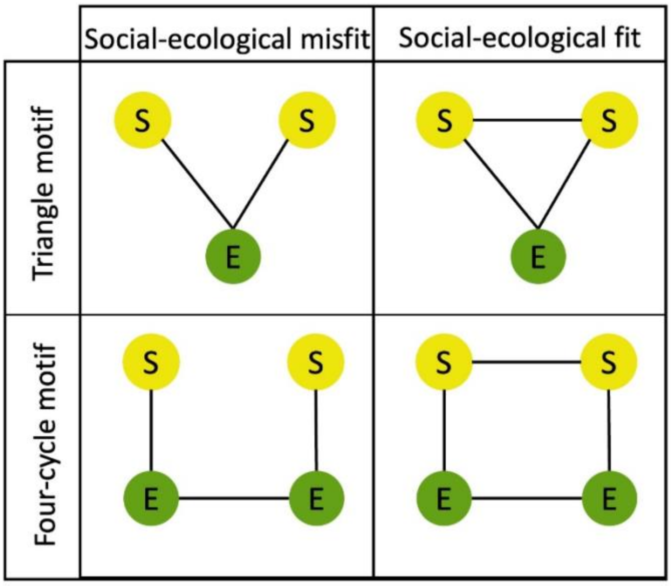

Figure 16: Illustration of triangle and four-cycle network motifs characterizing fit.

Research on governance networks often claims governance efficiency or governance outcomes are related to specific network patterns (Barnes et al., 2019; Bodin et al., 2016; Hamilton et al., 2019). Social-ecological fit is one way to identify network patterns that increase governance efficiency and benefit outcomes for the governance of SES. For example, Guerrero et al. (2015) analyze different governance challenges related to issues of social-ecological fit using network data from a biodiversity conservation initiative. The results show that actors indeed tend to collaborate to manage vegetation parcels – but only if actors manage the same parcels. As fit is essential for resolving environmental governance problems, the authors call for additional measures, such as collaboration across individual vegetation parcels, that increase fit for interconnected issues. Similarly, Bergsten et al. (2014) use a network approach to analyze interconnected wetlands in Sweden and how municipalities collaborate to manage these wetlands. As the authors identify only a weak social-ecological fit, the authors highlight the importance of meaningfully increasing collaboration between the municipalities to avoid isolated, disconnected wetland areas. Both Bergsten et al. (2014) and Guerrero et al. (2015), however, are mainly concerned with establishing network measures of fit and do not empirically measure governance outcomes in their case studies. Their studies are representative of the broader literature on social-ecological fit, as the link between fit and outcomes is often assumed a priori.

Also, in the broader literature on governance networks, there have long been claims linking network patterns and outcomes (Provan & Kenis, 2008; Raab et al., 2015). In structurally explicit studies, Carlsson and Sandström (2007) or Marwell et al. (1988) describe structural network properties such as density, centralization, and heterogeneity, as well as how they can benefit performance in collective action situations and help resolve issues in natural resource management. The underlying idea is that networks themselves are a type of resource that can be leveraged for the governance of SES. In an example of a more structurally implicit network study, Van Meerkerk et al. (2015) analyze the connective management of water governance networks and how such management influences the network performance of complex water projects in the Netherlands. Their water governance networks are not made explicit through formalization in terms of nodes and ties, but are rather based on different connective activities of governance actors. Analyzing connective management, they find that connective activities positively affect network performance in Dutch water projects.

The theory of fit is not limited to networks. It is also broadly used to analyze governance settings. The theory of fit can also be used more broadly, as fit does not necessarily have to be conceptualized based on networks to identify governance structures beneficial to the governance of SESs (Epstein et al., 2015a). For example, Haller et al. (2013) analyze institutional fit based on institutional change in pastoral commons in African floodplains using different theoretical approaches. Based on data from the precolonial and postcolonial times, they identify structural changes over time in the level of institutional fit. The results indicate that fit and misfit alternate but that some factors such as flexible institutions or mutual economic benefits under specific relations of bargaining power of actors can promote higher levels of fit. Lebel et al. (2013) similarly analyze institutional fit between institutional arrangements and features of ecosystems not based on networks but on different measures for water governance regimes. Those measures are then analyzed based on important dimensions of fit, such as allocation, integration, or adaption. Lebel et al. (2013) and Haller et al. (2013) both benefit from a research design that includes multiple comparable cases that allows them to make a statement about the impact of fit on governance outcomes controlling for case context. Especially in structurally explicit governance network studies of social-ecological fit, such comparable case studies remain rare.

Linking outcomes to social-ecological network fit

While the hypothesis of social-ecological fit being beneficial for outcomes is omnipresent (Bodin et al., 2016; Epstein et al., 2015a; Guerrero et al., 2015; Scott & Thomas, 2017), there are hardly any empirical studies that explicitly link an empirical measurement of fit to a measurement of governance outcomes (Bodin & Tengö, 2012; Epstein et al., 2015a). One reason for the lack of empirical data that links the fit to governance outcomes is the challenge of measuring governance outcomes, which is a predicate to successfully linking them to the existing theory of fit. Network conceptualizations can contribute to overcoming this gap by integrating data on governance outcomes into analysis (for example, see Schwartz et al. (2012)).

Hypothesis: *Network motifs characterizing social-ecological fit are associated with improved governance outcomes.*

The literature linking motifs of fit with an improvement in governance outcomes builds on the claim that network patterns influence governance outcomes (Folke et al., 2007; Guerrero et al., 2015; Widmer et al., 2019). The underlying causal assumption is that network motifs of fit (or network patterns in general) influence governance outcomes. In the same vein, research on SENs often implicitly assumes that the social system influences the ecological system rather than the other way around (Bodin et al., 2014; Widmer et al., 2019). Still, it is important to highlight that causality is likely to go both ways. While network motifs of fit might improve governance outcomes, the patterns in those networks are also influenced by their environment, such as the present ecosystem. In ecosystems defined by newly emerged dilemmas, collaboration patterns in networks are likely to differ compared to governance settings where the underlying dilemmas are constantly present over a long time (Berardo & Scholz, 2010; Scholz & Stiftel, 2010).

Materials and methods

Cases

We study the governance of wetlands. Wetlands are an important source of biodiversity in Switzerland (and worldwide). Even though wetlands only cover 0.7 % of the area of Switzerland, they are critical for the survival of many species (Müller-Wenk et al., 2003; Verhoeven, 2014). Though wetlands in Switzerland benefit from increasingly strict regulations and available funding for restoration projects, many wetlands nevertheless remain in poor condition (Müller-Wenk et al., 2003; Verhoeven, 2014). Here, we analyze ten cases of wetland governance across Switzerland. All our data is available and documented with additional details in Huber et al. (2022b).

We selected a set of ten wetlands for our study, broadly representative in terms of institutional settings at the national level, including all linguistic regions of Switzerland and a variety of cantons (the constituent states of Switzerland). Relevant wetlands need to show characteristic features of wetlands, such as a direct connection to a lake or river. Given our interest in wetlands governance, we also focused on cases with a high density of different social activities and excluded very small wetlands. Finally, the boundaries of the case studies are based not only on the geographical dimensions of the wetlands in question, but also include associated regions (e.g., close amphibian spawning areas or farming lands with potential spillover effects) that impact the governance of the wetlands.

The data gathering in the ten cases of wetland governance was structured in two phases. For the first phase of data gathering, we identified 3-4 actors for each case for exploratory expert interviews. The interviews focused on relevant governance outcomes and on how interdependent environmental issues influence those outcomes. Furthermore, we also gathered data on how actors influence governance outcomes based on different ecosystem management activities. Ecosystem management activities for wetlands are related to recreational activities such as fishing, the maintenance of paths in protected areas, or the operation of hydropower plants. In the second phase of data gathering, a customized survey was sent out to all state, civil society, and private sector actors identified as relevant for each of the ten cases. The surveys asked questions about actor collaboration and actors' involvement in the governance of the wetlands based on ecosystem management activities. Further, the surveys also included questions about the evaluation of the governance processes and outcomes.[15] Within those ten cases of wetland governance, 521 actors were identified to be relevant, and 349 (response rate 67 %) of those actors responded to the survey. Respondents per case ranged from 26 to 52, with a median of 32. This is roughly in line with other studies of small to medium-sized natural resource governance networks (Bodin et al., 2019).

Data structure

To test our hypothesis, we built a dataset of governance outcome assessments per actor for each governance outcome in an actor's case. For each governance outcome, we then calculated the proportion of closed versus open fit motifs associated with the outcome based on a multi-level network model. Table 8 shows how a typical record in our data looks in stylized form for some key variables.

Table 8: Assessments of governance outcomes by actors and associated share of open network motifs. Stylized example data.

Actor	Outcome assessment by actor	Share of closed versus open motifs associated with outcome	Case	Outcome
ORG001	Goal achieved	0.3	Reussebene	Timber harvesting
ORG001	Goal achieved	0.4	Reussebene	Biodiversity protection
ORG002	Goal not achieved	0.1	Maggia	Flood protection

Assessment of governance outcomes

The outcome assessment is the dependent variable of the analysis. The governance outcomes included in this analysis represent social and ecological dimensions relevant to the governance of wetlands (see Rhodes et al. (2020) for another example of how outcomes can be used to evaluate governance networks). The governance outcomes are evaluated based on the peer assessments of all relevant actors. Peer assessments are especially valuable for evaluating diverse elements at a comparable level if not much detailed information is available (Cebrián-Piqueras et al., 2017; Huang & Provan, 2007). The governance outcome assessment of the actors is based on one survey item where actors were asked to assess all the relevant governance outcomes in their particular case of wetland governance identified in the previous expert interviews on a scale from "goal achieved", "goal partially achieved", to "goal not achieved". The dependent variable is, therefore, an ordinal variable on a three-point rating scale giving information about actors' perception of the qualitative state of all governance outcomes present in an actor's case.

Conceptualization of multi-level networks

The multi-level networks for the ten cases (see Appendix D, Figure A43 for network illustration) build equally on survey data and expert interviews. The survey data is used to establish collaboration networks with actors as nodes and collaboration as ties for each case of

[15] For all survey questions relevant to this article, see Appendix D: Survey questions.

wetland governance. Collaboration between two actors exists if they indicated collaborating with other actors from a roster of all relevant actors. For the analysis of fit, the collaboration network is symmetrized using a weak criterion.[16] Symmetrizing the network using a weak criterion, we establish an undirected collaboration tie for every actor pair if at least one of the actors indicated to collaborate. The reason to symmetrize the collaboration network is that directionality usually is not considered in the literature analyzing fit (Bodin & Tengö, 2012; Guerrero et al., 2015; Widmer et al., 2019). Additionally, the survey data is also used to establish a network between actors and ecosystem management activities as the two types of nodes and ties between them when actors are involved in ecosystem management activities.

The data from the expert interviews are used to connect ecosystem management activities to environmental issues. Ties between environmental issues exist if they have a direct causal impact on other environmental issues. For the purpose of this article, the environmental issues are used to match ecosystem management activities. Therefore, ecosystem management activities have a connecting tie if they both impact the same environmental issues, but environmental issues themselves are not included in the multi-level network (see Appendix D, Figure A43 for illustration of network transformation).

The network of matched ecosystem management activities and actors is then used to identify triangle and four-cycle motifs characterizing the level of fit. Therefore, the ecosystem management activities, matched based on shared environmental issues, represent the ecological system, while actors and collaboration ties between them represent the social system. Further, network motifs of fit are connected to governance outcomes identified in the expert interviews. The governance outcomes are connected to a network motif if the relevant ecosystem management activities have a connection representing a causal effect on a governance outcome through one or multiple environmental issues.

We then end up with ten multi-level networks that characterize the wetland governance for each of the cases. Across all cases, 6319 triangles, 6091 four-cycle motifs, and 12 overarching wetlands governance outcomes could be identified. Some of the governance outcomes are present in all cases, while others are only present in a few cases, given differences in bio-physical structures and usage patterns. As all participating actors evaluated all relevant governance outcomes, we have a total of 1087 assessments of governance outcomes that can be used to evaluate the impact of network motifs of fit of the multi-level networks on governance outcomes.

Network motifs of social-ecological fit

We identify open and closed network motifs of fit within our multi-level network. The effect of fit is hypothesized to be strongest for small network motifs, such as triangle motifs or four-cycles (Guerrero et al., 2015; Widmer et al., 2019). The reason for our focus on smaller motifs of triangles and four-cycles is that actors' awareness of social-ecological interdependencies decreases with larger network motifs, as excessive complexity can hinder governance (Bodin et al., 2016; Huber, 2022). In a triangle motif, two actors are connected to one common entity representing the ecosystem. In a four-cycle, two actors are connected to two different entities of the ecosystem that are connected (see Figure 16). The triangle or four-cycle motifs are closed if the two actors collaborate together and therefore contribute to the fit. Further, for each

[16] Using a more restrictive criterion where a tie between two actors only exists if both actors indicated collaboration results in a highly disconnected collaboration network. However, also with such a disconnected network, the observed trends for network motifs of fit remain robust. For details, see Appendix D, Figure A42.

outcome, a separate variable is calculated for triangle and four-cycle motifs, indicating the share of closed motifs by motif type using the R package motifr (Angst & Seppelt, 2020).

Popularity of governance outcomes

To control for differences in the structural embeddedness of outcomes in the multi-level networks, we also include a measure of popularity of governance outcomes in the analysis. Popularity is a measure that functions as an indicator for the level of embeddedness based on the connecting ties of a node – here, outcomes – traditionally used in social network analysis (Robins et al., 2012). The popularity of a governance outcome, in our case, refers to the number of factors influencing the specific outcome. The underlying idea for the interpretation of the popularity of governance outcomes is that achieving good governance outcomes is more challenging in situations of high popularity when outcomes are dependent on many environmental issues that potentially have diverging effects (Waltner-Toews et al., 2008). In this regard, the popularity of outcomes is also a sign of governance complexity varying between cases and complexity varying between nested governance outcomes.

Variability across cases, actors, and governance outcomes

Furthermore, we control for actor, governance outcome, and case-level variability. Accounting for variability is essential in our case as the outcome assessment potentially fundamentally differs depending on the actor, outcome, and case at stake. For actors, a key source of variability is that some actors might tend to systematically assess outcomes lower or higher by internally referring to a different rating baseline. Another source of between-actor variability might be that assessments within one outcome category of high relevance to an actor might bias assessments in other categories. Further, also variability among governance outcomes is important to consider. For example, some governance outcomes might be of higher or lower priority, such as biodiversity versus security issues, or specific governance outcomes are more straightforward to achieve than others. Finally, it is essential to account for variability across cases as some cases are generally in a better condition in terms of outcome achievement than others. In our cases, particularly recent revitalization projects are likely to have a substantial impact on the assessment of governance outcomes or, more generally, on the level of conflict (e.g., use conflicts) present in the governance of a particular wetland.

Model specification

To analyze the dataset, we use a Bayesian multi-level ordinal regression model (Bürkner & Vuorre, 2019) to predict the likelihood of each category of governance outcome assessment by an actor based on the proportion of closed triangle and four-cycle motifs. For the reporting of the Bayesian analysis, we use the Bayesian analysis reporting guidelines (BARG) by Kruschke (2021) (for details, see Appendix D: Table A16 with key reporting points based on Bayesian analysis reporting guidelines).

The model's dependent variable is the assessment of governance outcomes captured as an ordinal variable. We use a cumulative ordinal regression model to model how network motifs of fit influence governance outcomes. Further, the model has a multi-level structure as the dataset includes actors' assessments of governance outcomes nested within ten cases for eleven outcomes.

The linear predictor η encodes our hypothesis about the influence of relevant network motifs of fit and popularity of governance outcomes in the β parameters. The α parameters stand in for the multi-level parameters of the model accounting for varying intercepts. For our outcome of interest, the state of governance outcomes, the linear predictor $\eta_{\text{governance outcome}}$ is of the form:

$$\eta_{governance\ outcome} = \alpha_{1[case]} + \alpha_{2[outcome]} + \alpha_{3[actor]} + \beta_{1\ triangle} + \beta_{2\ four-cycle} + \beta_{3\ triangle*four-cycle} + \beta_{4\ outcome\ popularity}$$

For the α and β parameters, we rely on weakly informative normal (0,5) priors[17] (Gelman et al., 2008). In Appendix D (see Figure A36), the model's prior and posterior predictive checks can be seen. Without empirical data, the model does not perform well in predicting the empirically observed outcome distribution. However, the predictive performance improves drastically when the model is updated with empirical data. Beyond model fit, this indicates that the observed results are mostly shaped by the empirical observations captured in the dataset and not by the prior choice.

We fit the model using Markov Chain Monte Carlo (MCMC) to derive the posterior distribution, using 4 chains with 10000 iterations and a burn-in of 5000. The potential scale reduction factor (PSRF) values (Brooks & Gelman, 1998) were consistently one for all parameters, indicating that chains converged successfully. The tail effective sample size (ESS) or, alternatively, the effective MCMC length was above the recommended 10000 (Kruschke, 2014) for all variables (for details on PSRF and ESS values, see Appendix D: Table A17). To calculate the models in R (R Core Team, 2021), the brms package (Bürkner, 2018) is used. All modeling steps can be replicated using the dataset and code provided in the open online repository.

Results

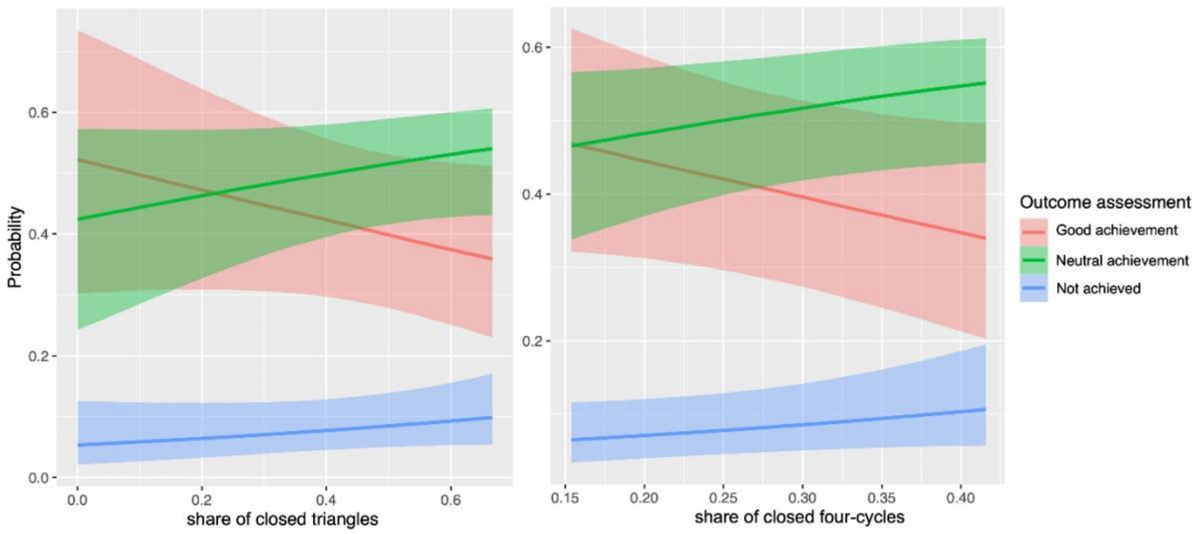

Figure 17: Marginal effects of the share of the closed triangle and four-cycle motifs on governance outcomes assessments. The probabilities of all three states of governance outcomes sum to one for every configuration of inputs. To interpret the figure, the likelihood of the state of a governance outcome falling within the highest versus the lowest category with an increasing share of closed versus open motifs of fit can be compared. Solid lines within ribbons show the median posterior density. Ribbons indicate the 88% credibility interval. The range of the x-axis differs for the share of closed triangles and four-cycle motifs as it is based on the empirically observed range.

[17] The posterior is not sensitive to more or less restrictive alternative prior specifications. For details see Appendix D Figure A40.

The marginal effects (posterior predictions)[18] of the Bayesian multi-level regression model (see Figure 17) indicate that an effect for the network motifs of fit on our measurement of governance outcomes can be identified. The identified trends are similar for triangle and four-cycle motifs for good, neutral, and poor governance outcomes. Differences between the network motifs can be recognized in the comparative share of the three states of governance outcomes, as triangle motifs are generally associated with higher shares of good governance outcomes and fewer shares of neutral and poor governance outcomes. As our primary interest is in the impact of open vs. closed network motifs on governance outcomes and not in the differences between different motifs, the description and interpretation of the results will focus on trends for the impact of motifs of fit on governance outcomes. As these trends are similar for triangle and four-cycle motifs, we will generally refer to network motifs of fit, and not distinguish between triangle and four-cycle motifs.

Based on the share of closed network motifs in Figure 17 the relation between closed network motifs and good and neutral outcome assessments appears particularly strong. For the probability of good governance outcomes assessments, higher shares of closed network motifs have a likely negative and substantial effect. For neutral governance outcomes assessments, a reverse effect can be identified as the share of closed network motifs has a likely positive effect, increasing the chance of neutral governance outcomes assessment. These observations indicate that the effect of network motifs of fit differs between the three states of outcome assessments.

For poor outcome assessments, the effect of network motifs of fit is relatively weak, which should, however, be put in the context of an overall low baseline level of occurrence of poor outcome assessments. The insecurity for poor outcome assessments is relatively big compared to the change of the slope, making the recognition of any clear trends difficult. Therefore, the interpretation and discussion of the results focus less on poor governance outcomes.

We can summarize that, unlike hypothesized, we observe a negative relation between closed network motifs and good governance outcomes, given our model. This effect is particularly strong for good governance outcomes, which are more likely to be present in the absence of closed network motifs, even though the absence of closed motifs indicates a social-ecological misfit. Therefore, even though the effect of network motifs on governance outcomes can likely be identified, the results do not support the hypothesis.

Discussion

Network research related to governance is constantly developing. Still, empirical evidence on the relation between network patterns and governance outcomes is rare (Bodin et al., 2019; Kluger et al., 2020). Our study provides valuable information on the relation between network patterns characterizing fit and the state of governance outcomes based on a comparative study of ten wetland areas in Switzerland.

Results show that network motifs are related to governance outcomes. However, unless hypothesized, the probability of good governance outcomes decreases with an increasing share of closed network motifs representing social-ecological fit. Our hypothesis is not supported by our empirical test, as we cannot find evidence for the oft-claimed influence of network motifs on governance outcomes.

The reason that the relation between network motifs of fit and governance outcomes has an unexpected direction might be due to our lack of temporal network data. Without temporal

[18] For a more complete picture of the posterior distribution for parameters not directly relevant to the hypotheses, see Appendix D, Figure A37, Figure A38, and Figure A39.

network data on the co-evolution of network motifs and outcomes, making any statement about the causality between both variables is difficult. Causality between network patterns and governance outcomes is likely to go both ways. The literature linking motifs of fit with an improvement in governance outcomes builds on the underlying causal assumption that network motifs of fit (or network patterns in general) influence governance outcomes (Folke et al., 2007; Guerrero et al., 2015; Widmer et al., 2019). In the same vein, research on SENs often implicitly assumes that the social system influences the ecological system rather than the other way around (Bodin et al., 2014; Widmer et al., 2019).

Yet, not only might governance outcomes be a result of network motifs of fit – as claimed in the literature on social-ecological networks – but network patterns can also be a result of governance outcomes and the surrounding ecosystem environment. In ecosystems defined by newly emerged dilemmas, collaboration patterns in networks are likely to differ compared to governance settings where the underlying dilemmas are constantly present over a long time (Berardo & Scholz, 2010; Scholz & Stiftel, 2010).

An effect of governance outcomes on network motifs of fit is likely as collaboration patterns are more flexible in adapting to the state of governance outcomes than vice versa (Bodin et al., 2014; Widmer et al., 2019). Following this line of thinking, we would first observe a change in motifs of fit based on collaboration ties adapting to the state of governance outcomes, and only then levels of social-ecological fit would influence governance outcomes.

Such logic would correspond with the so-called risk hypothesis by Berardo and Scholz (2010) that assumes a reverse effect of the governance setting on network patterns. The risk hypothesis suggests that in high-risk situations, bonding ties between actors gain in importance, while in low-risk situations, bridging ties are more important. The underlying assumption is that in high-risk settings, actors benefit from closely knitted network structures that create trust and allow for the punishment of defection, while in low-risk settings, actors favor the creation of bridging structures that solve coordination problems across distant parts of the network. Bridging structures in networks can be characterized by open triangles and bonding structures by closed triangles.

The level of risk associated with a governance setting can be characterized by different factors, such as the emergence of new policy arenas (Berardo & Scholz, 2010), the associated levels of environmental stress (Berardo, 2014b), or differences in agenda-setting behavior among actors (McAllister et al., 2015). The state of governance outcomes, as assessed in this article, could also indicate the perceived risk of governance settings. It can be assumed that poor states of governance outcomes are characteristic of higher levels of risk and good governance outcomes are characteristic of lower levels of risk. Based on this characterization of risk, a possible alternative hypothesis accounting for our findings could be that good governance outcomes imply low-risk governance situations characterized by bridging structures.

For example, an actor perceiving a poor state of water quality is likely to seek collaboration with other actors responsible for water quality. To address such a potentially conflictive and risky situation, actors – according to the risk hypothesis – create bonding and closed network structures. By contrast, in low-risk settings, actors likely favor the creation of more open network structures and bridging that link different environmental issues without the additional costs of many collaboration ties. If actors generally perceive an outcome to be good – e.g., water quality, they have little incentive to invest in an additional collaboration tie with actors related to water quality but might rather deal with the coordination between water quality and other environmental issues such as the use of pesticides close to waterways.

The risk hypothesis implying an effect of the state of governance outcomes on network patterns does not necessarily compete with the original fit hypothesis tested in this article, but both logics could co-exist. Indeed, it likely must be assumed that network patterns and governance settings relevant to the governance of SESs mutually influence each other (Berardo, 2014b). First, based on the risk hypothesis, high-risk settings characterized by governance outcomes in a poor state make the presence of closed motifs more likely. Later, based on the fit hypothesis, those closed motifs increasing the level of fit might benefit the improvement of the state of governance outcomes. Detecting such complex co-occurrence of different network logics would need observations of network patterns and governance settings over a longer period. Based on our empirical observations, we could not investigate different causal directions for the interdependence between network patterns and governance outcomes, but can only suggest the potential co-occurrence of both logics.

While the mutual influence of network patterns and governance settings is rarely assessed in empirical studies, relevant theoretical frameworks suggest that such effects exist. The SES framework (Ostrom, 2007a), for example, assumes that the governance system influences interaction situations between actors and that, at the same time, interaction situations also define the governance system. Similarly, Lubell and Morrison (2021b) highlight the importance of co-evolutionary dynamics of institutional navigation between actor networks and institutional structures. A goal for further research should be to fully account for such mutuality between network patterns and governance settings based on empirical network studies.

Conclusion

Our analysis of motifs in multi-level networks in ten cases of governance of ecosystems in Swiss wetlands provides empirical evidence of a link between network structures and governance outcomes. However, counter to both our hypothesis and a frequent claim in the literature, closed network motifs of fit are not associated with a higher probability of good governance outcomes. This finding does not mean that network motifs of fit cannot positively impact governance outcomes, but suggests that other mechanisms and directions of causality, such as proposed by the risk hypothesis, are also in play. Network research is thus right to justify its importance by potential relations to governance outcomes, but the relation is likely more complex than the simple assumption of “good” network structures leading to “good” outcomes.

To sum up, this article illustrates the inherent complexity of governance characterized by complex social-ecological interdependencies. The article further shows the benefit of network conceptualizations to account for such complexity and to design long-term governance strategies. However, for the meaningful interpretation of network conceptualizations, more research is needed linking theoretical network concepts of SESs, such as the theory of fit, with empirical data on the governance of ecosystems. This should be done in different contexts and taking different outcomes assessments into account. Research on the effect of network structure on SES outcomes could also greatly benefit from either observing networks and outcomes over time or testing the effects of network interventions (e.g., to increase fit) to better grasp causal mechanisms at play.

Multi-level network dataset of ten Swiss wetlands governance cases based on qualitative interviews and quantitative surveys

Abstract

The dataset of this paper originated from quantitative online surveys and qualitative expert interviews with organizational actors relevant to the governance of ten Swiss wetlands from 2019 till 2021. Multi-level networks represent the wetlands governance for each of the ten cases. The collaboration networks of actors form the first level of the multi-level networks and are connected to multiple other network levels that account for the social and ecological systems those actors are active in. 521 actors relevant to the management of the ten wetlands are included in the collaboration networks; quantitative survey data exists for 71% of them. A unique feature of the collaboration networks is that it differentiates between positive and negative forms of collaboration specified based on actors' activity areas. Therefore, the data describes not only if actors collaborate but also how and where actors collaborate. Further additional two-mode networks (actor participation in forums and involvement in other regions outside the case area) are elicited in the survey and connected to the collaboration network. Finally, the dataset also contains data on ecological system interdependencies in the form of conceptual maps derived from 34 expert interviews (3-4 experts per case).

Huber, M. N., Angst, M., & Fischer, M. (2022). Multi-level network dataset of ten Swiss wetlands governance cases based on qualitative interviews and quantitative surveys. Data in brief, 43, 108401. https://doi.org/10.1016/j.dib.2022.108401

Specifications Table

Subject	Social Science
Specific subject area	Governance of social-ecological systems
Type of data	Tables & Graphs
How data were acquired	Qualitative expert interviews across ten cases with 34 participants. Quantitative online surveys (see Repository/data_gathering) across ten cases with 371 participants.
Data format	Raw and partially filtered because of reasons of confidentiality.
Description of data collection	The goal of the sampling is to include the set of most important actors relevant to wetland management in the respective case study area. In order to arrive at this set of actors, we rely on a combination of decisional, positional, and reputational approaches (Knoke, 1993). From this initial set of actors, some actors that are exceptionally experienced in the local case study areas are selected for expert interviews. The expert interviews should give a qualitative overview of local wetland governance processes from different perspectives and complement the initial selection of actors. For the survey, all actors identified using the combination of decisional, positional, and reputational approaches, as well as additional actors that are mentioned to be relevant by experts, are included. The expert interviews were organized as semi-structured face-to-face interviews. Instead of transcribing the interviews, we used the experts' statements in the interview to construct a conceptual map that was also used to guide the interviews. An online survey to gather quantitative data on actor networks, activities, and additional characteristics was sent to all actors identified beforehand and a few other actors that were identified later during the survey process. Depending on the location of the case study area, the survey was made available in one or multiple of the following languages: German, French, and Italian. The case study areas are located in either German-, French-, or Italian-speaking regions of Switzerland or on the border of two language regions.
Data source location	Country: Switzerland Regions (see Figure 20 for map of cases): Rhein (Canton Graubünden / St. Gallen) Murtensee (Canton Freiburg / Waadt) Reussebene (Canton Aargau / Zürich / Zug) Rhonemündung (Canton Wallis / Waadt) Neuenburgersee (Canton Graubünden / St. Gallen) Sense (Canton Freiburg / Neuenburg / Waadt)

	Alte Aare (Canton Bern) Maggia (Canton Tessin) Untere Saane (Canton Freiburg) Bolle (Canton Tessin)
Data accessibility	Repository name: Zenodo identification number: 10.5281/zenodo.6907175 Direct URL to data: https://doi.org/10.5281/zenodo.6907175

Value of the Data

- The dataset is particularly useful as it combines social and ecological interdependencies into one multi-level network. Therefore, collaboration patterns can be analyzed using underlined structures of the ecological and/or social systems. Further, the multi-level networks are not only available for one wetland but across ten comparable cases. The comparative setting across multiple cases for multi-level networks of social-ecological systems is unique and allows to analyze the results within and across cases.
- All research interested in the governance of ecosystems and intertwined social-ecological systems can benefit from the dataset. While the separate analysis of the social and ecological systems included in the data is possible, the dataset is particularly valuable for researchers interested in the analysis of interdependent systems.
- The dataset is valuable to researchers who want to compare our analysis results on social-ecological networks with other cases around the world. Further, the nested structure of the multi-level networks enables the analysis of the dataset from multiple perspectives, many of which are not yet fully exploited. Finally, the dataset can also be used by researchers who want to perform a systematic review and meta-analysis study in the future.
- The dataset can be used to inform policy making in wetlands and, more broadly, for the governance of threatened ecosystems. Especially for policies that want to promote integrated, collaborative governance approaches, the data set gives valuable insights as it combines information on collaborative structures among actors with information on environmental interdependencies.

Data Description

We collected data from ten cases of wetlands governance in Switzerland that are presented in the form of a separate multi-level network for each case. For each case, face-to-face interviews with at least three local experts for the management of those wetlands were conducted. In the following, online surveys were sent out to all actors present in the wetlands and relevant for the wetlands governance. The survey structure was identical for all cases, but some of the questions were slightly modified to fit the particular case settings. The questions for the expert interviews, the online survey, all resulting datasets, and the codebooks describing the variables are available through Zenodo (see Table 9 for the structure of the dataset (Huber et al., 2022a)).

Table 9: Overview of datasets.

	Dataset ID	Data content	Data file name
Survey data	1	Node attributes of actors	dataset/1_na_actors.csv
	2	Edge list of collaboration networks	dataset/2_el_collab.csv
	3	Edge list of two-mode network actor-activity	dataset/3_el_actor_activity.csv
	4	Edge list of two-mode network actor-forum	dataset/4_el_actor_forum.csv
	5	Edge list of two-mode network actor-outside area	dataset/5_el_actor_outside.csv
	6	Edge list of power relations	dataset/6_el_actor_power.csv
Interview data	7	Node attributes of conceptual map	dataset/7_na_conceptual_map.csv
	8	Edge list of conceptual maps	dataset/8_el_conceptual_map.csv
Cases	9	List of cases	dataset/9_cases.csv
Supporting information	10	Codebook	codebook.csv
	11	Interview structure	data_gathering/interview_structure.pdf
	12	Survey structure (German)	data_gathering/survey_structure_de.pdf
	13	Survey structure (English)	data_gathering/survey_structure_en.pdf

Primarily, the dataset contains information to construct the multi-level networks from sub-networks across all cases. Network data on two unipartite (actor collaboration and conceptual maps) and two bipartite (forum participation and involvement outside wetland area of actors) is stored in edge list form containing a specific set of links and link attributes between network nodes. Second, two-node attribute datasets contain additional node attributes for nodes present within collaboration networks and conceptual maps. The dataset also contains supporting information on the data gathering, case information, and structure of the dataset.

The dataset is structured around the collaboration network of actors (Dataset ID: 2). Further, a conceptual map – or ecological network – exists that conceptualizes ecosystem interdependencies relevant to the governance of those wetlands (Dataset ID: 8). Additionally, three two-mode networks exist that are connected to the collaboration network (see Figure 18 for an illustration of the interdependencies between datasets). The first two-mode network has actors and activities as the two types of nodes, and ties indicate for which activities actors are responsible (Dataset ID: 3). Note that even though the networks from all cases are aggregated together, no ties between the cases are possible. The nodes in the second two-mode network are actors and forums, and ties exist when actors participate in a forum (Dataset ID: 4). The third two-mode network has actors and outside areas as the two types of nodes (Dataset ID: 5). Outside areas are wetlands not directly included in the analysis but located within the same region. A tie between an actor and an outside area exists if an actor is active in one or multiple of those outside areas. Further, power relations among actors are stored in a directed network dataset where a tie indicates that a sender perceives the receiver to be powerful related to a prioritized outcome of wetlands governance in a given case (Dataset ID: 6). Actors can perceive other actors to be powerful regardless of whether they share a collaboration tie or not. Additional to the network, multiple datasets contain information on the network nodes (Dataset ID 1 & 7) that are also mostly based on interviews and surveys. Besides the datasets ID 1-8 mostly based on interviews and surveys a separate dataset lists all the relevant cases (Dataset ID: 9). Finally, the last threethre datasets contain information on the interview and survey structure (Dataset ID: 11-13). For confidentiality reasons, any comments, qualitative data, or other personal information such as contact details of actors were removed from the dataset.

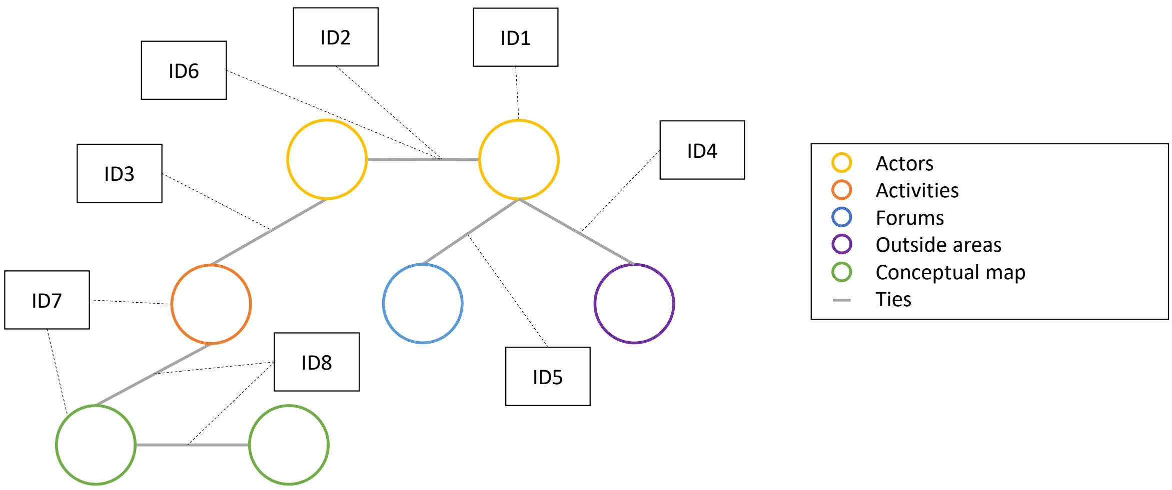

Figure 18: Illustrations of the interdependencies between the datasets.

1 Node attributes of actors – survey data

The survey participants were asked multiple questions that served to characterize the participants. Those questions can be grouped into two categories. First, the participants were asked to rank outcomes related to the governance of wetlands based on their prioritization and describe the state of those outcomes on a 3-point scale. Second, participants were asked if they agreed to some wetland-specific statements based on a 4-point scale. Further, some information that was easy to gather by the researchers and/or not possible to ask for by the participants was added manually. This includes information on (1) actor type (state actors, cantonal actors, municipal actors, NGOs, and associations, and others), (2) the region an actor is active in on the level cantons (the equivalent of states in the US), and (3) if actors responded to the online survey.

Not all of the questions mentioned above are relevant to all the survey participants as the statements are sometimes specific to one particular case. In such cases, "NR" indicates that those questions are not relevant for those specific actors.

2 Survey data – Edge list of collaboration networks

To elicit collaboration ties between actors, participants were confronted with a list of potential collaboration partners. Potential collaboration partners are actors that are present in the wetlands and directly or indirectly relevant to the management of the wetlands. Collaboration exists when actors exchange information, collaborate on projects, or if actors generally have worked together within the past three years. The participants could choose collaboration partners from this list but also add further collaboration partners if needed. Actors not included in the list of collaboration partners but still mentioned by multiple participants were in a follow-up also asked to participate in the survey. Further participants are also asked to indicate based on which ecosystem management activities they collaborate with other actors and if the collaboration is mostly positive or negative. Positive/Negative collaboration exists when participants agree/disagree with their indicated collaboration partner regarding management outcomes and approaches to reach those outcomes relevant for the indicated activity.

3 Survey data – Edge list of two-mode network actor-activity

In the survey, participants were confronted with a list of ecosystem governance activities present in the conceptual map of the specific wetland. Based on their answers, a two-mode network is constructed where actors can have one or multiple outgoing ties connecting them with ecosystem management activities. The actor-activity network can be used to connect the conceptual map (Dataset ID 7) with the collaboration network (Dataset ID 2). Information on the network nodes can be found in datasets ID 1 & 6.

4 Survey data – Edge list of two-mode network actor-forum

The survey also included one question where the participants could indicate from a list of forums where they participated or also add new forums to the list. Forums are organizations or platforms that enable cross-sectoral coordination; that is, they facilitate contact among actors from public administration, science, and public and private interest organizations. Based on the answers from the participants, a two-mode network with directed ties from actors to forums is constructed. Further information on the actor nodes can be found in dataset ID 1.

5 Survey data – Edge list of two-mode network actor-outside area

The survey also included one question where the participants could indicate from a list of wetlands outside the case areas but still in the same region if they are active there. Additionally, participants could also add new areas to the list. Based on the answers from the participants, a two-mode network with directed ties from actors to outside areas is constructed. Further information on the actor nodes can be found in dataset ID 1.

6 Survey data – Edge list of power relations among actors

In the survey, participants also had to indicate which other actors they perceived to be powerful for achieving the governance outcome that is most important for them. Actors could therefore choose from the same list of actors that are also potential collaboration partners regardless if they prior choose them as collaboration partners or not. For every other actor they perceive to be powerful, a directed tie exists. Further Infomation on the actor nodes can be found in dataset ID 1.

7 Conceptual map – Node attributes of conceptual map

The node attributes of the conceptual maps are based on three questions from the expert interviews:

1. The participants were asked what relevant outcomes to the management of the specific wetland are. Outcomes can be objectives to nature conservation and generally to activities present in the wetlands (e.g., biodiversity or recreational value). Also, the participants had to indicate how they would describe the state of the outcomes based on a 3-point scale. As the outcome state is only relevant for the outcome category, it is for all other categories in the dataset marked as not relevant ("NR").
2. Participants were asked which threats and chances (e.g., water quality or fish population) directly or indirectly impact the achievement of the governance outcomes mentioned before. Later threats and chances were combined to general factors.
3. The participants had to indicate which ecosystem management activities (e.g., fishing or hiking) influence the factors present in the wetland. The activities are later grouped into multiple categories (e.g., leisure-related activities) by the researchers.

For each case, outcomes, factors, and ecosystem management activities are elicited multiple times based on separate expert interviews and later aggregated by the researchers (see section Data gathering for further information on the conceptual maps).

8 Conceptual map – Edge list of conceptual maps

To construct the conceptual map (see Figure 19), the participants in the expert interviews were not only asked about outcomes, factors, and ecosystem management activities as described above but also about interdependencies between the three types of nodes. However, not between all types of nodes ties are possible. Activities can only have a tie to factors but not to other activities or outcomes. Factors can have ties to all the others nodes and also to other factors. Outcomes can have ties to all the others nodes but not to other outcomes. All ties are directed and are either positive or negative. However, the positivity/negativity of the ties is not based on the expert interviews but later added by the researcher. An example of a positive impact is the operation of a wastewater treatment plant that improves water quality. It is important to mention that the level of the factors is never specified, and the ties just describe a general increase/decrease but do not give any information about the actual level of the factors. As for the dataset ID 7, separate conceptual maps are elicited in the expert interviews and then later aggregated on a case level by the researchers.

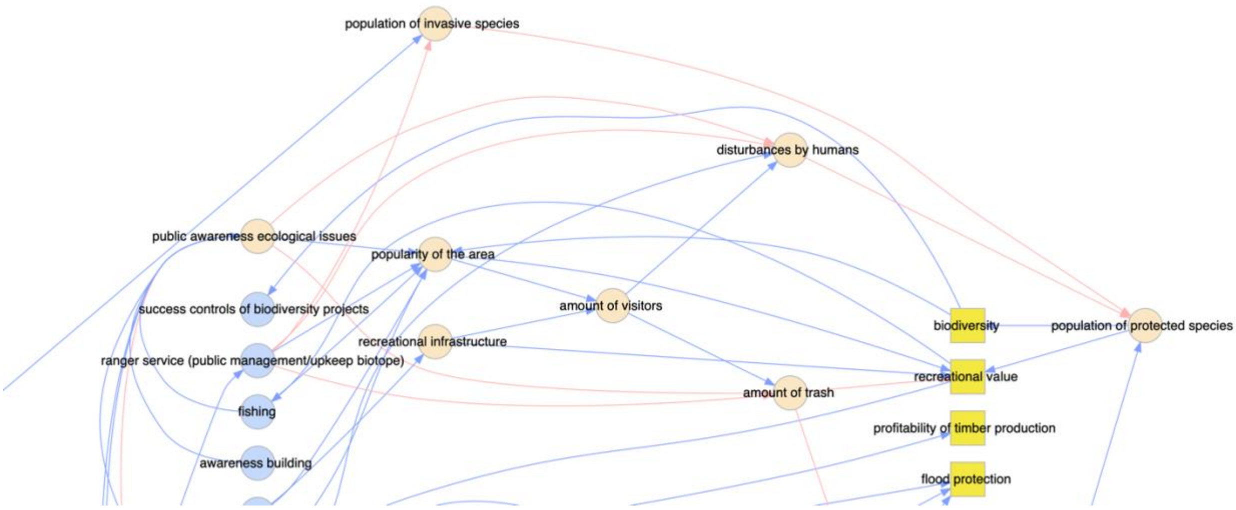

Figure 19: Cutout from the conceptual map from Alte Aare that shows how ecosystem management activities (blue), factors (orange), and outcomes (yellow) are connected by positive (blue) and negative (red) ties.

9 Cases – List of cases

This dataset gives basic information on the cases and the data gathering process. This includes information on the researchers responsible for the data gathering, the expert interviews, and further information on the case areas. Finally, also the shortcodes for the names of the cases are listed, which are used later in the other datasets when referring to individual cases.

10 Supporting information – Codebook

The codebook lists all column names of the datasets and gives information about the type of content and how the content needs to be interpreted. The information is grouped in four categories: 1) An identifier that specifies the relevant dataset, 2) The name of the variable, 3) The type of the variable (e.g., number or character), and 4) A short description for the interpretation of the variable.

11 Supporting information – Interview structure

The dataset ID 11 contains information about the organization of the semi-structured expert interviews. As the interviews are semi-structured, not a full transcript of the questions are listed but rather key elements and concepts that should be explained in the same way for all the expert interviews.

12/13 Supporting information – Survey translation

The dataset ID 12/13 contain information about the survey structure. To ensure the long-term availability of the dataset ID 12/13, not the original online survey, but a simplified offline version is provided where variables items are marked in square brackets. Dataset ID 12 contains the original survey version in German, and dataset ID 13 contains the English translation of it.

Experimental Design, Materials, and Methods

Case selection

We selected the ten cases of wetlands (see Figure 20) in Switzerland based on multiple criteria. First, only wetlands were considered that are listed in the inventory for alluvial wetlands of national importance (Bundesamt für Umwelt, 2014). This ensures that all areas show characteristic features of Swiss wetlands. Second, the case selection covers different regions and cantonal administrations across Switzerland to account for geographical and socio-cultural diversity. While some cases are located within one canton's administration area, other cases cut across cantonal borders and are governed by multiple cantons. Third, types of wetlands were selected that represent goal conflicts between societal, economic, and ecological interests. Therefore, the focus lies on river wetlands and wetlands along lakes, often located in densely populated areas. Finally, the wetlands' size was also a factor when deciding on the case selection of the wetlands. Small wetlands (< 0.6 km^2) were excluded from the study to avoid cases with only a few actors. To identify cases based on the criteria listed above, we used ArcGIS (Geographic Information System) (Esri, 2011). ArcGIS particularly supports the identification of cases of wetlands that are split up into different sections but still form one wetlands system due to factors such as spatial proximity or presence in the same river catchment areas. From the wetlands that fulfill all criteria, we selected ten cases across Switzerland that are included in the analysis.

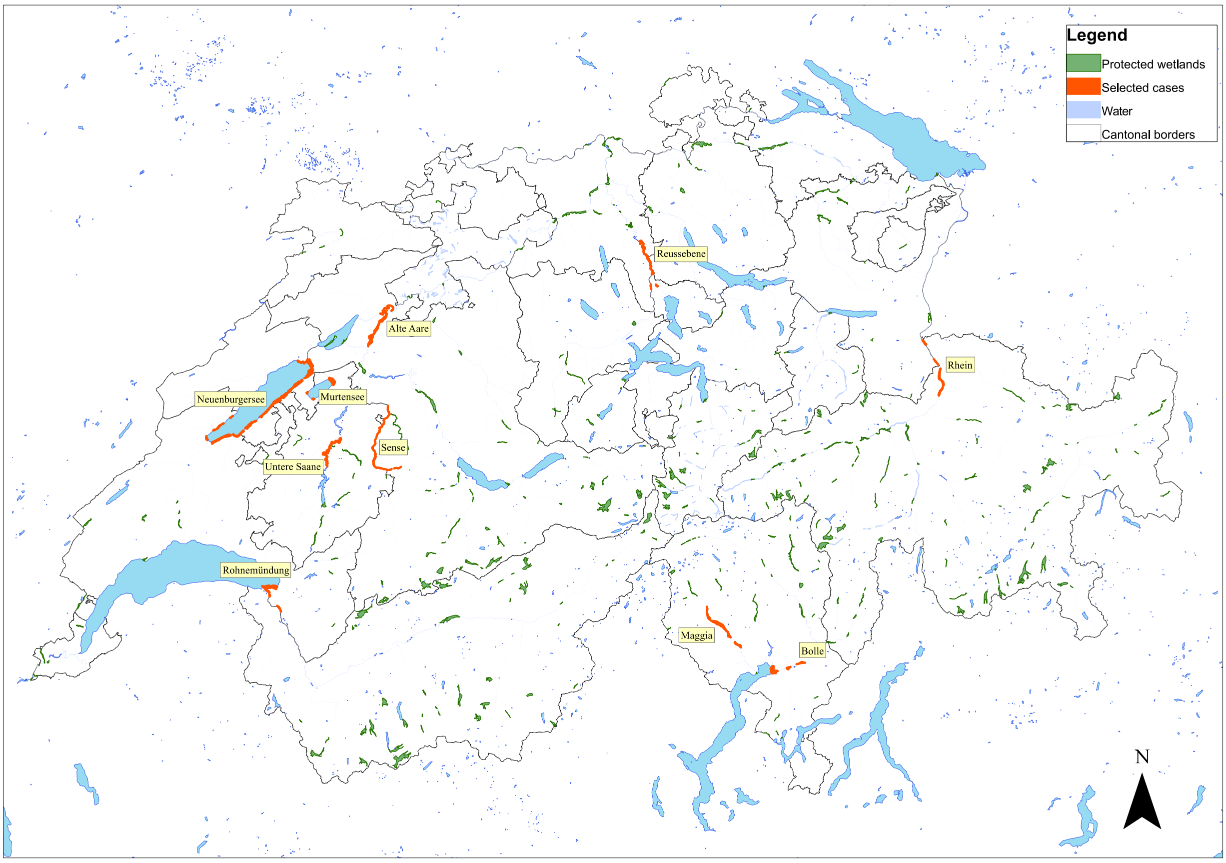

Figure 20: Map of Switzerland with the ten selected wetlands in red and other protected wetlands listed in the inventory for alluvial wetlands of national importance in green.

Data gathering

The data gathering was conducted in three phases from 2019 to 2021. The first phase of the data gathering aims to confirm the case areas and identify an initial set of relevant actors. To analyze the case-specific institutional settings, desktop research included documents, such as action plans, project reports, fact sheets, or monitoring reports. The case selection was also discussed together with the Federal Office of the Environment (FOEN) for its external validation. To identify an initial set of actors, we used a combination of decisional, positional, and reputational approaches (Knoke, 1993) to analyze the data from the document analysis. First, we identified actors with decisional power, that is, actors that participate in events relevant to wetland governance in the case areas. In line with the positional approach, we identified actors with formal decision-making positions in deciding about processes relevant to the wetland governance in the relevant areas. Those actors do not need to be present at events but can influence the decision-making process, such as the government or parliament. Finally, in line with the reputational approach, we validated the actors identified with local experts in the area. The combination of decisional, positional, and reputational approaches allows us to identify the most relevant actors for the cases.

The second phase of the data gathering is based on expert interviews with a limited number of experienced actors for each case. The experienced actors are selected out of the actor list from the initial data gathering phase. The selection of experienced actors is not based on quantitative criteria but should give a qualitative overview of local wetland governance processes from different perspectives. Therefore, we equally included cantonal, municipal, and private actors for the expert interviews. The expert interviews (for details on the structure of expert interviews, see Repository/data_gathering/interview_structure) were organized as semi-structured interviews aimed at developing a conceptual map of the area based on the Open Standards (OS) framework (Schwartz et al., 2012). The OS framework is applied and developed mostly by conservation practitioners to inform projects by structuring the governance of ecosystems as conceptual maps. Therefore, the OS framework is well suited to capture issues related to the governance of ecosystems. The conceptual maps are structured based on the categories of ecosystem management activities of actors, threats/chances (direct and indirect), management outcomes, and interdependencies between the latter ones. The threats and chance were later aggregated to factors (in some of the publications on the dataset, factors are also referred to as ecological issues). The individual conceptual maps from the expert interviews were later aggregated on the case level by the researchers. The aggregation of the conceptual map was done in a collaborative and iterative effort between the involved researchers till further iterations did not result in any changes anymore. Together with the initial analysis, the conceptual maps aggregate and illustrate the available case knowledge.

The case knowledge from the first two phases of data gathering is then used in the third phase to construct a survey (for details on the structure of surveys, see Repository/data_gathering/survey_structure) sent out to all previously identified actors relevant to the governance of the wetlands. To build the survey, we used LimeSurvey (LimeSurvey Project Team, 2015). The survey is mainly used to identify which actors collaborate for the governance of wetlands. Additionally, the survey also assessed the achievement of individual governance outcomes and which actors are especially influential in achieving those governance outcomes. Besides, the survey also explores how the participants perceive governance settings and if they agree with current governance decisions. Finally, the participants also had the chance to add additional actors, which were then also included in the survey if relevant.

Survey participation ranged from 26 to 52 across cases (median 32), which accumulates to a total number of 371 actors and a response rate of 71%. The number of actors in the dataset is, however, higher as all actors are included in the dataset regardless of whether they participated. To account for missing data due to the non-response but also as not all questions were answered by all participants, imputation should be considered. One way to do so is by imputing missing information using the mice package (van Buuren & Groothuis-Oudshoorn, 2011) in R to estimate incomplete multivariate data by chained equations.

Ethics Statement

All interviewees and survey participants were thoroughly informed about the content and the scope of the study before participation. Thus, informed consent was obtained from the participants prior to the interviews/surveys. Participation was completely voluntary. Moreover, the anonymity of the data is guaranteed by excluding all personally identifiable information of respondents. No further ethical approval was not needed as the participants represent organizations and not individuals. Therefore, no personal, sensitive information is included in the dataset.

CRediT author statement

Martin Nicola Huber: Data gathering (survey management and interviews), Data curation, Conceptualization, Writing manuscript

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships which have or could be perceived to have influenced the work reported in this article. The research leading to these results has received funding from the Swiss National Science Foundation (SNF) for the project: Ecosystem governance and socio-ecological networks in Switzerland: bringing politics back in.

Appendix

Table A10: Similarity and differences between the four research papers and the dataset Paper presented in the PhD thesis bases on the Papers type, cases involved, relevant research questions, how the data is conceptualized as networks, and the main methods used for the analysis.

	Paper 1	**Paper 2**	**Paper 3**	**Paper 4**	**Paper 5**
Type	Research article	Research article	Research article	Research article	Data article
Cases	1 case (water governance in Engadin)	8 cases (wetland governance in Switzerland)	10 cases (wetland governance in Switzerland)	10 cases (wetland governance in Switzerland)	10 cases (wetland governance in Switzerland)
RQs	1 & 2	1 & 2	1 & 3	1 & 3	-
Network type	Actors contact networks	Actor-env. issue networks (structure of fully articulated SEN)	Multi-level networks with actors, ecosystem management activities, and governance outcomes as nodes	Multi-level networks with actors, ecosystem management activities, and governance outcomes as nodes	Multi-level networks with actors, ecosystem management activities, env. Issues and governance outcomes as nodes
Method to analyze Networks	ERGMs	ERGMs	Bayesian models	Bayesian models	-

Appendix A – Cross-sectoral information and actors' contact networks in natural resource governance in the Swiss alps

Survey questions

1. Which of the following categories describe your organization best? (Multiple answers possible)
    a. Cantonal Office
    b. Cantonal Administration
    c. Municipal Office
    d. Municipal Administration
    e. Regional Association
    f. Local Association
    g. Private Company
    h. Other
2. How is your organization connected to water management?
    a. Public administration, politics[19]
    b. Energy
    c. Tourism
    d. Agriculture
    e. Ecology
    f. Other
3. In which Municipalities is your organization active / has your organization responsibilities?
    a. List with all municipalities of the Engadin.
4. How well is your organization informed on water management-related issues of actors in the following activity areas?

	very well informed	well informed	poorly informed	very poorly informed
Politics/Administration				
Energy				
Tourism				
Agriculture				
Ecology				

5. Please mark all the actors with whom you had contact based on your activities in the Engadin regarding the management of water.
    a. List with all relevant actors in the Engadin grouped into management sectors
6. Belief questions

[19] For the paper, we do not consider the sector of "Public administration, politics". This is as the sector of "Public administration, politics" is very general and often overlays with actors' activities in other sectors. The reason, therefore, is that actors that selected the sector of "Public administration, politics" are mostly political parties and administrative organizations on different organizational levels (e.g., municipal, cantonal).

a. Would your organization participate in:
   i. Meetings on the municipal level to coordinate activities or establish collaboration with actors from different sectors (public administration/politics, energy, tourism, agriculture, ecology).
   ii. Regional meetings to coordinate activities or establish collaboration with actors from different sectors (public administration/politics, energy, tourism, agriculture, ecology)
   iii. The development of a common strategy for water management (e.g., coordination of requirement for the utilization and protection of the water) on the local level.
   iv. The development of a common strategy for water management (e.g., coordination of requirement for the utilization and protection of the water) on the municipal level.
   v. The development of a common strategy for water management (e.g., coordination of requirement for the utilization and protection of the water) on the regional level.
   vi. The development of a common strategy for water management (e.g., coordination of requirement for the utilization and protection of the water) on the cantonal level.
b. How do you perceive future challenges for water management in the Engadin?
   i. Water management is based on the principles of sustainability, and goals are developed based on ecological, economic, and social criteria.
   ii. Long-term development goals are the fundament of planning.
   iii. The management of the water is based on transparent and understandable processes, including all the affected stakeholders.
   iv. For the development of goals, the interests for utilization and protection of available resources from all the affected stakeholders are included.
   v. For the mean of success control, to improve the existing system, for the mean of early detection of potential challenges, the water quality, and water-related infrastructure needs to be surveilled.
   vi. The cantonal and municipal administration, including other relevant stakeholder groups, has the lead for the water management and is responsible for the development of goals, planning, surveillance, and coordination of their realizations.
c. Do you agree to the further statements?
   i. Municipal autonomy is a problem for the sustainable management of water-related resources.
   ii. The water management should be split up based on administrative units (e.g., Municipalities).

iii. Climate change will strongly influence the water management in the Engadin for the 50 years to come.

Robustness test for operationalization of the contact network

Table A11: The table shows the ERGM results using a directed contact network instead of an undirected contact network. As the contact network is directed, we additionally distinguish between incoming, and outgoing ties for the variable of cross-sectoral information. As the effects of cross-sectoral information for incoming and outgoing ties are still positive and significant the ERGM results suggest that the results remain robust regardless of the conceptualization of the contact network.

	Estimate (logged odds)	**Std. Error**	**P-Value**
edges	-4.49	1.40	0
mutual	0.04	0.16	0.81
esp (1)	-0.42	0.14	0
H: Cross-sectoral information (nodeocov)	0.84	0.32	0.01
H: Cross-sectoral information (nodeicov)	0.80	0.33	0.02
CV: Sectoral information (edgecov)	1.44	1.2	0.2
CV: Interaction of cross-sectoral information x sector homophily (edgecov)	-0.37	1.26	0.77
CV: Sector homophily (edgecov)	0.43	0.44	0.32
CV: Beliefs – Integrated gov. (nodecov)	-1.30	0.33	0
CV: Beliefs – Integrated gov. (edgecov)	-0.82	0.42	0.05
CV: Beliefs – Long-term orientation of gov. (nodecov)	0.48	0.36	0.17
CV: Beliefs – Long-term orientation of gov. (edgecov)	0.38	0.33	0.25
CV: Beliefs – Multi-level gov. (nodecov)	-0.34	0.23	0.14
CV: Beliefs – Multi-level gov. (edgecov)	0.16	0.32	0.61
CV: Location homophily (edgecov)	0.59	0.20	0
CV: Type homophily (nodematch)	-0.01	0.13	0.93
CV: Municipal actor (nodefactor)	1.28	0.63	0.04
CV: Cantonal actor (nodefactor)	2.20	0.62	0
CV: Political party (nodefactor)	0.56	0.65	0.39
CV: Private company (nodefactor)	1.01	0.62	0.11
CV: Association/NGO (nodefactor)	1.5	0.63	0.02

Calculations of similarity matrices

$$\text{Euclidean distance metric} = \sqrt{\sum_{k=1}^{n}(x_{ik} - x_{jk})^2}$$

$$\text{Cosine similarity metric} = \frac{\sum_{k=1}^{n} x_{ik}x_{jk}}{\sqrt{\sum_{k=1}^{n} x_{ik}^2}\sqrt{\sum_{k=1}^{n} x_{jk}^2}}$$

x_i: Attribute i to be compared with j

x_j: Attribute j to be compared with i

r_k: range of variable k

Additional tables

Table A12: Explanation of the variables included in the ERGM.

Group	Name	Interpretation of positive coefficients	Implementation
Hypothesis	cross-sectoral information	*If actors active in a sector perceive themselves to be* informed *about other sectors, they are more likely to establish contacts with actors active in other sectors.*	nodecove [0-1]
Control Variables	Interaction of cross-sectoral information x sector homophily	Interaction between actors that are active in the same sectors and interact with each other, and the perceived cross-sectoral information	edgecove [0,1]
	Sector homophily	Actors active in the same sectors are more likely to collaborate.	edgecove [0-1]
	integrated governance	*Actors with similar beliefs are more likely to establish contact than actors with dissimilar integration-related beliefs*.	edgecove [0-1]
	long-term orientation of governance		edgecove [0-1]
	multi-level governance		edgecove [0-1]
	Integrated governance	*Actors with the same level of support of related measures are more likely to establish contacts with other actors*.	nodecove [0-1]
	Sustainable governance		nodecove [0-1]
	Multi-level governance		nodecove [0-1]
	Sectoral information	*If actors perceive themselves similarly informed about sectors, they are more likely to establish contacts with others.*	edgecove [0-1]
	Type homophily	Similarity in the type of actors increases the chance of a common tie.	nodefactor/ nodematch [Municipal actor, Cantonal actor, Political party, Private company,

			and Association/NGO]
	Location homophily	Similarity in the activity areas of actors increases the chance of a common tie.	edgecove [0-1]
	Number of edges in the network	Number of edges in the network.	edges
	Triadic closure by number of edgewise shard partners	Triadic closure by number of edgewise shard partners.	esp

Additional figures

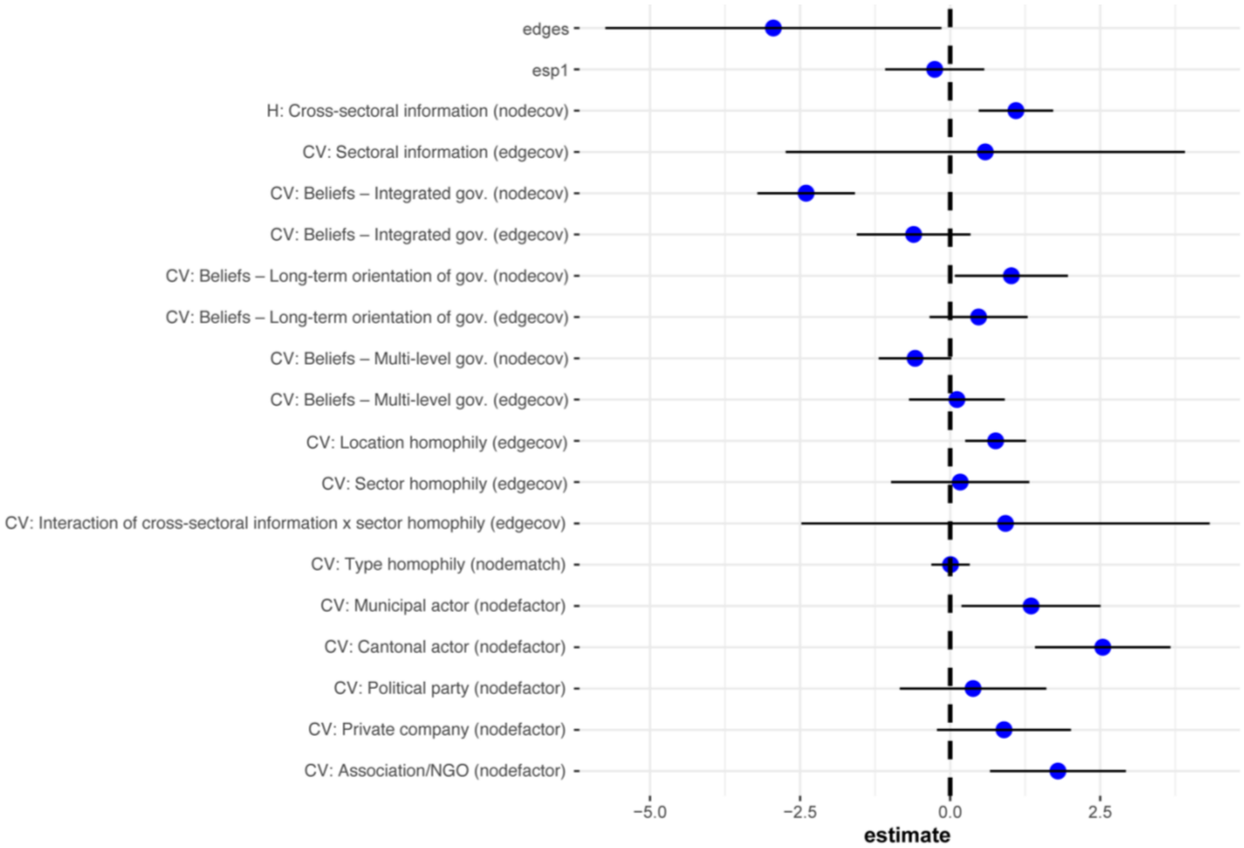


Figure A21: Coefficient plot of ERGM results.

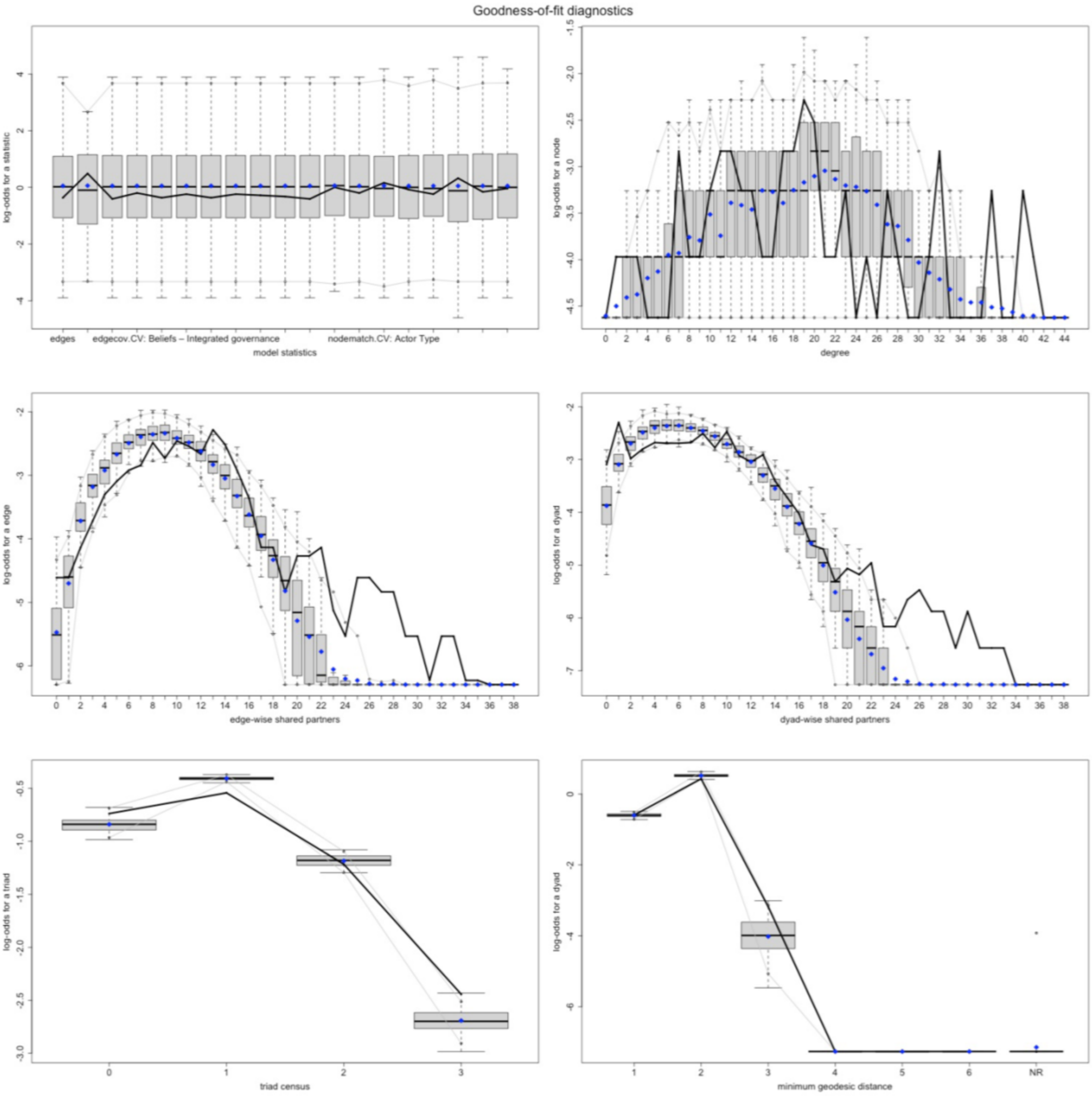


Figure A22: GOF for the ERGM.

Appendix B – How the qualities of actor-issue interdependencies influence collaboration patterns

Further information on data gathering and data conceptualization

Location of selected wetlands

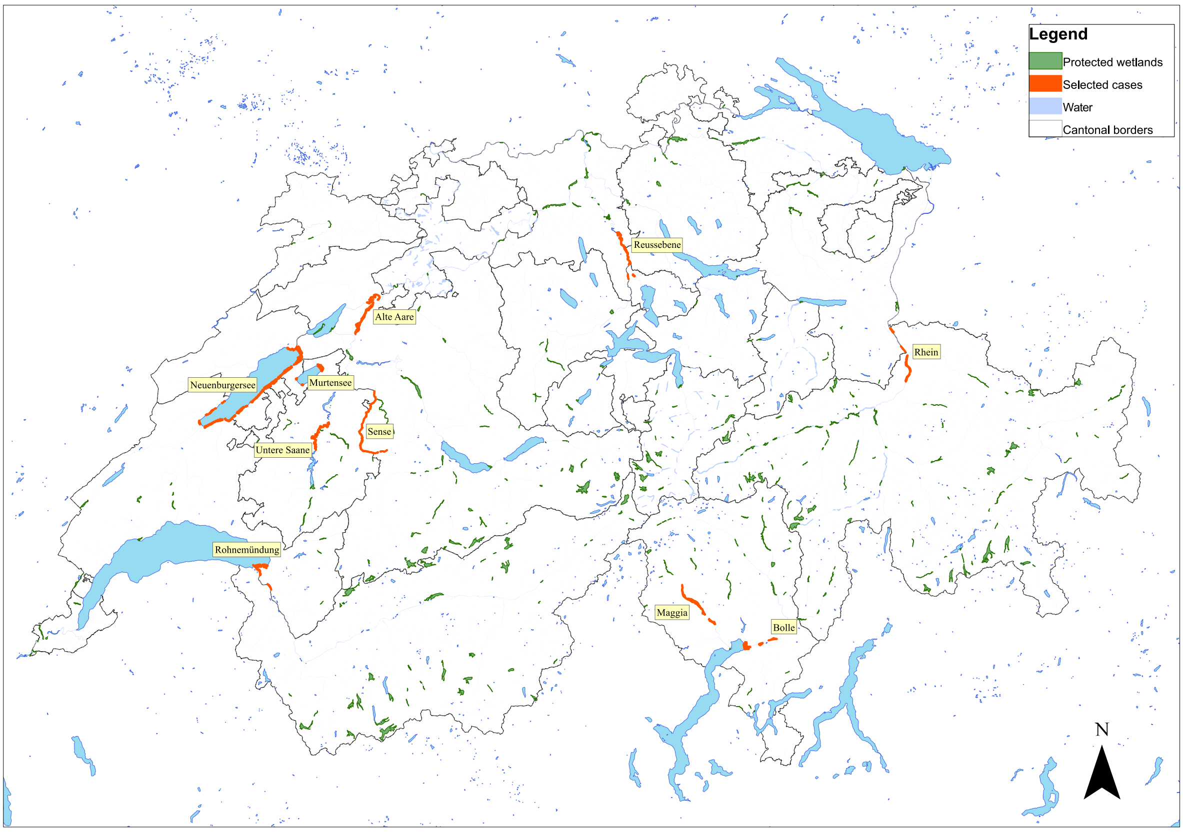


Figure A23: Map of Switzerland with the selected wetlands (red), including the two wetlands that are not part of the analysis of this paper.

Data gathering

Data gathering was conducted in three phases. The first phase aims to confirm the case areas and identify an initial set of relevant actors. Therefore, I conducted a desktop research that included documents, such as action plans, project reports, fact sheets, or monitoring reports. The initial set of actors is identified based on those documents using a combination of decisional, positional, and reputational approaches (Knoke, 1993). The second phase of the data gathering is based on semi-structured interviews with a limited number of key experts for each case. The data is used to develop a conceptual map (for further details on conceptual maps, see Appendix B, Conceptual maps) for each case. To structure the interviews, I used the Open Standards (OS) framework that is normally applied to organize conservation projects (Schwartz et al., 2012). The case knowledge from the first two phases of data gathering is then in the third phase used to construct a survey (for further details on survey structure and questions, see Appendix B, Survey text) that was sent out to all previously identified actors relevant to the governance of the wetlands. On average, 35 actors participated in each case in the survey, which accumulates to a total number of 276 actors and a response rate of 70 %. Additionally to the actors who participated in the survey also the other relevant actors of the case study areas are included in the further analysis. The missing information for actors that did not answer the survey questions is estimated using the R package mice (van Buuren & Groothuis-Oudshoorn, 2011) to impute incomplete multivariate data by chained equations.

Detailed conceptualization of the actor-issue networks

The nodes at the actor network level are actors that are relevant for the governance of the wetlands. Actors are included if they are identified as active in the specific region and participated and/or are mentioned by other relevant actors. Actors that were determined to be relevant in the initial data gathering phase but did not participate in the survey nor were mentioned by any other actors are assumed to be irrelevant for the analysis and are therefore excluded. For an actor to have an outgoing tie to another actor, the actors need to specify that they collaborate in the survey. While collaboration is a reciprocal activity involving two actors, I choose to conceptualize collaboration based on directed ties. This is because often, actors do not agree on the perception of collaboration. Therefore, to capture these differences in perceived collaboration, I decided to conceptualize the collaboration ties to be directional.

To identify ties across network levels, I use environmental management activities (e.g., fishing, planning/realization of restoration projects, or farming) to connect actors to specific environmental issues. Environmental management activities as an intermediate step are needed because actors do not directly influence environmental issues but only do so through their environmental management activities. All actors needed to specify in the survey for which environmental management activities they are responsible for. Based on the conceptual maps from the expert interviews, I know what effect specific environmental management activities have on environmental issues. Finally, while the ties within the actor network level are value-neutral, the ties across the network level have either an increasing or decreasing impact on the state of environmental issues. For example, an actor responsible for the environmental management activity labeled "ranger" potentially reduces the amount of trash in the area. Therefore, the actor has a decreasing tie to the environmental issues of "amount of trash".

The nodes in the issue network are environmental issues, and ties between the environmental issues represent how issues can increase/decrease the state of another environmental issue. Habitat quality and trout population, for example, are connected because an increase in habitat quality leads to an increase in the trout population. The information about the ties and nodes comes from the interviews with the individual cases' experts. Similarly, as environmental issues can be increased/decreased by incoming ties from other environmental issues, environmental issues can also be increased/decreased by incoming ties from actors. It is important to mention that the state of the environmental issues can not be compared between different environmental issues, and the ties just describe a general increase/decrease but do not give any information about the actual state of the environmental issue.

Detailed examples for the operationalization of the independent variables

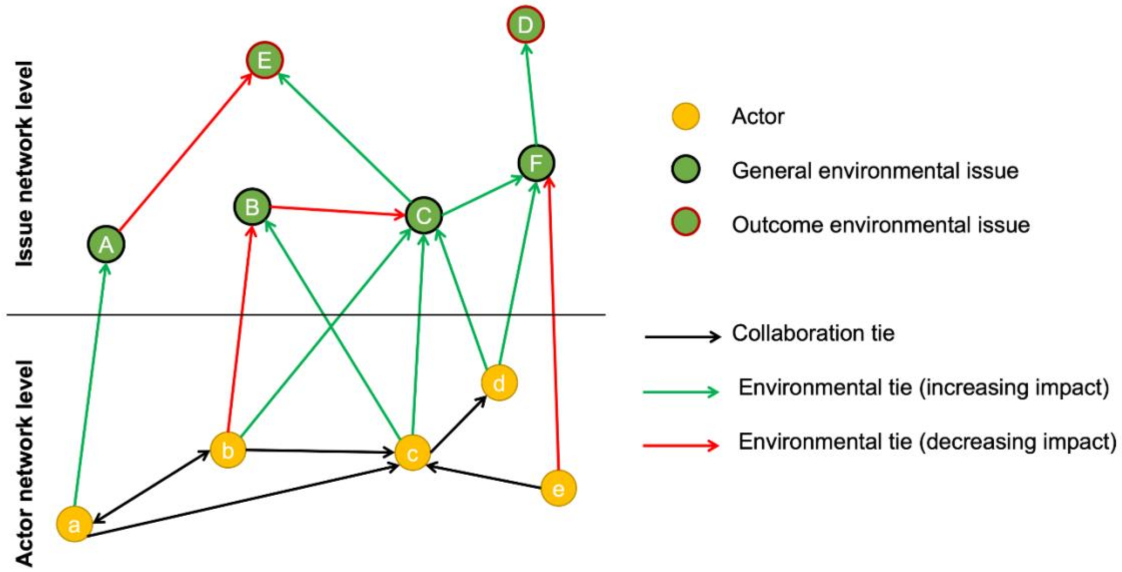


Figure A24: This illustration highlights the characteristic features of the actor-issue network used for the analysis. The illustration is split into two dimensions: 1) The actor network level with actors as nodes (yellow) and directed collaboration ties. 2) The issue network consists of environmental issues (green) and directed ties based on the impact of environmental issues. The environmental issues are split into general environmental issues (black border) and outcome environmental issues (red border). The color of the ties illustrates if environmental issues have an increasing or decreasing impact on the state of other nodes. Additionally, ties across the network levels exist when actors have a direct impact on environmental issues.

Following, I describe two examples for the calculation of the variables for the three hypotheses:

1. Hypothesis: The actor-issue path length of actor d and e [d-F-e] is two, and the actor-issue path length of actor c and e [c-C-F-e] is three. Since an actor-issue path length of one is not possible, all paths are subtracted by one. The corrected actor-issue path length of d and e is one and two for c and e. Therefore, based on the first hypothesis, I assume that actors d and e are more likely to collaborate since their connecting path is shorter.
2. Hypothesis: Two actor-issue paths exist that connect actor b and c [b-B-c / b-C-c]. Therefore, those two actors have a multiplexity index of two. Also, actors, a and b, have two connecting paths [a-A-E-C-b / a-A-E-C-B-b]. But as the second path is longer than the first path and, therefore, does not represent the shortest connecting path between the actors a and b, the second path is weighted less. Therefore, I assume that actors b and c are overall more likely to collaborate than actors a and b.
3. Hypothesis: The impact of actors on outcome environmental issues is calculated based on their increasing (+1) or decreasing (-1) impact on general environmental issues and dependent outcome environmental issues. First, the directionality of impact for each actor on outcome environmental issues is calculated separately based on the multiplicated value of increasing/decreasing ties. The impact of actor a and c on the outcome environmental issue E is for actor a: *1*-1 [a-A-E] = -1* and for actor c: *1*1 [c-C-E] = 1*. The impact of the actor b and d based on the outcome environmental issues D is for actor b: *(-1*-1*1*1 [b-B-C-F-D] + 1*1*1 [b-C-F-D])/2 = 1* and for d: (*1*1 [d-F-D] + 1*1*1 [d-C-F-D])/2 = 1*. Based on the third hypothesis c and d are more likely to collaborate since they both have the same impact on the outcome environmental issue. In a second step, all those separate paths are then used to

calculate a similarity index that combines all outcome environmental issues using the Euclidean similarity metric (Liberti et al. 2014).

$$p(q,p) = \sqrt{\sum_{i=1}^{n} (q_i - p_i)^2}$$

Conceptual maps

The colors of the nodes in the conceptual map represent 1) yellow: outcomes, 2) orange: factors, 3) blue: activities, and 4) grey: external factors. For this paper, factors and activities are both combined to environmental issues, while external factors are not included in the analysis of this paper. The colors of the ties in the map stand for 1) blue: increasing ties and 2) orange: decreasing ties. Here only the conceptual maps of two exemplary cases are used – the same ones that are also in-depth analyzed in the discussion section of this paper.

Example of the conceptual map for the case of Bolle

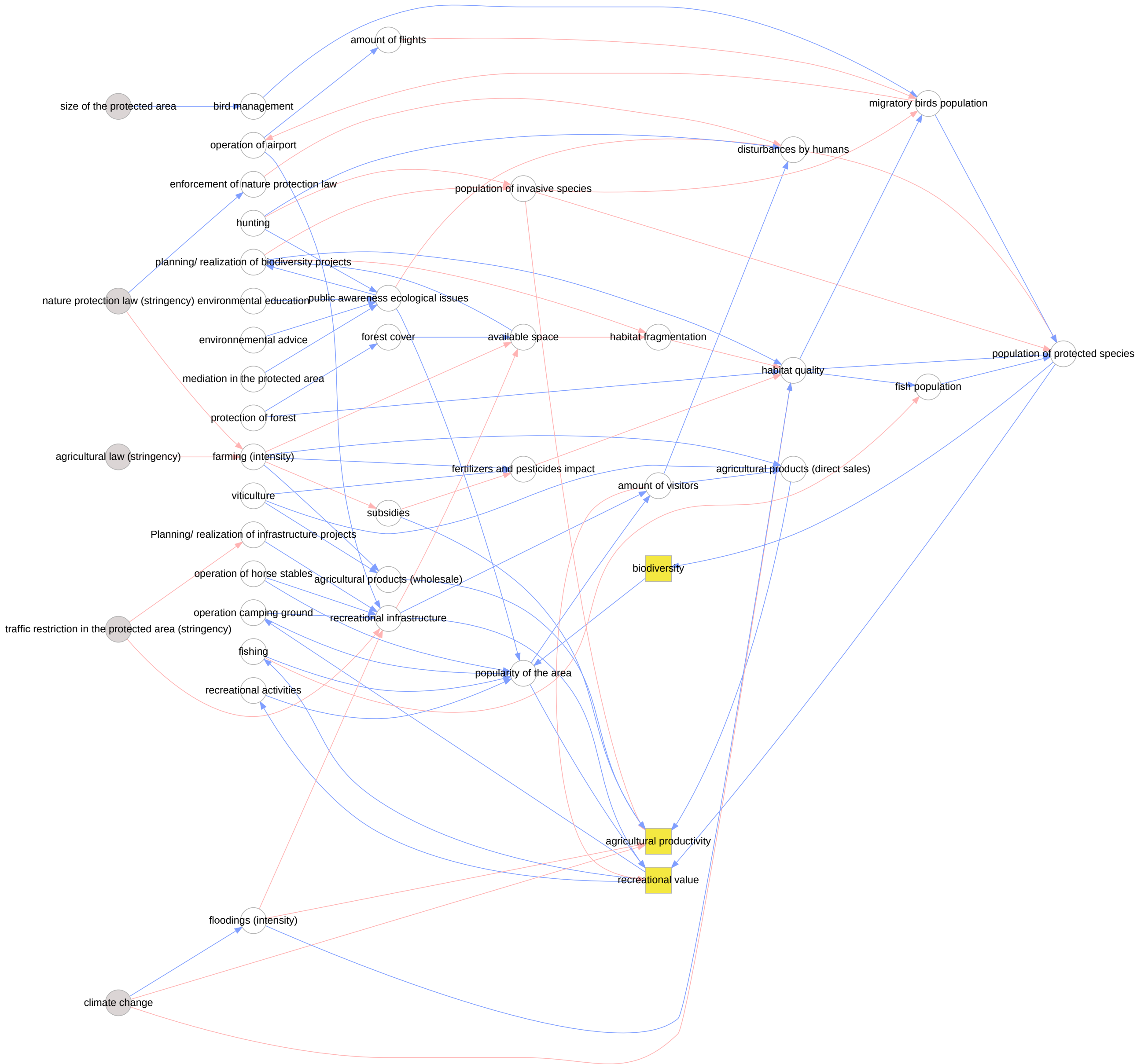


Figure A25: Conceptual map for the case of Bolle. Nodes: activities (blue), factors (orange), and outcome (yellow), external factors (grey); Ties: increasing tie (blue) and decreasing tie (orange).

Example of the conceptual map for the case of Neuchatel

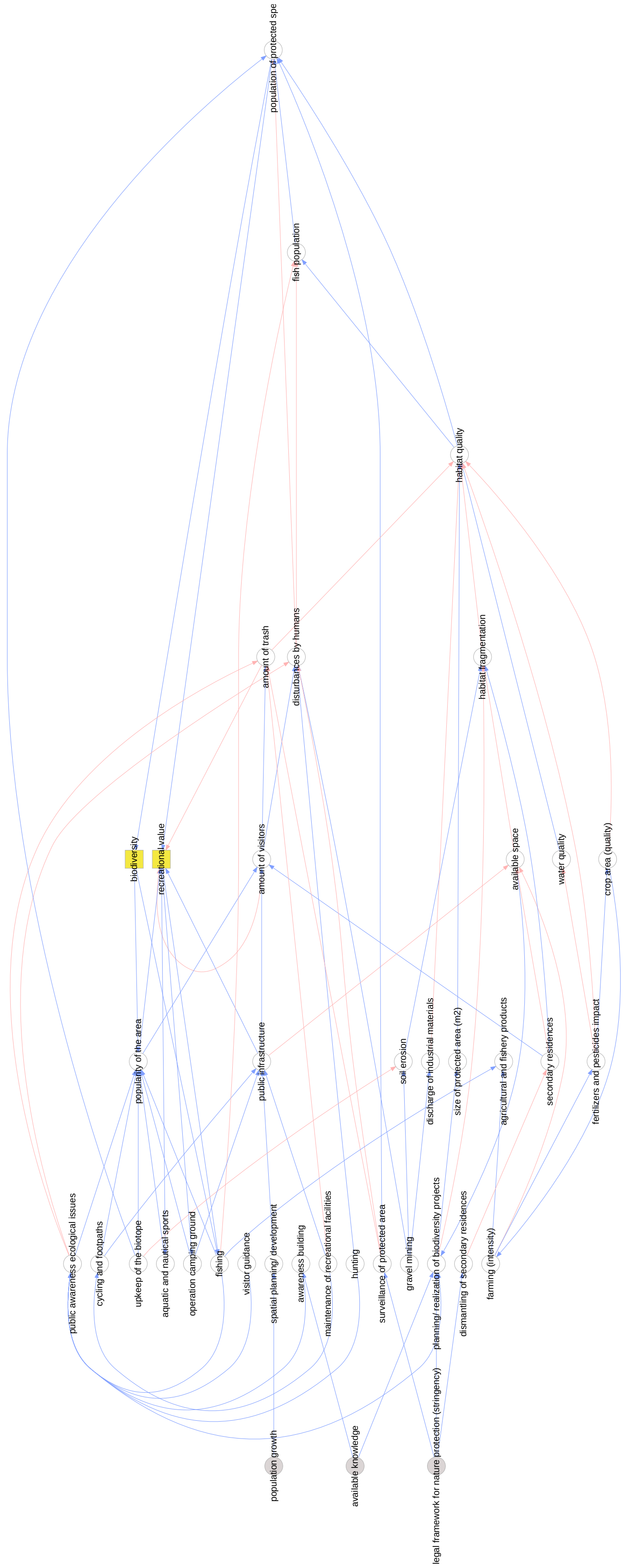


Figure A26: Conceptual map for the case of Neuchatel. Nodes: activities (blue), factors (orange), and outcome (yellow), external factors (grey); Ties: increasing tie (blue) and decreasing tie (orange).

Survey text

Explanation
The survey was conducted in multiple cases using LimeSurvey. Using LimeSurvey, the survey made use of multiple filtering steps that cannot be reproduced in an offline format of the survey. Therefore, instances that are variable within or across surveys are marked with square brackets containing basic information about the information content that was presented to the survey participants.

Floodplain management in the [case area]
<u>Introduction Text</u>

Research project

In floodplain areas, various interrelated problems come together in a limited area, ranging from biodiversity protection to visitor management and flood protection. In a research project funded by the Swiss National Science Foundation, Eawag, the water research institute of the ETH Domain, is investigating various floodplain areas in Switzerland. We are interested in how public authorities, civil society organizations, and also companies exchange and organize themselves around problems in floodplain areas. Our goal is to identify what constitutes successful floodplain management - and where there might be potential for improvement.

The [case area]

As part of this research project, we are also investigating floodplain management in the [case area]. Specifically, we are looking at the floodplain shown in dark red on the map below and other nearby wetlands and floodplains and their surrounding areas (shown in light red) [map of case area]. The organization for which you are active has been identified in our research as a relevant organization in at least one aspect of floodplain management in the [case area].

The Survey

Therefore, in order to get a as complete picture as possible of floodplain management in the [case area], we would like to ask you about your organization's activities in the [case area] through the following brief survey. In particular, we are interested in your collaboration with other organizations and your priorities regarding various possible goals in the [case area].

Completing the survey should take no more than 20 minutes on average. Your answers will be treated confidentially. Results of the surveys are published in anonymized form as standard and in non-anonymized form only after an explicit request for permission.

We would be very pleased about your participation. Please do not hesitate to contact us [contact information] if you have any questions or are interested in further information.

Kind regards and many thanks already in advance

The project team.

Your organization

We would like to ask you to complete this survey on behalf of the organization for which you work in the [case area]. In the following, the term organization can refer to public authorities (e.g., municipalities or cantonal offices), associations, NGOs, and private companies.

What is the name of the organization and organizational unit for which you are completing this survey?

By organizational unit we mean the smallest unit (e.g., department/section) within the organization for which you work.

Your name

[empty field]

Your activities in the [case area]

Which of the activities below has your organization been involved in over the past three years in the [case area]?

By activity, we mean both planning, decision-making, implementation, and evaluation of projects. [Please select the answers that apply:]

[List of activities]

Cooperation with other organizations

Which of the organizations listed below have you regularly collaborated with in the past three years as part of your activities in the [case area]?

Regular cooperation includes:

- in-depth exchange of information and expertise (more than once a year)
- joint planning, decision-making, implementation and evaluation of projects

[Please select the answers that apply:]

[List of actors.]

Which farms in the [case area] do you work with?

[empty field]

Are there other organizations you work with that are not on this list?

[empty field]

Below is a selection of other floodplain areas near the [case area]. Do you regularly work with organizations in these areas?

[Map of surroundings of case area]

[List of actors]

What are the main organizations you work with in the selected areas?

[empty field]

More about your cooperation with other organizations

Below you will find a list of organizations and activities that you have pre-selected. Please indicate those organizations with which you regularly collaborate in the respective activities.

Example [picture with example]: In this example, the organization regularly cooperates with organization A regarding visitor guidance. Regarding nature conservation, the filling organization regularly cooperates with organization B.

[List of relevant actors and activities]

Disagreements with other organizations

Subsequently, you will see your selected cooperation partners again. With which of them do you regularly have disagreements regarding procedures and goals in the activities you carry out?

Example [picture with example]: In this example, the organization regularly has discrepancies with organization B regarding visitor management. Regarding nature conservation, the filling organization regularly has discrepancies with organization B.

[List of relevant actors and activities]

Targets in the [case area]

Below are [Number of goals] possible goals for floodplain areas in the [case area]. How well do you think these goals are being achieved?

[List of destinations]

Which goals in the [case area] are particularly important for your organization?

All your answers must be different, and must be assigned.

Arrange the elements in the right list (highest rating at the top). The elements can be moved with the mouse. Double-click moves an element to the other list.

Are there other goals in the [case area] that are particularly important to your organization?

Influence of other organizations on the achievement of goals in the [case area].

You mentioned [goal] as the most important goal for floodplains in the [case area]. Which of the organizations below do you think are particularly important in achieving this goal?

Do you agree with the following statements?

My organization is sufficiently involved in decisions that affect the [case area].

[Disagree fully / Disagree by majority / Agree by majority / Agree full]

When decisions are made in the [case area], all stakeholders are involved on an equal level.

[Disagree fully / Disagree by majority / Agree by majority / Agree full]

Floodplain management in the [case area] is well positioned to deal with the challenges of the future.

[Disagree fully / Disagree by majority / Agree by majority / Agree full]

[List of additional questions regarding specific situations in the case area]

<u>Forums</u>

Has your organization participated in events at the following forums in the past three years?

[List of forums]

Has your organization participated in other events that address issues in the [case area]?

[empty field]

<u>Questions and interest in the study results</u>

May we contact you regarding any queries about the survey?

- Yes, by email:
- Yes, by phone:
- I'd rather not:

Do you want to be continuously informed about the results of this investigation?

- Yes
- Yes, only important results
- No
- No answer

Would you be interested in attending a workshop where the results of this research would be presented?

- Yes
- Under certain circumstances (see comment)
- No
- No answer

ERGM results and GOF statistics

The result tables and GOF statistics of the ERGMs appear below. The two capital letters in the result tables of the ERGMs indicate the type of ERGM term:

- EC (edgecov): This term adds one statistic to the model, equal to the sum of the covariate values for each tie appearing in the network (Hunter et al., 2021).
- NM (nodematch): The number of ties whose incident nodes match the value of the nodal attribute (Hunter et al., 2021).

- NF (nodefactor): The number of times that nodes with a given level of a categorical nodal attribute appear within the tie set (Hunter et al., 2021).

A positive value for any of the terms indicates that this specific variable positively influences the probability of collaboration ties. For further information on ERGM terms and the interpretation of GOF statistics, see: www.statnet.org/Workshops/ergm_tutorial.html (Statnet Development Team).

The terms relevant to the three hypotheses are EC.H1_length (length of actor-issue paths), EC. H2_multiplexity (multiplexity of actor-issue paths), and EC. H3_similarity (similarity of actor-issue paths) and are all based on the edgecov term. Additionally, the control variable of power is also built on the edgecov term. The control variable of power is based on a matrix with information if actor A perceives actor B to be powerful. The remaining control variables are based on nodematch and nodefactor terms. The control variable of location uses information on the activity area of actors. The activity area of actors is split up into the different cantons of Switzerland, including two additional categories (inter-cantonal and others) for actors that are active in more than one canton and actors that cannot be attributed to a specific physical location. The control variable actor type differentiates between five types of actors relevant to the management of the wetlands (state actors, cantonal actors, municipal actors, NGOs and associations, and other actors). Finally, the control variable of response accounts for how the actors were involved in the survey based on four categories (normal answer, normal no answer, add later answer, and add later no answer). The labels “normal” and “ad later” indicate if actors were included from the beginning on in the list of possible collaboration partners or if they were only added later based on the other participants’ feedback. Actors that were only added later are not listed in the default list of possible collaboration partners and therefore had to be added manually by the other survey participants. Further, the label “answer” indicates that an actor participated in the survey, while “no answer” indicates that an actor did not participate in the survey.

As the ERGMs are all based on small-n samples, p-values, standard errors as well as overall GOF statistics indicate relatively high uncertainties (Foulley, 2019; Wasserstein et al., 2019). However, given the presence of multiple comparable case studies in this article, the main conclusions rely on the qualitative meta-regression analysis that combines the results from the different case studies. The qualitative meta-regression analysis is weighted based on the p-values of the individual results and assesses whether differences across cases, based on the four conditions of governance complexity (number of actors in actor network, number of ties in issue network, case area structure, and cantonal borders), influence the impact of the variables of path length, multiplexity, and similarity on the probability of collaboration ties. In order to keep the individual ERGM results comparable across cases, no additional ERGM terms (e.g., weighted terms for edge-wise shared partner [gwesp]) are implemented, even though the model fit in general and the fit of the edge-wise and dyad-wise shared partner distributions, in particular, could be improved. Additional analyses including weighted terms for edge-wise and dyad-wise shared partners as well as additional case-specific terms on the dyad level (e.g., belief similarity) show that results remain robust.

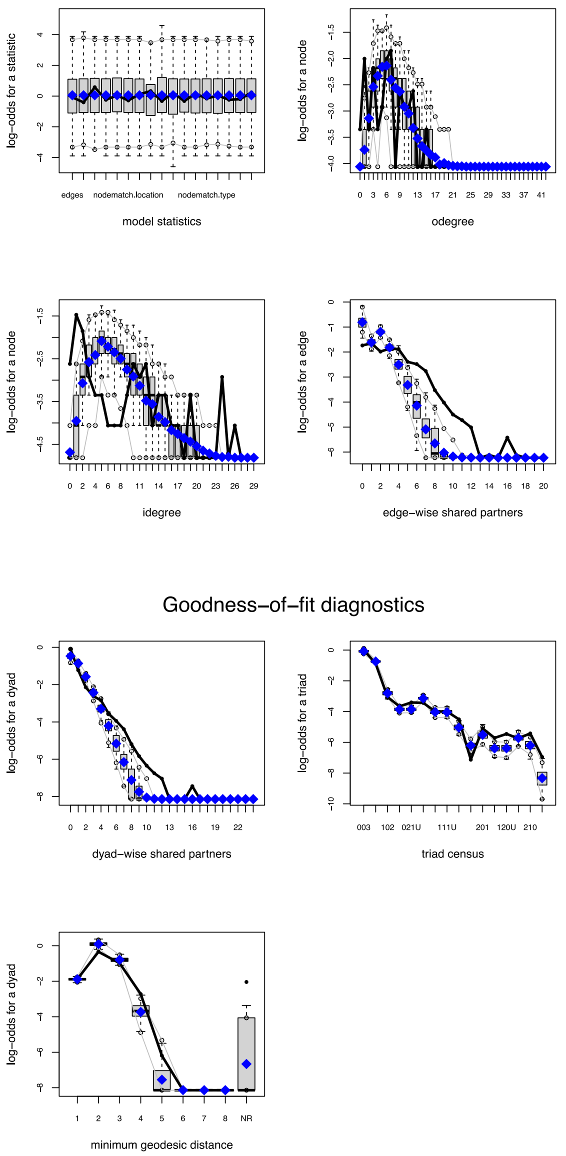
Aggregated covariance table for the three hypotheses

Table A13: Covariance table for the three hypotheses separated based on the eight cases included in the analysis. Covariance between the dyad-level covariates of path length, multiplexity, and similarity exists as all of them are based on actor-issue paths connecting actor pairs. The values of the dyad-level covariates used to calculate the covariance table are all normalized on a scale from 0 to 1. Overall, the covariance table indicates a significant interdependence between the three dyad-level covariates of path length, multiplexity, and similarity. Consequently, the dyad-level covariates for the three hypotheses are modeled separately to single out the effect of each dyad-level covariate on collaboration ties.

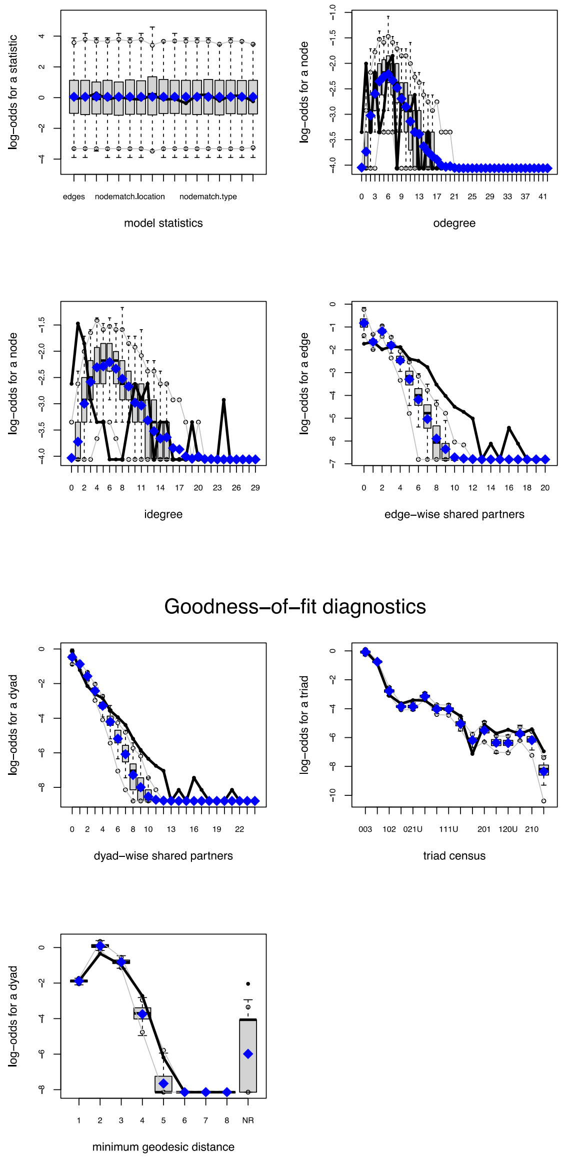
	H1	**H2**	**H3**
Alte_Aare_H1	0.49	-0.4	-0.27
Alte_Aare_H2	-0.4	1.8	-0.35
Alte_Aare_H3	-0.27	-0.35	0.41
Reussebene_H1	0.19	-0.2	-0.09
Reussebene_H2	-0.2	0.89	-0.16
Reussebene_H3	-0.09	-0.16	0.18
Rhonemündung_H1	0.82	-0.23	-0.47
Rhonemündung_H2	-0.23	1.25	-0.42
Rhonemündung_H3	-0.47	-0.42	0.58
Sense_H1	0.55	-0.29	-0.32
Sense_H2	-0.29	1.45	-0.37
Sense_H3	-0.32	-0.37	0.44
Untere_Saane_H1	0.35	-0.29	-0.2
Untere_Saane_H2	-0.29	1.11	-0.21
Untere_Saane_H3	-0.2	-0.21	0.33
Murtensee_H1	0.43	-0.29	-0.23
Murtensee_H2	-0.29	1.68	-0.44
Murtensee_H3	-0.23	-0.44	0.41
Neuchatel _H1	0.37	-0.08	-0.23
Neuchatel _H2	-0.08	0.86	-0.24
Neuchatel _H3	-0.23	-0.24	0.26
Bolle_H1	0.2	-0.03	-0.13
Bolle_H2	-0.03	0.53	-0.2
Bolle_H3	-0.13	-0.2	0.19

Case Alte Aare, hypotheses 1 & 2

	Estimate	Std. Error	MCMC %	Z value	Pr (>|z|)
edges	-1.95	0.32	0	-6.07	0
mutual	0.78	0.18	0	4.35	0
esp1	-0.69	0.12	0	-5.76	0
EC.H1_length	-0.18	0.24	0	-0.76	0.45
EC.power	0.01	0.16	0	0.07	0.95
NM.location	0.12	0.12	0	0.94	0.35
NF.location.inter-cantonal	0.6	0.14	0	4.29	0
NF.location.other	0.88	0.45	0	1.94	0.05
NM.response	-0.06	0.11	0	-0.53	0.6
NF.response.add_later_no_answer	-0.43	0.25	0	-1.74	0.08
NF.response.normal_answer	0.71	0.15	0	4.72	0
NF.response.normal_no_answer	0.47	0.15	0	3.14	0
NM.type	-0.24	0.14	0	-1.75	0.08
NF.type.Federal_Office	-1.28	0.21	0	-6.22	0
NF.type.Municipality	-0.69	0.11	0	-6.13	0
NF.type.NGO_organization_association	-0.67	0.12	0	-5.66	0
NF.type.Other	-0.92	0.14	0	-6.73	0



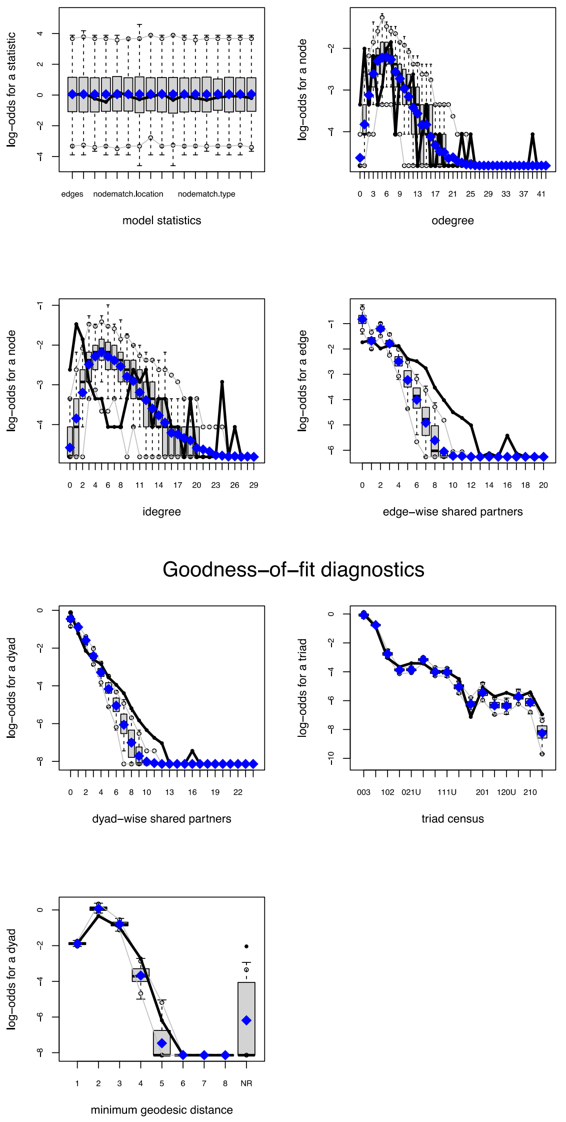
	Estimate	Std. Error	MCMC %	Z value	Pr (>|z|)
edges	-1.91	0.32	0	-5.95	0
mutual	0.78	0.18	0	4.34	0
esp1	-0.7	0.12	0	-5.85	0
EC.H2_multiplexity	-0.46	0.5	0	-0.92	0.36
EC.power	0	0.16	0	0.01	0.99
NM.location	0.11	0.13	0	0.86	0.39
NF.location.inter-cantonal	0.59	0.14	0	4.25	0
NF.location.other	0.87	0.45	0	1.93	0.05
NM.response	-0.05	0.11	0	-0.47	0.64
NF.response.add_later_no_answer	-0.44	0.26	0	-1.73	0.08
NF.response.normal_answer	0.7	0.15	0	4.63	0
NF.response.normal_no_answer	0.46	0.15	0	3.1	0
NM.type	-0.23	0.14	0	-1.68	0.09
NF.type.Federal_Office	-1.28	0.21	0	-6.22	0
NF.type.Municipality	-0.7	0.11	0	-6.36	0
NF.type.NGO_organization_association	-0.68	0.12	0	-5.83	0
NF.type.Other	-0.92	0.14	0	-6.66	0

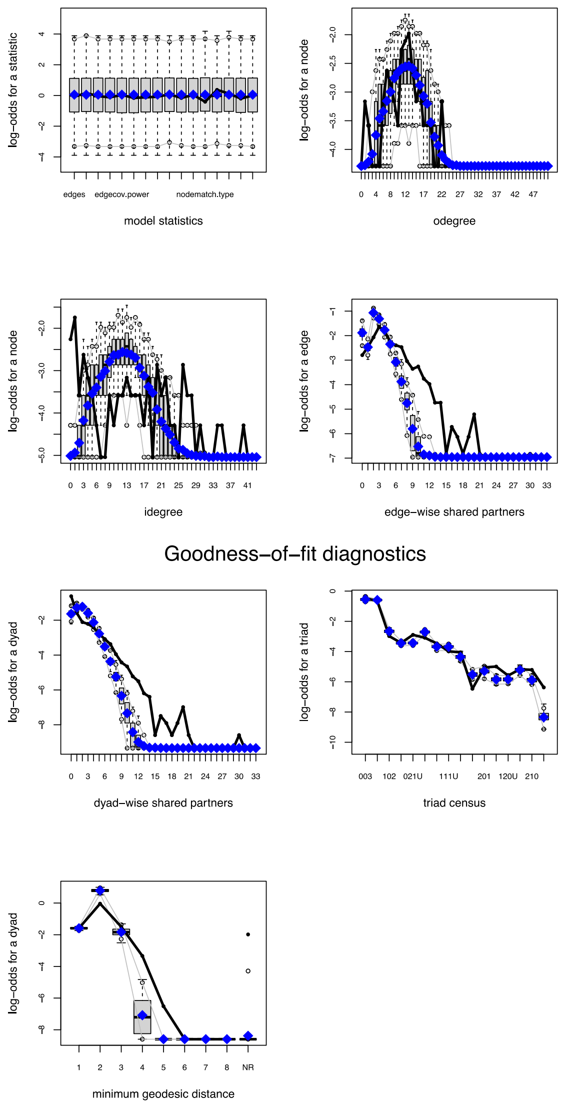


Case Alte Aare, hypothesis 3 & case Bolle, hypothesis 1

	Estimate	Std. Error	MCMC %	Z value	Pr (>|z|)
edges	-1.94	0.32	0	-6.14	0
mutual	0.78	0.18	0	4.33	0
esp1	-0.69	0.12	0	-5.63	0
EC.H3_similarity	-0.15	0.21	0	-0.71	0.48
EC.power	0.01	0.16	0	0.05	0.96
NM.location	0.11	0.13	0	0.87	0.38
NF.location.inter-cantonal	0.6	0.14	0	4.43	0
NF.location.other	0.88	0.44	0	1.98	0.05
NM.response	-0.06	0.11	0	-0.51	0.61
NF.response.add_later_no_answer	-0.43	0.25	0	-1.72	0.09
NF.response.normal_answer	0.71	0.15	0	4.85	0
NF.response.normal_no_answer	0.47	0.15	0	3.24	0
NM.type	-0.23	0.13	0	-1.73	0.08
NF.type.Federal_Office	-1.29	0.2	0	-6.4	0
NF.type.Municipality	-0.69	0.11	0	-6.4	0
NF.type.NGO_organization_association	-0.68	0.12	0	-5.67	0
NF.type.Other	-0.92	0.14	0	-6.69	0

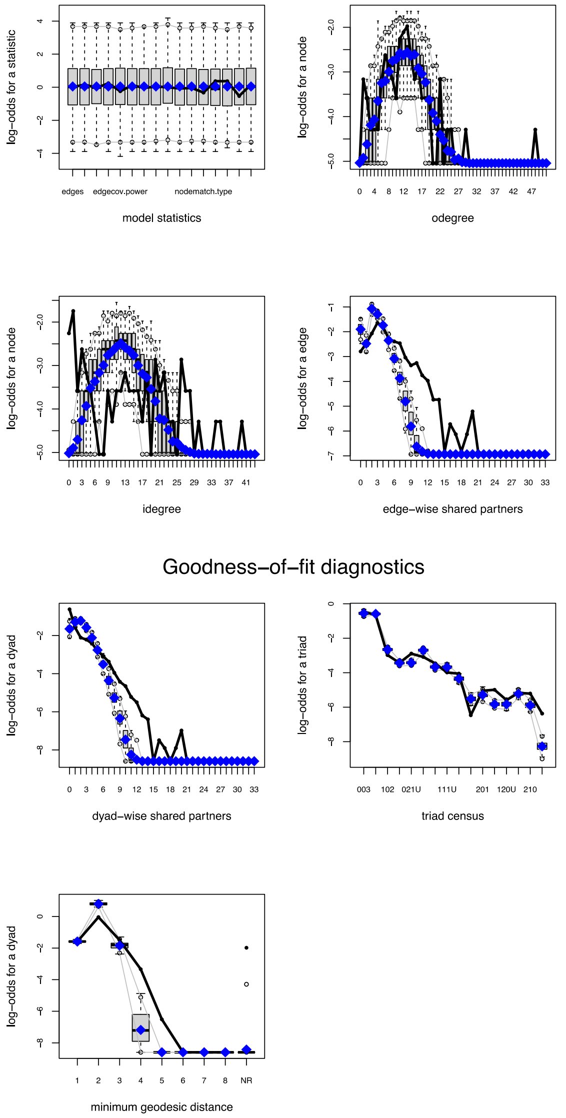
	Estimate	Std. Error	MCMC %	Z value	Pr (>|z|)
edges	-2.14	0.38	0	-5.62	0
mutual	0.57	0.12	0	4.68	0
esp1	-1.1	0.12	0	-9.21	0
EC.H1_length	0.14	0.15	0	0.93	0.35
EC.power	0.52	0.11	0	4.83	0
NM.location	-0.24	0.15	0	-1.62	0.1
NF.location.Tessin	0.23	0.14	0	1.64	0.1
NM.response	-0.06	0.08	0	-0.75	0.45
NF.response.add_later_no_answer	-0.2	0.22	0	-0.91	0.36
NF.response.normal_answer	0.35	0.18	0	1.91	0.06
NF.response.normal_no_answer	0.15	0.18	0	0.8	0.42
NM.type	0.21	0.09	0	2.35	0.02
NF.type.Federal_Office	-0.12	0.12	0	-1	0.32
NF.type.Municipality	-0.18	0.09	0	-1.99	0.05
NF.type.NGO_organization_association	-0.28	0.07	0	-4.18	0
NF.type.Other	-0.43	0.07	0	-5.91	0



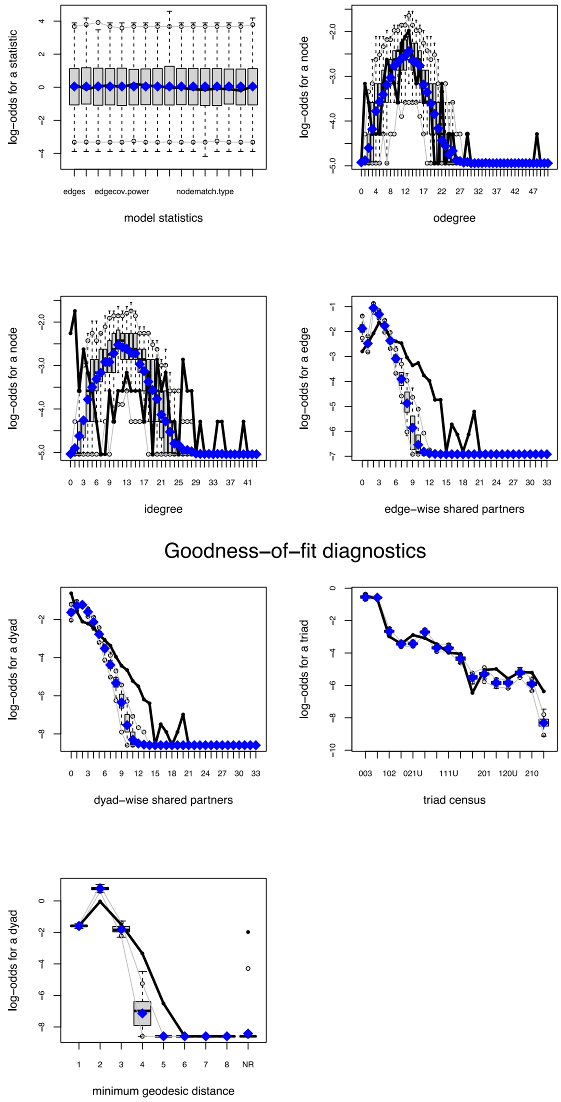


Case Bolle, hypotheses 2 & 3

	Estimate	Std. Error	MCMC %	Z value	Pr (>|z|)
edges	-2.15	0.39	0	-5.44	0
mutual	0.57	0.12	0	4.56	0
esp1	-1.1	0.12	0	-9.27	0
EC.H2_multiplexity	0.54	0.27	0	1.99	0.05
EC.power	0.52	0.11	0	4.82	0
NM.location	-0.23	0.15	0	-1.51	0.13
NF.location.Tessin	0.22	0.14	0	1.57	0.12
NM.response	-0.05	0.07	0	-0.71	0.48
NF.response.add_later_no_answer	-0.21	0.22	0	-0.93	0.35
NF.response.normal_answer	0.35	0.19	0	1.83	0.07
NF.response.normal_no_answer	0.14	0.19	0	0.74	0.46
NM.type	0.21	0.09	0	2.32	0.02
NF.type.Federal_Office	-0.11	0.12	0	-0.88	0.38
NF.type.Municipality	-0.17	0.09	0	-1.85	0.06
NF.type.NGO_organization_association	-0.28	0.07	0	-3.99	0
NF.type.Other	-0.43	0.07	0	-5.73	0



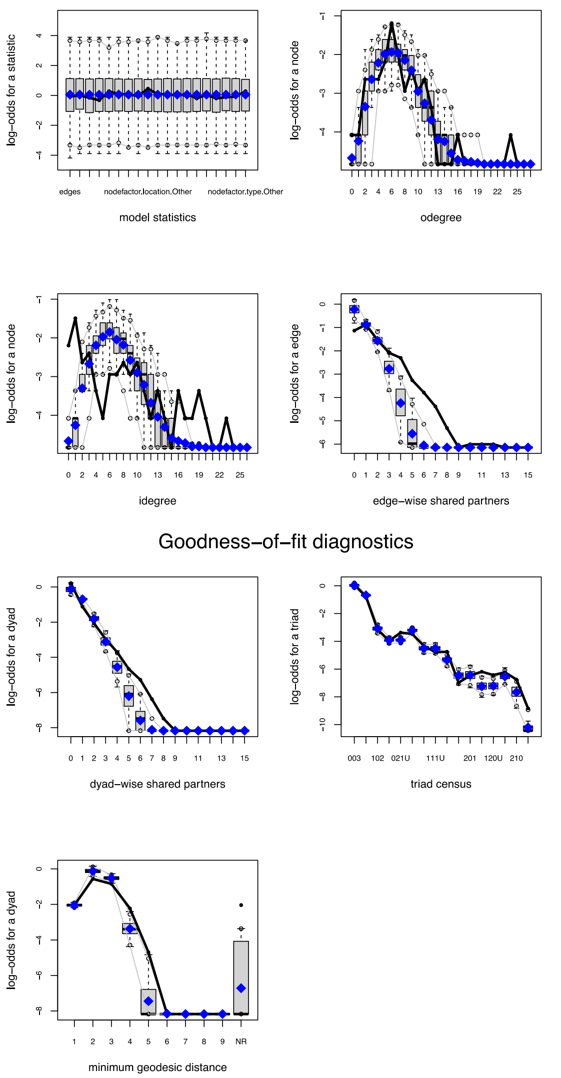
	Estimate	Std. Error	MCMC %	Z value	Pr (>|z|)
edges	-2.14	0.39	0	-5.53	0
mutual	0.57	0.12	0	4.61	0
esp1	-1.1	0.12	0	-9.1	0
EC.H3_similarity	0.15	0.12	0	1.27	0.2
EC.power	0.53	0.11	0	5	0
NM.location	-0.24	0.16	0	-1.5	0.13
NF.location.Tessin	0.22	0.14	0	1.53	0.13
NM.response	-0.06	0.07	0	-0.78	0.44
NF.response.add_later_no_answer	-0.2	0.22	0	-0.91	0.36
NF.response.normal_answer	0.35	0.18	0	1.92	0.05
NF.response.normal_no_answer	0.15	0.18	0	0.8	0.42
NM.type	0.21	0.08	0	2.46	0.01
NF.type.Federal_Office	-0.11	0.12	0	-0.97	0.33
NF.type.Municipality	-0.18	0.09	0	-1.95	0.05
NF.type.NGO_organization_association	-0.28	0.07	0	-4.23	0
NF.type.Other	-0.43	0.07	0	-5.85	0

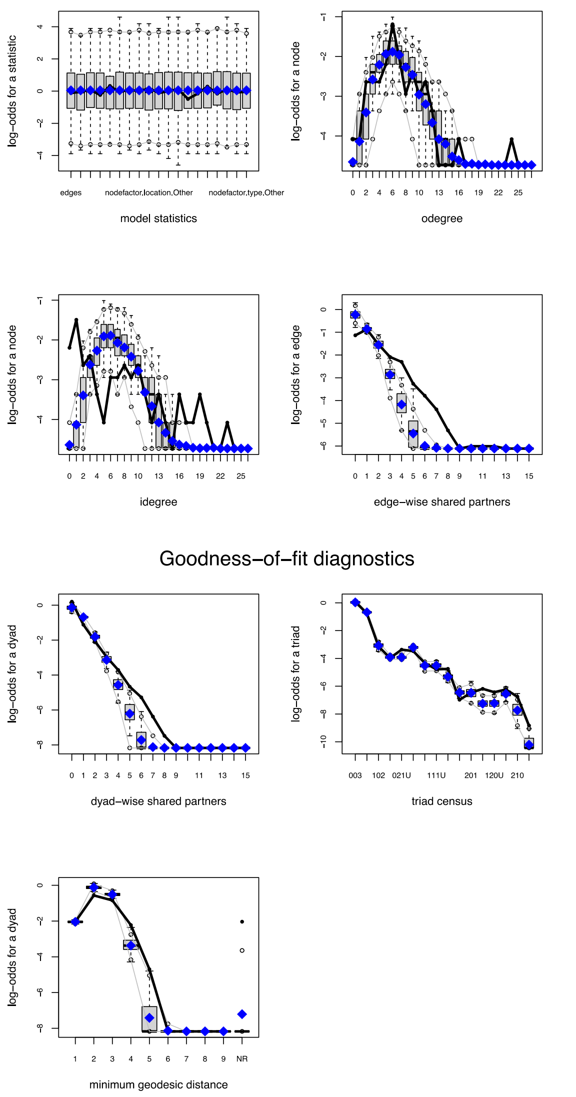


Case Murtensee, hypothesis 1 & 2

	Estimate	Std. Error	MCMC %	Z value	Pr (>|z|)
edges	-3.87	0.99	0	-3.89	0
mutual	0.73	0.19	0	3.81	0
esp1	-0.23	0.1	0	-2.18	0.03
EC.H1_length	0.21	0.25	0	0.81	0.42
EC.power	0.28	0.16	0	1.74	0.08
NM.location	0.18	0.11	0	1.55	0.12
NF.location.Fribourg	0.14	0.24	0	0.6	0.55
NF.location.inter-cantonal	0.15	0.24	0	0.63	0.53
NF.location.other	0.05	0.33	0	0.16	0.88
NF.location.Waadt	0.25	0.24	0	1.06	0.29
NM.response	-0.05	0.11	0	-0.46	0.65
NF.response.add_later_no_answer	0.55	0.47	0	1.17	0.24
NF.response.normal_answer	0.96	0.47	0	2.07	0.04
NF.response.normal_no_answer	0.93	0.46	0	2	0.05
NM.type	0.3	0.12	0	2.54	0.01
NF.type.Federal_Office	-0.45	0.2	0	-2.22	0.03
NF.type.Municipality	-0.12	0.12	0	-0.98	0.33
NF.type.NGO_organization_association	-0.32	0.11	0	-2.95	0
NF.type.Other	-0.41	0.11	0	-3.82	0

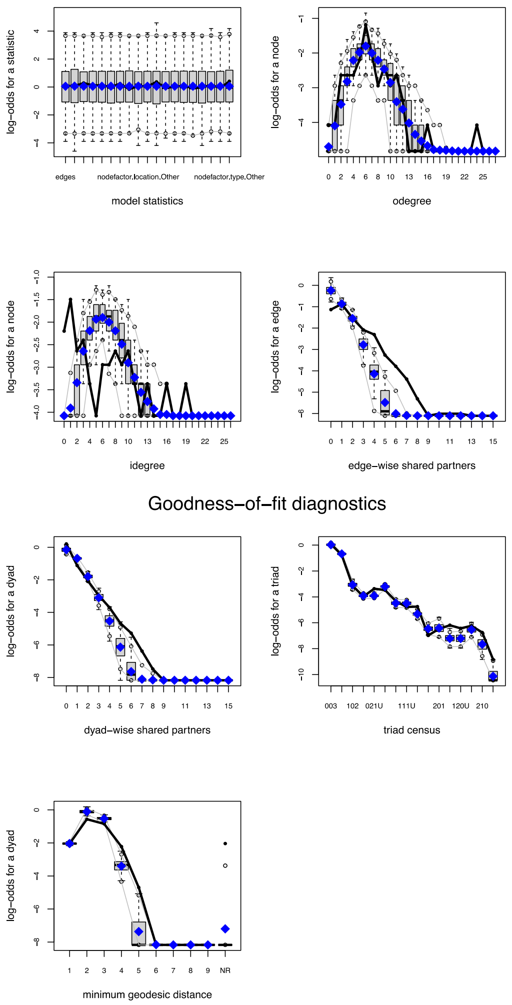
	Estimate	Std. Error	MCMC %	Z value	Pr (>|z|)
edges	-3.88	1.03	0	-3.76	0
mutual	0.72	0.19	0	3.71	0
esp1	-0.23	0.11	0	-2.15	0.03
EC.H2_multiplexity	0.31	0.51	0	0.61	0.54
EC.power	0.27	0.16	0	1.7	0.09
NM.location	0.18	0.11	0	1.53	0.13
NF.location.Fribourg	0.15	0.23	0	0.63	0.53
NF.location.inter-cantonal	0.16	0.25	0	0.64	0.52
NF.location.other	0.06	0.33	0	0.17	0.87
NF.location.Waadt	0.26	0.24	0	1.07	0.28
NM.response	-0.05	0.11	0	-0.52	0.61
NF.response.add_later_no_answer	0.57	0.49	0	1.16	0.25
NF.response.normal_answer	0.97	0.47	0	2.04	0.04
NF.response.normal_no_answer	0.93	0.47	0	1.97	0.05
NM.type	0.31	0.12	0	2.53	0.01
NF.type.Federal_Office	-0.44	0.21	0	-2.13	0.03
NF.type.Municipality	-0.12	0.12	0	-1	0.32
NF.type.NGO_organization_association	-0.32	0.11	0	-3.03	0
NF.type.Other	-0.41	0.1	0	-3.92	0



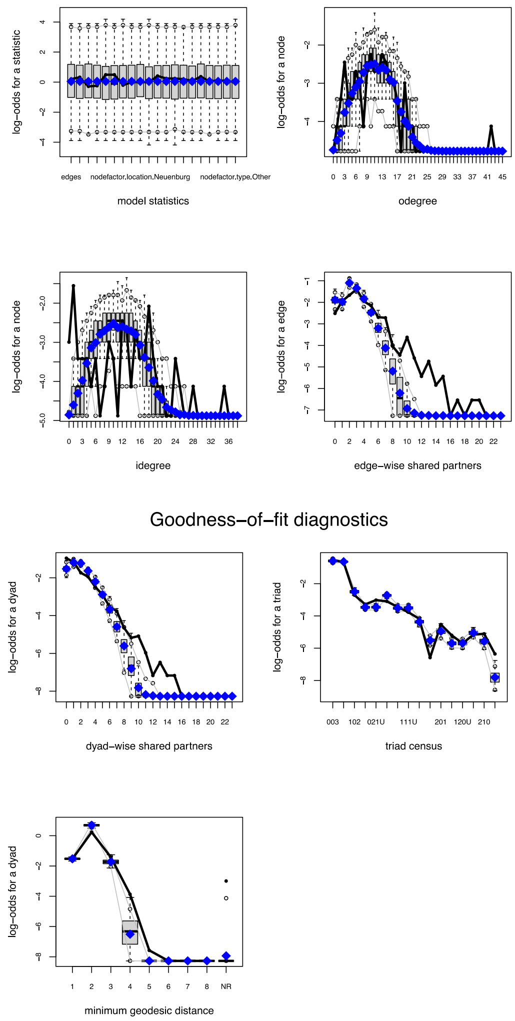


Case Murtensee, hypothesis 3 & case Neuchatel, hypothesis 1

	Estimate	Std. Error	MCMC %	Z value	Pr (>|z|)
edges	-3.86	1.03	0	-3.74	0
mutual	0.72	0.2	0	3.6	0
esp1	-0.23	0.1	0	-2.18	0.03
EC.H3_similarity	0.17	0.22	0	0.77	0.44
EC.power	0.27	0.17	0	1.61	0.11
NM.location	0.17	0.11	0	1.51	0.13
NF.location.Fribourg	0.15	0.23	0	0.67	0.5
NF.location.inter-cantonal	0.16	0.24	0	0.66	0.51
NF.location.other	0.06	0.32	0	0.19	0.85
NF.location.Waadt	0.26	0.23	0	1.12	0.26
NM.response	-0.05	0.11	0	-0.49	0.62
NF.response.add_later_no_answer	0.54	0.49	0	1.11	0.27
NF.response.normal_answer	0.96	0.47	0	2.04	0.04
NF.response.normal_no_answer	0.91	0.47	0	1.95	0.05
NM.type	0.3	0.12	0	2.59	0.01
NF.type.Federal_Office	-0.43	0.2	0	-2.15	0.03
NF.type.Municipality	-0.12	0.12	0	-0.99	0.32
NF.type.NGO_organization_association	-0.32	0.11	0	-2.92	0
NF.type.Other	-0.41	0.11	0	-3.83	0



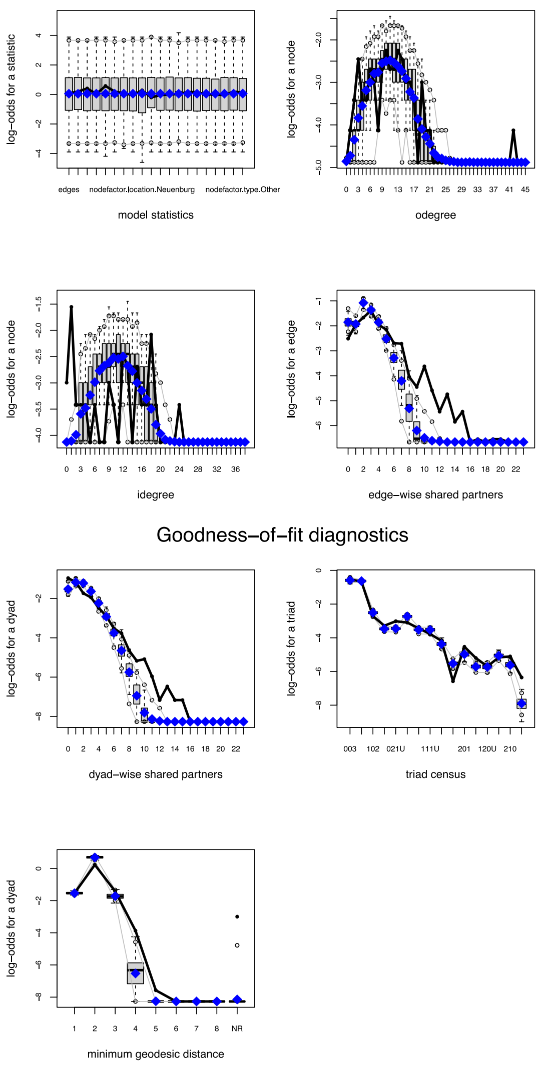
	Estimate	Std. Error	MCMC %	Z value	Pr (>|z|)
edges	-4.15	0.93	0	-4.48	0
mutual	0.75	0.14	0	5.32	0
esp1	-0.64	0.11	0	-5.64	0
EC.H1_length	-0.33	0.2	0	-1.72	0.09
EC.power	0.21	0.11	0	1.88	0.06
NM.location	0.3	0.09	0	3.18	0
NF.location.Fribourg	0.56	0.28	0	2.01	0.04
NF.location.inter-cantonal	0.68	0.3	0	2.26	0.02
NF.location.Neuenburg	0.05	0.3	0	0.16	0.88
NF.location.other	0.62	0.36	0	1.71	0.09
NF.location.Waadt	0.44	0.28	0	1.55	0.12
NM.response	-0.08	0.09	0	-0.82	0.41
NF.response.add_later_no_answer	0.28	0.42	0	0.68	0.5
NF.response.normal_answer	1	0.39	0	2.61	0.01
NF.response.normal_no_answer	0.74	0.38	0	1.95	0.05
NM.type	-0.08	0.1	0	-0.75	0.45
NF.type.Federal_Office	-0.57	0.17	0	-3.45	0
NF.type.Municipality	-0.19	0.08	0	-2.31	0.02
NF.type.NGO_organization_association	-0.27	0.12	0	-2.27	0.02
NF.type.Other	-0.47	0.09	0	-5.13	0

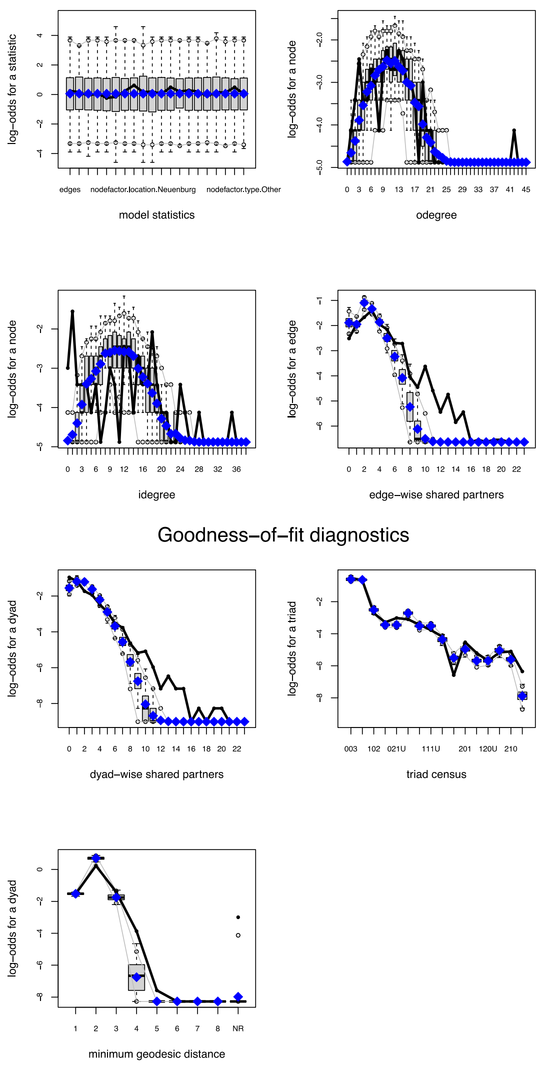


Case Neuchatel, hypotheses 2 & 3

	Estimate	Std. Error	MCMC %	Z value	Pr (>|z|)
edges	-4.2	0.91	0	-4.64	0
mutual	0.74	0.14	0	5.24	0
esp1	-0.64	0.11	0	-5.79	0
EC.H2_multiplexity	-0.48	0.39	0	-1.25	0.21
EC.power	0.21	0.11	0	1.87	0.06
NM.location	0.29	0.09	0	3.12	0
NF.location.Fribourg	0.57	0.27	0	2.08	0.04
NF.location.inter-cantonal	0.69	0.29	0	2.35	0.02
NF.location.Neuenburg	0.06	0.29	0	0.21	0.83
NF.location.other	0.63	0.36	0	1.78	0.08
NF.location.Waadt	0.44	0.28	0	1.6	0.11
NM.response	-0.07	0.09	0	-0.81	0.42
NF.response.add_later_no_answer	0.3	0.39	0	0.76	0.44
NF.response.normal_answer	1.02	0.37	0	2.77	0.01
NF.response.normal_no_answer	0.76	0.37	0	2.07	0.04
NM.type	-0.07	0.1	0	-0.72	0.47
NF.type.Federal_Office	-0.58	0.16	0	-3.52	0
NF.type.Municipality	-0.19	0.08	0	-2.28	0.02
NF.type.NGO_organization_association	-0.27	0.12	0	-2.35	0.02
NF.type.Other	-0.46	0.09	0	-4.9	0

	Estimate	Std. Error	MCMC %	Z value	Pr (>|z|)
edges	-4.23	0.89	0	-4.74	0
mutual	0.74	0.14	0	5.29	0
esp1	-0.64	0.11	0	-5.63	0
EC.H3_similarity	-0.29	0.14	0	-1.99	0.05
EC.power	0.2	0.11	0	1.77	0.08
NM.location	0.3	0.09	0	3.19	0
NF.location.Fribourg	0.59	0.27	0	2.19	0.03
NF.location.inter-cantonal	0.7	0.29	0	2.4	0.02
NF.location.Neuenburg	0.08	0.29	0	0.27	0.79
NF.location.other	0.65	0.35	0	1.84	0.07
NF.location.Waadt	0.46	0.27	0	1.72	0.09
NM.response	-0.08	0.09	0	-0.84	0.4
NF.response.add_later_no_answer	0.33	0.41	0	0.81	0.42
NF.response.normal_answer	1.03	0.37	0	2.78	0.01
NF.response.normal_no_answer	0.77	0.37	0	2.1	0.04
NM.type	-0.08	0.1	0	-0.76	0.44
NF.type.Federal_Office	-0.57	0.17	0	-3.42	0
NF.type.Municipality	-0.19	0.08	0	-2.42	0.02
NF.type.NGO_organization_association	-0.27	0.11	0	-2.37	0.02
NF.type.Other	-0.47	0.09	0	-5.12	0

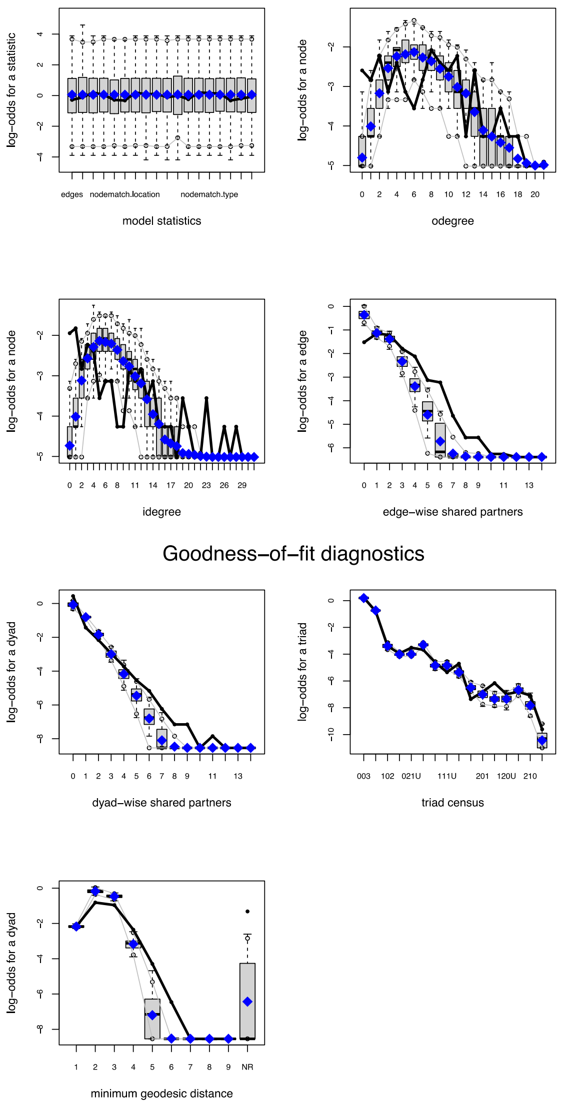


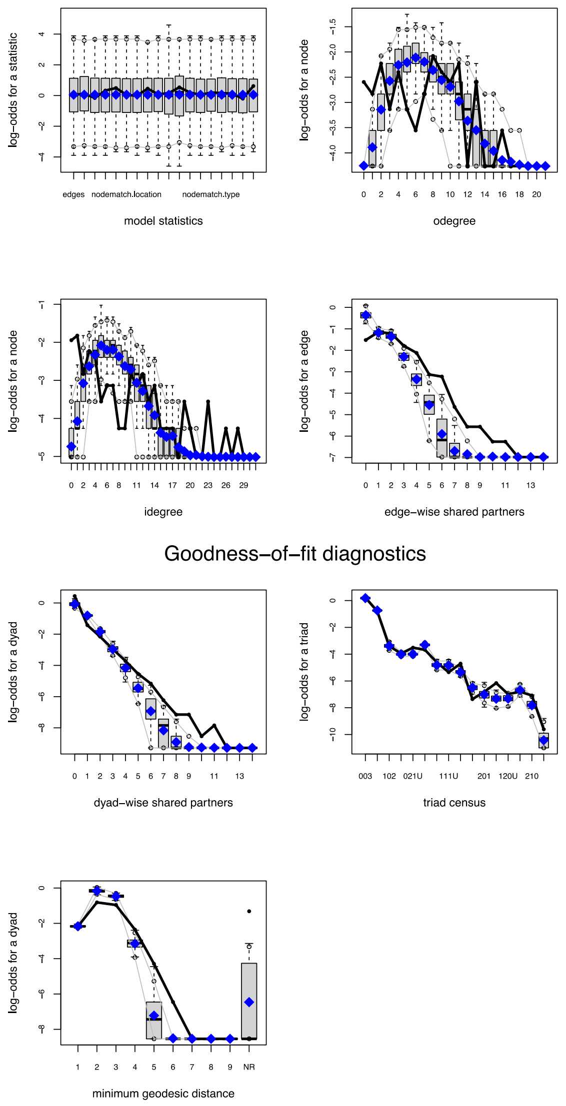


Case Reussebene, hypotheses 1 & 2

	Estimate	Std. Error	MCMC %	Z value	Pr (>|z|)
edges	-3.41	0.44	0	-7.75	0
mutual	0.15	0.19	0	0.8	0.43
esp1	-0.41	0.1	0	-4.18	0
EC.H1_length	0.1	0.21	0	0.49	0.63
EC.power	0.18	0.14	0	1.25	0.21
NM.location	1.09	0.1	0	10.76	0
NF.location.inter-cantonal	0.36	0.09	0	3.84	0
NF.location.Zug	0.07	0.09	0	0.79	0.43
NF.location.Zürich	-0.24	0.1	0	-2.44	0.01
NM.response	-0.46	0.12	0	-3.81	0
NF.response.add_later_no_answer	-0.04	0.35	0	-0.11	0.91
NF.response.normal_answer	1	0.22	0	4.54	0
NF.response.normal_no_answer	1.02	0.22	0	4.69	0
NM.type	0.22	0.11	0	1.99	0.05
NF.type.Federal_Office	-0.56	0.17	0	-3.3	0
NF.type.Municipality	-0.68	0.11	0	-6.11	0
NF.type.NGO_organization_association	-0.57	0.09	0	-6.04	0
NF.type.Other	-0.72	0.1	0	-6.95	0

	Estimate	Std. Error	MCMC %	Z value	Pr (>|z|)
edges	-3.4	0.44	0	-7.8	0
mutual	0.15	0.19	0	0.78	0.44
esp1	-0.41	0.1	0	-4.16	0
EC.H2_multiplexity	0.2	0.46	0	0.43	0.66
EC.power	0.18	0.14	0	1.25	0.21
NM.location	1.09	0.1	0	10.79	0
NF.location.inter-cantonal	0.36	0.09	0	3.78	0
NF.location.Zug	0.07	0.09	0	0.76	0.45
NF.location.Zürich	-0.24	0.1	0	-2.44	0.01
NM.response	-0.45	0.12	0	-3.75	0
NF.response.add_later_no_answer	-0.03	0.36	0	-0.08	0.94
NF.response.normal_answer	0.99	0.22	0	4.46	0
NF.response.normal_no_answer	1.01	0.21	0	4.73	0
NM.type	0.22	0.11	0	1.95	0.05
NF.type.Federal_Office	-0.55	0.17	0	-3.28	0
NF.type.Municipality	-0.68	0.11	0	-6.14	0
NF.type.NGO_organization_association	-0.57	0.09	0	-6.16	0
NF.type.Other	-0.73	0.11	0	-6.86	0

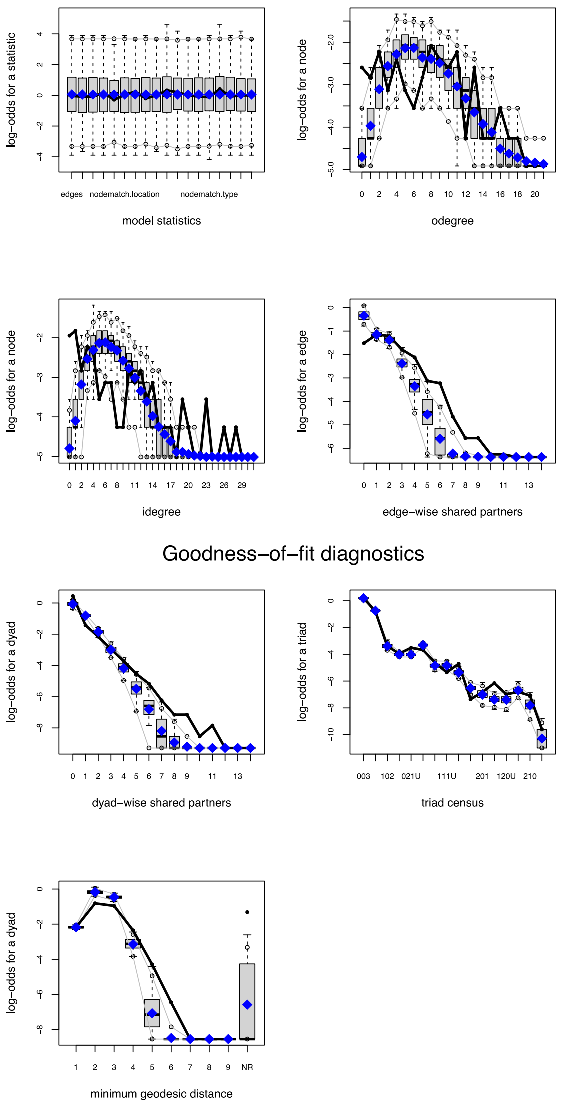


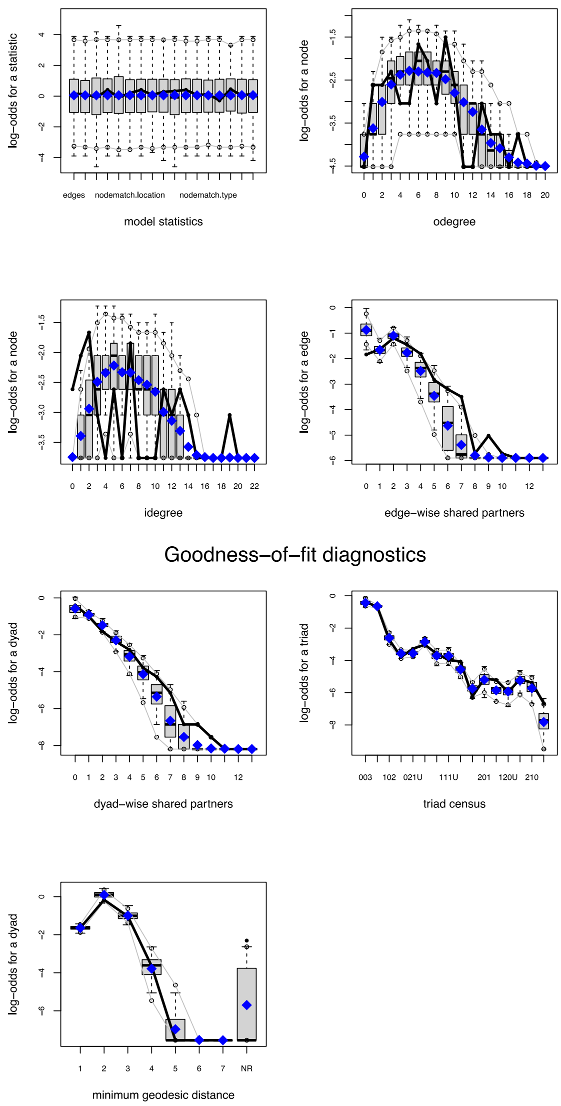


Case Reussebene, hypothesis 3 & case Rhonemündung, hypothesis 1

	Estimate	Std. Error	MCMC %	Z value	Pr (>|z|)
edges	-3.42	0.44	0	-7.74	0
mutual	0.15	0.18	0	0.8	0.42
esp1	-0.41	0.1	0	-4.34	0
EC.H3_similarity	0.21	0.21	0	1	0.32
EC.power	0.17	0.14	0	1.25	0.21
NM.location	1.09	0.1	0	10.62	0
NF.location.inter-cantonal	0.36	0.09	0	3.92	0
NF.location.Zug	0.08	0.09	0	0.83	0.4
NF.location.Zürich	-0.24	0.09	0	-2.49	0.01
NM.response	-0.45	0.12	0	-3.8	0
NF.response.add_later_no_answer	-0.05	0.35	0	-0.15	0.88
NF.response.normal_answer	0.99	0.22	0	4.42	0
NF.response.normal_no_answer	1.01	0.22	0	4.62	0
NM.type	0.23	0.11	0	2.06	0.04
NF.type.Federal_Office	-0.55	0.16	0	-3.37	0
NF.type.Municipality	-0.67	0.11	0	-6.06	0
NF.type.NGO_organization_association	-0.56	0.09	0	-6.18	0
NF.type.Other	-0.72	0.1	0	-7	0

	Estimate	Std. Error	MCMC %	Z value	Pr (>|z|)
edges	-2.62	0.73	0	-3.59	0
mutual	0.65	0.22	0	2.95	0
esp1	-0.73	0.14	0	-5.02	0
EC.H1_length	-0.19	0.32	0	-0.61	0.54
EC.power	0.37	0.17	0	2.16	0.03
NM.location	0.3	0.14	0	2.15	0.03
NF.location.Waadt	0.07	0.12	0	0.58	0.56
NF.location.Wallis	0	0.14	0	-0.01	0.99
NM.response	0.07	0.14	0	0.45	0.65
NF.response.add_later_no_answer	0.08	0.41	0	0.19	0.85
NF.response.normal_answer	0.63	0.37	0	1.69	0.09
NF.response.normal_no_answer	0.56	0.37	0	1.51	0.13
NM.type	0.11	0.15	0	0.73	0.47
NF.type.Federal_Office	-0.15	0.19	0	-0.76	0.44
NF.type.Municipality	-0.15	0.14	0	-1.05	0.29
NF.type.NGO_organization_association	-0.55	0.14	0	-3.99	0
NF.type.Other	-0.39	0.12	0	-3.33	0

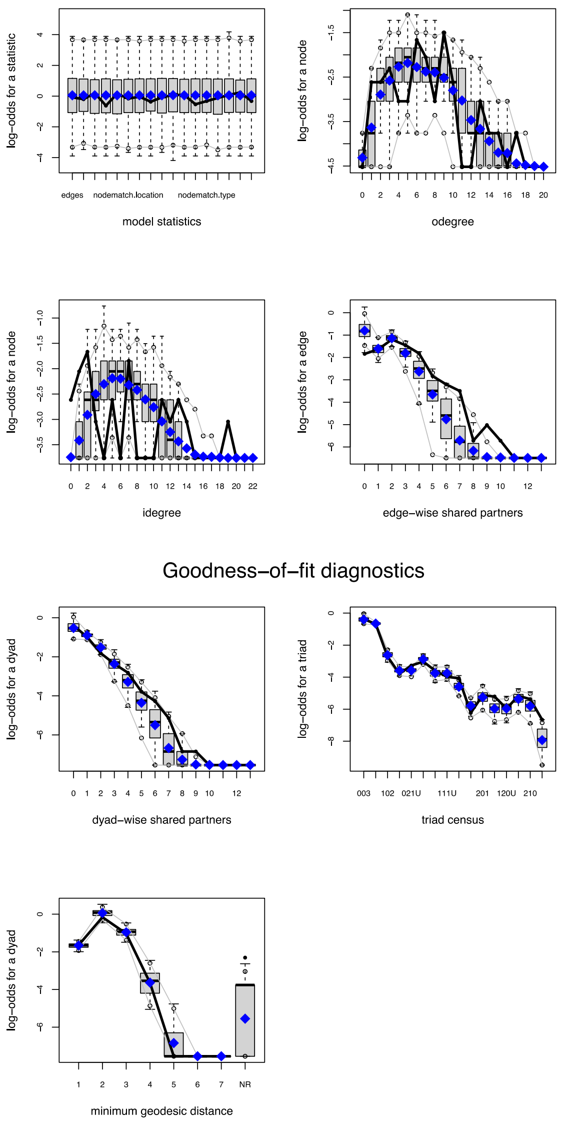


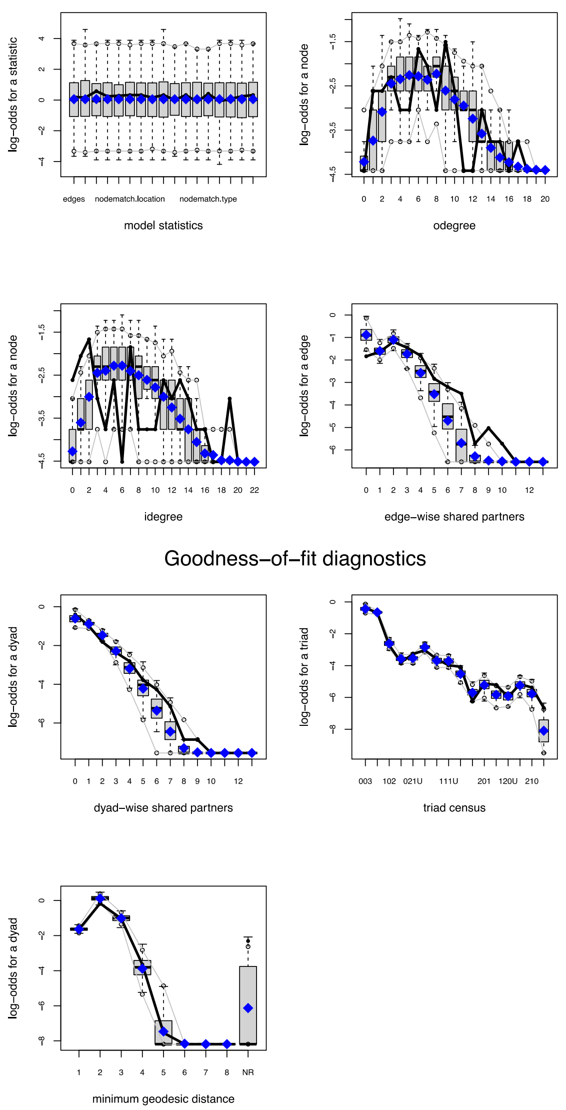


Case Rhonemündung, hypotheses 2 & 3

	Estimate	Std. Error	MCMC %	Z value	Pr (>|z|)
edges	-2.66	0.7	0	-3.81	0
mutual	0.66	0.21	0	3.09	0
esp1	-0.72	0.15	0	-4.9	0
EC.H2_multiplexity	-0.08	0.49	0	-0.16	0.87
EC.power	0.38	0.17	0	2.23	0.03
NM.location	0.3	0.14	0	2.17	0.03
NF.location.inter-cantonal	0.07	0.13	0	0.51	0.61
NF.location.other	0	0.15	0	-0.02	0.99
NM.response	0.08	0.14	0	0.56	0.57
NF.response.add_later_no_answer	0.09	0.4	0	0.23	0.82
NF.response.normal_answer	0.64	0.36	0	1.78	0.07
NF.response.normal_no_answer	0.57	0.36	0	1.59	0.11
NM.type	0.12	0.15	0	0.76	0.45
NF.type.Federal_Office	-0.15	0.18	0	-0.81	0.42
NF.type.Municipality	-0.16	0.14	0	-1.12	0.26
NF.type.NGO_organization_association	-0.55	0.13	0	-4.12	0
NF.type.Other	-0.39	0.12	0	-3.29	0

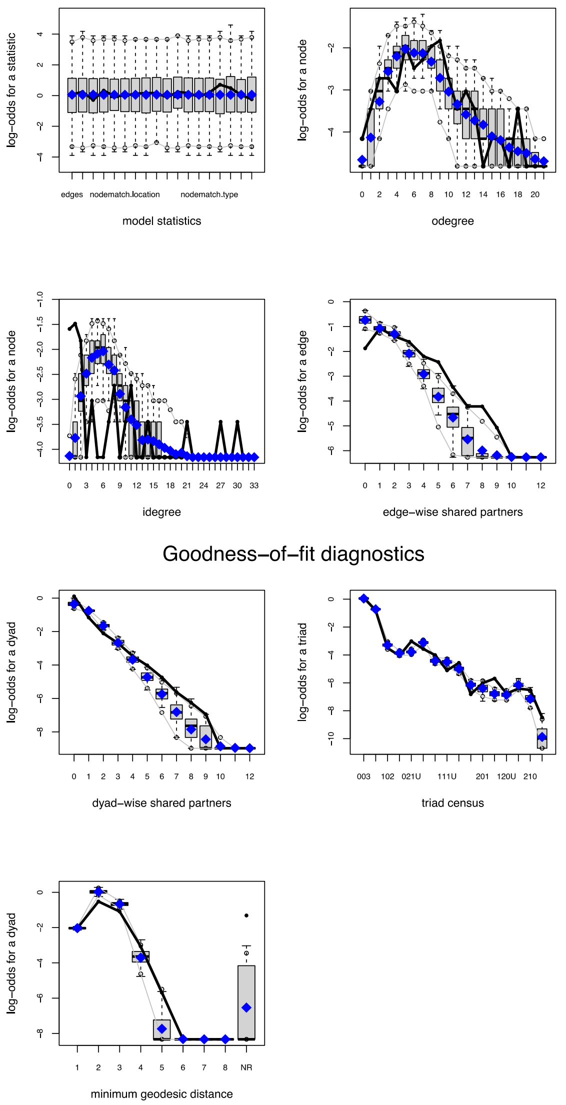
	Estimate	Std. Error	MCMC %	Z value	Pr (>|z|)
edges	-2.61	0.69	0	-3.79	0
mutual	0.66	0.22	0	3.03	0
esp1	-0.72	0.14	0	-5.07	0
EC.H3_similarity	-0.2	0.25	0	-0.8	0.42
EC.power	0.38	0.17	0	2.23	0.03
NM.location	0.29	0.14	0	2.11	0.03
NF.location.inter-cantonal	0.07	0.13	0	0.56	0.58
NF.location.other	0	0.15	0	-0.02	0.99
NM.response	0.08	0.14	0	0.56	0.57
NF.response.add_later_no_answer	0.08	0.39	0	0.2	0.84
NF.response.normal_answer	0.63	0.35	0	1.79	0.07
NF.response.normal_no_answer	0.57	0.35	0	1.6	0.11
NM.type	0.12	0.15	0	0.8	0.42
NF.type.Federal_Office	-0.15	0.19	0	-0.82	0.41
NF.type.Municipality	-0.16	0.14	0	-1.16	0.25
NF.type.NGO_organization_association	-0.56	0.14	0	-3.99	0
NF.type.Other	-0.4	0.12	0	-3.43	0



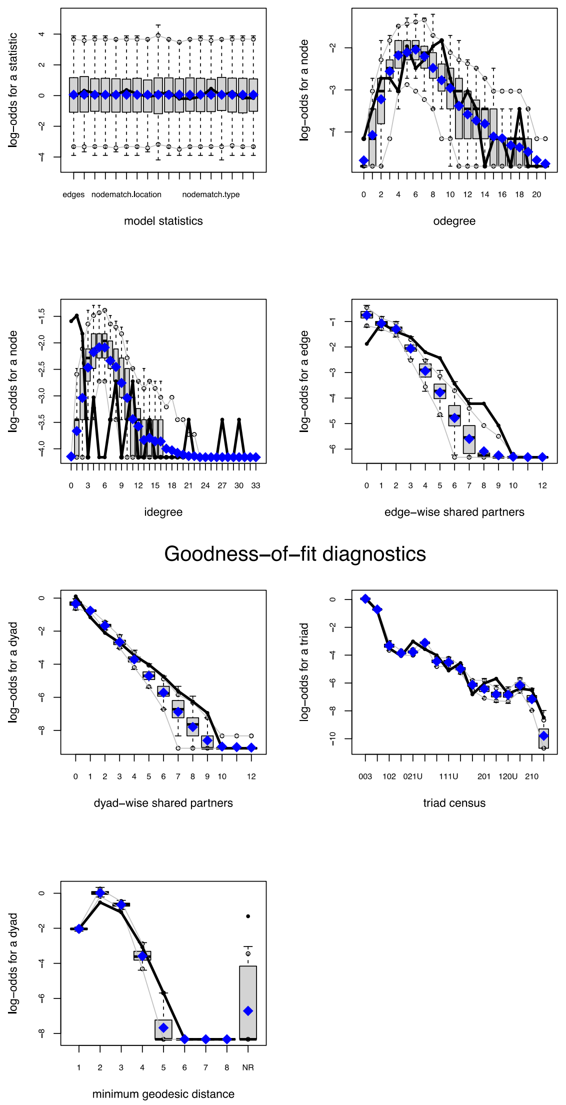


Case Sense, hypotheses 1 & 2

	Estimate	Std. Error	MCMC %	Z value	Pr (>|z|)
edges	-2.04	0.47	0	-4.37	0
mutual	0.19	0.19	0	0.98	0.32
esp1	-0.27	0.1	0	-2.82	0
EC.H1_length	0.24	0.22	0	1.12	0.26
EC.power	0.58	0.13	0	4.36	0
NM.location	0.54	0.11	0	4.93	0
NF.location.Fribourg	-0.16	0.07	0	-2.19	0.03
NF.location.inter-cantonal	0.08	0.13	0	0.61	0.54
NF.location.other	0.08	0.32	0	0.25	0.8
NM.response	-0.2	0.11	0	-1.9	0.06
NF.response.add_later_no_answer	-0.34	0.31	0	-1.1	0.27
NF.response.normal_answer	0.78	0.23	0	3.39	0
NF.response.normal_no_answer	0.45	0.23	0	1.96	0.05
NM.type	-0.32	0.13	0	-2.43	0.02
NF.type.Federal_Office	-0.83	0.22	0	-3.69	0
NF.type.Municipality	-0.77	0.1	0	-7.45	0
NF.type.NGO_organization_association	-0.59	0.13	0	-4.6	0
NF.type.Other	-0.95	0.13	0	-7.29	0

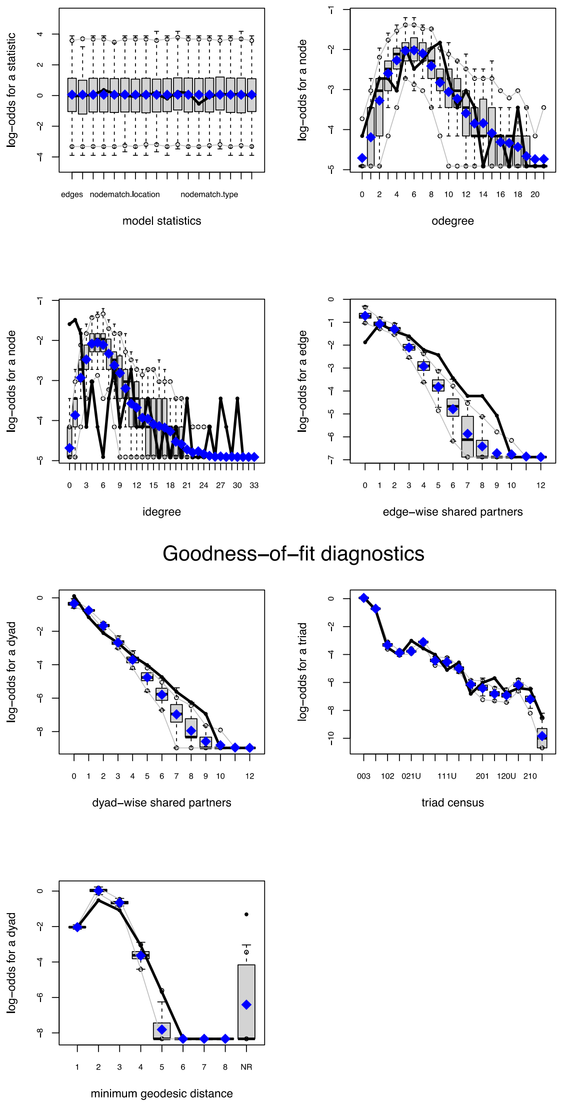


	Estimate	Std. Error	MCMC %	Z value	Pr (>|z|)
edges	-2.04	0.47	0	-4.35	0
mutual	0.18	0.2	0	0.93	0.35
esp1	-0.27	0.1	0	-2.7	0.01
EC.H2_multiplexity	0.41	0.4	0	1.02	0.31
EC.power	0.58	0.13	0	4.31	0
NM.location	0.53	0.1	0	5.1	0
NF.location.Fribourg	-0.16	0.07	0	-2.11	0.03
NF.location.inter-cantonal	0.08	0.14	0	0.55	0.58
NF.location.other	0.06	0.32	0	0.2	0.84
NM.response	-0.21	0.11	0	-1.98	0.05
NF.response.add_later_no_answer	-0.34	0.31	0	-1.11	0.27
NF.response.normal_answer	0.79	0.23	0	3.43	0
NF.response.normal_no_answer	0.45	0.23	0	2	0.05
NM.type	-0.32	0.13	0	-2.41	0.02
NF.type.Federal_Office	-0.83	0.22	0	-3.78	0
NF.type.Municipality	-0.78	0.1	0	-7.51	0
NF.type.NGO_organization_association	-0.59	0.13	0	-4.62	0
NF.type.Other	-0.95	0.12	0	-7.6	0

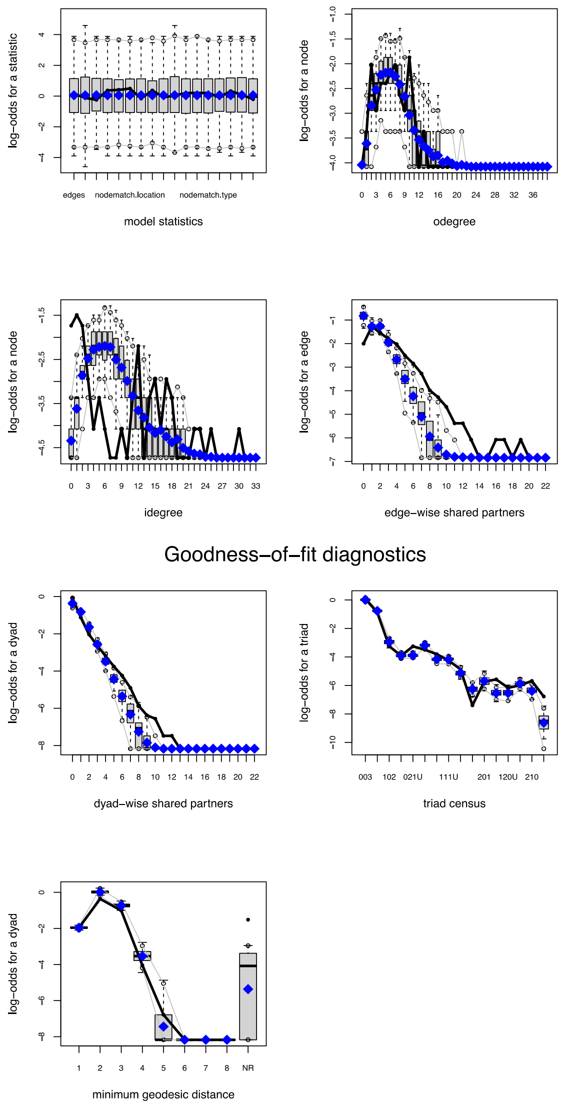


Case Sense, hypothesis 3 & Case Untere Saane, hypothesis 1

	Estimate	Std. Error	MCMC %	Z value	Pr (>|z|)
edges	-2.05	0.48	0	-4.3	0
mutual	0.18	0.2	0	0.92	0.36
esp1	-0.27	0.1	0	-2.68	0.01
EC.H3_similarity	0.19	0.17	0	1.08	0.28
EC.power	0.58	0.13	0	4.34	0
NM.location	0.53	0.1	0	5.11	0
NF.location.Fribourg	-0.16	0.07	0	-2.25	0.02
NF.location.inter-cantonal	0.08	0.13	0	0.62	0.53
NF.location.other	0.06	0.31	0	0.2	0.84
NM.response	-0.2	0.11	0	-1.85	0.06
NF.response.add_later_no_answer	-0.35	0.3	0	-1.15	0.25
NF.response.normal_answer	0.79	0.23	0	3.38	0
NF.response.normal_no_answer	0.46	0.23	0	1.97	0.05
NM.type	-0.32	0.13	0	-2.47	0.01
NF.type.Federal_Office	-0.83	0.23	0	-3.66	0
NF.type.Municipality	-0.78	0.1	0	-7.65	0
NF.type.NGO_organization_association	-0.59	0.12	0	-4.74	0
NF.type.Other	-0.95	0.13	0	-7.23	0



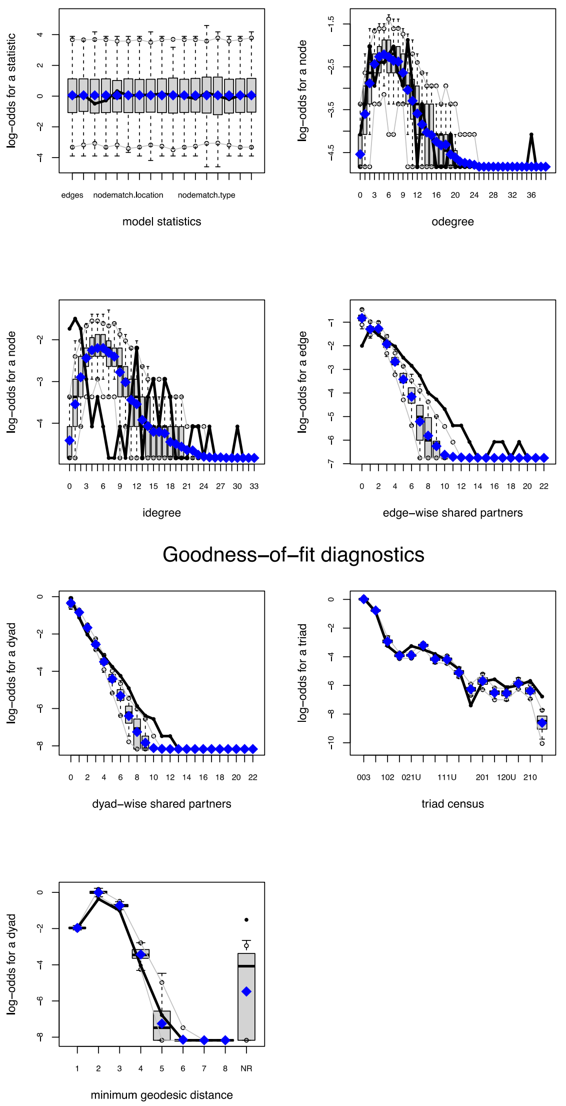
	Estimate	Std. Error	MCMC %	Z value	Pr (>|z|)
edges	-3.21	0.74	0	-4.37	0
mutual	0.63	0.19	0	3.31	0
esp1	-0.37	0.11	0	-3.47	0
EC.H1_length	0.44	0.24	0	1.81	0.07
EC.power	0.36	0.14	0	2.59	0.01
NM.location	0.37	0.12	0	3.09	0
NF.location.inter-cantonal	0.57	0.11	0	5.02	0
NF.location.other	0.36	0.29	0	1.24	0.21
NM.response	-0.11	0.11	0	-1.04	0.3
NF.response.add_later_no_answer	0.19	0.4	0	0.47	0.64
NF.response.normal_answer	1.27	0.36	0	3.51	0
NF.response.normal_no_answer	0.69	0.36	0	1.91	0.06
NM.type	0.07	0.13	0	0.55	0.58
NF.type.Federal_Office	-0.76	0.18	0	-4.15	0
NF.type.Municipality	-0.77	0.12	0	-6.24	0
NF.type.NGO_organization_association	-0.69	0.12	0	-5.92	0
NF.type.Other	-0.8	0.13	0	-6.2	0

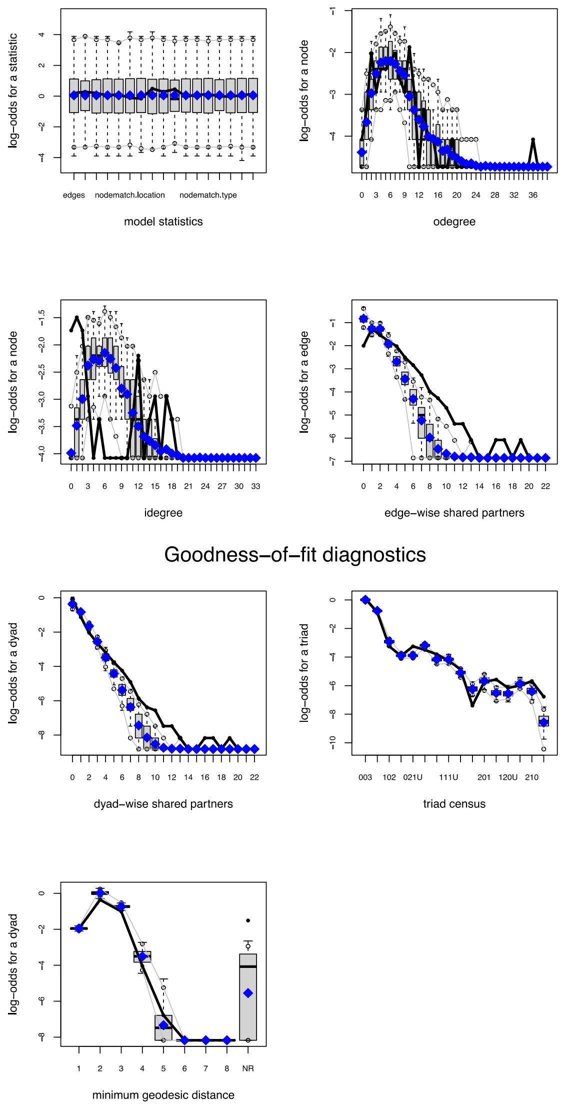


Case Untere Saane, hypotheses 2 & 3

	Estimate	Std. Error	MCMC %	Z value	Pr (>|z|)
edges	-3.23	0.71	0	-4.53	0
mutual	0.64	0.19	0	3.35	0
esp1	-0.37	0.11	0	-3.39	0
EC.H2_multiplexity	0.62	0.47	0	1.34	0.18
EC.power	0.36	0.14	0	2.51	0.01
NM.location	0.37	0.13	0	2.9	0
NF.location.inter-cantonal	0.57	0.12	0	4.81	0
NF.location.other	0.36	0.29	0	1.25	0.21
NM.response	-0.12	0.11	0	-1.08	0.28
NF.response.add_later_no_answer	0.19	0.38	0	0.51	0.61
NF.response.normal_answer	1.29	0.34	0	3.76	0
NF.response.normal_no_answer	0.72	0.36	0	2.02	0.04
NM.type	0.07	0.13	0	0.54	0.59
NF.type.Federal_Office	-0.76	0.18	0	-4.17	0
NF.type.Municipality	-0.77	0.13	0	-6.15	0
NF.type.NGO_organization_association	-0.7	0.12	0	-5.6	0
NF.type.Other	-0.8	0.14	0	-5.81	0

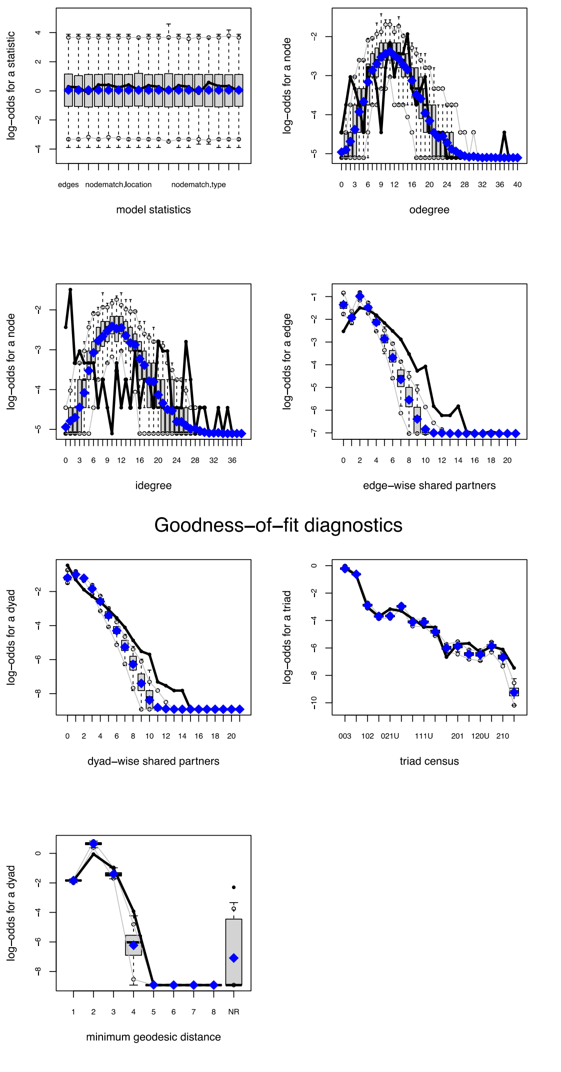
	Estimate	Std. Error	MCMC %	Z value	Pr (>|z|)
edges	-3.23	0.73	0	-4.41	0
mutual	0.65	0.19	0	3.51	0
esp1	-0.37	0.11	0	-3.48	0
EC.H3_similarity	0.34	0.24	0	1.44	0.15
EC.power	0.36	0.14	0	2.58	0.01
NM.location	0.36	0.12	0	2.99	0
NF.location.inter-cantonal	0.56	0.11	0	5.03	0
NF.location.other	0.37	0.3	0	1.25	0.21
NM.response	-0.11	0.11	0	-1.03	0.3
NF.response.add_later_no_answer	0.2	0.4	0	0.5	0.62
NF.response.normal_answer	1.28	0.36	0	3.58	0
NF.response.normal_no_answer	0.7	0.36	0	1.97	0.05
NM.type	0.07	0.13	0	0.57	0.57
NF.type.Federal_Office	-0.74	0.19	0	-3.92	0
NF.type.Municipality	-0.76	0.13	0	-5.95	0
NF.type.NGO_organization_association	-0.69	0.12	0	-5.76	0
NF.type.Other	-0.8	0.13	0	-6.07	0



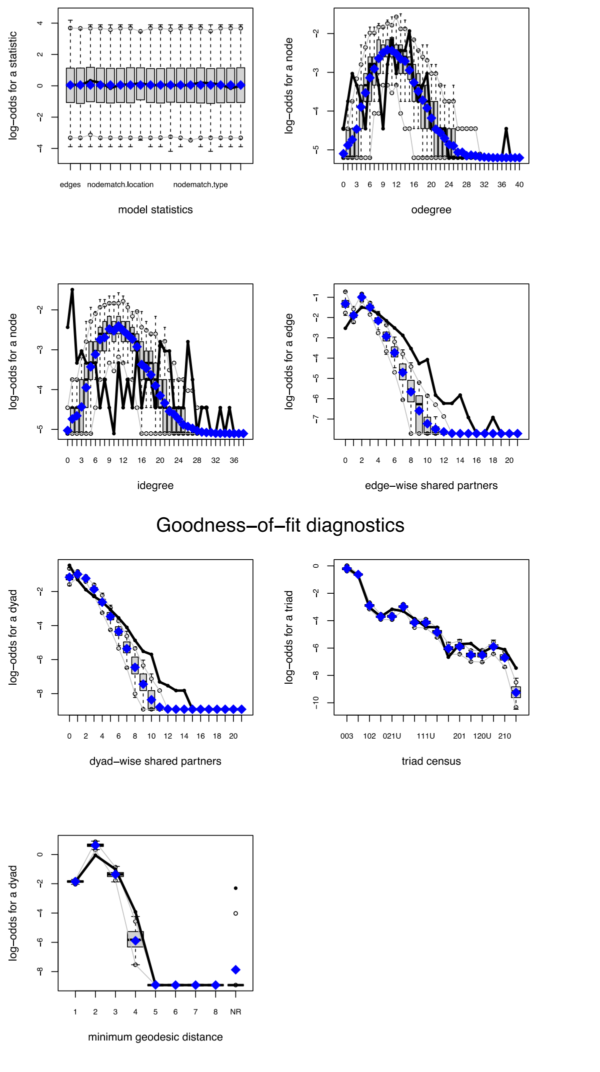


Case Rhein, hypotheses 1 & 2 (additional ERGM results and GOF statistics not included in the analysis)

	Estimate	Std. Error	MCMC %	Z value	Pr (>|z|)
edges	-5.29	1.25	0	-4.24	0
mutual	0.61	0.12	0	4.94	0
esp1	-0.87	0.09	0	-9.75	0
EC.H1_length	-0.03	0.16	0	-0.17	0.86
EC.power	0.32	0.09	0	3.39	0
NM.location	0.38	0.07	0	5.73	0
NF.location.inter-cantonal	0.17	0.05	0	3.59	0
NF.location.other	0.2	0.24	0	0.83	0.41
NF.location.St. Gallen	0.12	0.04	0	2.8	0.01
NM.response	-0.09	0.07	0	-1.2	0.23
NF.response.add_later_no_answer	1.65	0.63	0	2.63	0.01
NF.response.normal_answer	1.85	0.62	0	2.98	0
NF.response.normal_no_answer	1.78	0.62	0	2.86	0
NM.type	0.06	0.08	0	0.76	0.45
NF.type.Federal_Office	-0.48	0.1	0	-4.58	0
NF.type.Municipality	-0.29	0.07	0	-4.14	0
NF.type.NGO_organization_association	-0.38	0.07	0	-5.63	0
NF.type.Other	-0.46	0.07	0	-6.29	0

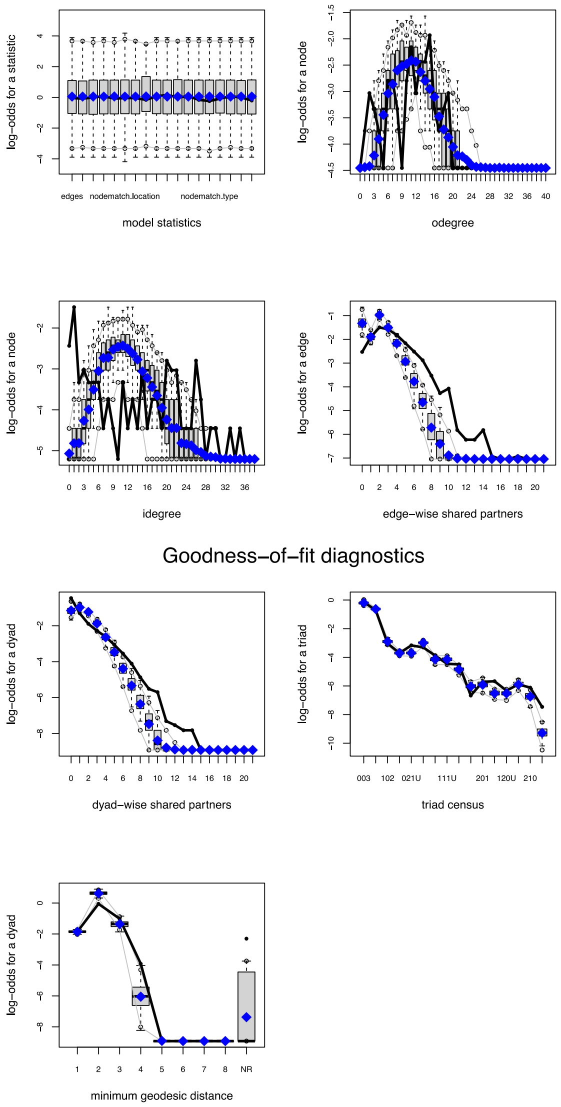


	Estimate	Std. Error	MCMC %	Z value	Pr (>|z|)
edges	-5.26	1.21	0	-4.34	0
mutual	0.61	0.12	0	5.14	0
esp1	-0.87	0.09	0	-9.69	0
EC.H2_multiplexity	-0.02	0.33	0	-0.06	0.95
EC.power	0.32	0.09	0	3.47	0
NM.location	0.38	0.07	0	5.81	0
NF.location.inter-cantonal	0.17	0.05	0	3.63	0
NF.location.other	0.19	0.23	0	0.81	0.42
NF.location.St. Gallen	0.12	0.04	0	2.85	0
NM.response	-0.09	0.07	0	-1.2	0.23
NF.response.add_later_no_answer	1.64	0.61	0	2.69	0.01
NF.response.normal_answer	1.84	0.6	0	3.04	0
NF.response.normal_no_answer	1.76	0.6	0	2.92	0
NM.type	0.06	0.08	0	0.75	0.45
NF.type.Federal_Office	-0.48	0.1	0	-4.6	0
NF.type.Municipality	-0.29	0.07	0	-4.15	0
NF.type.NGO_organization_association	-0.38	0.07	0	-5.8	0
NF.type.Other	-0.46	0.07	0	-6.4	0

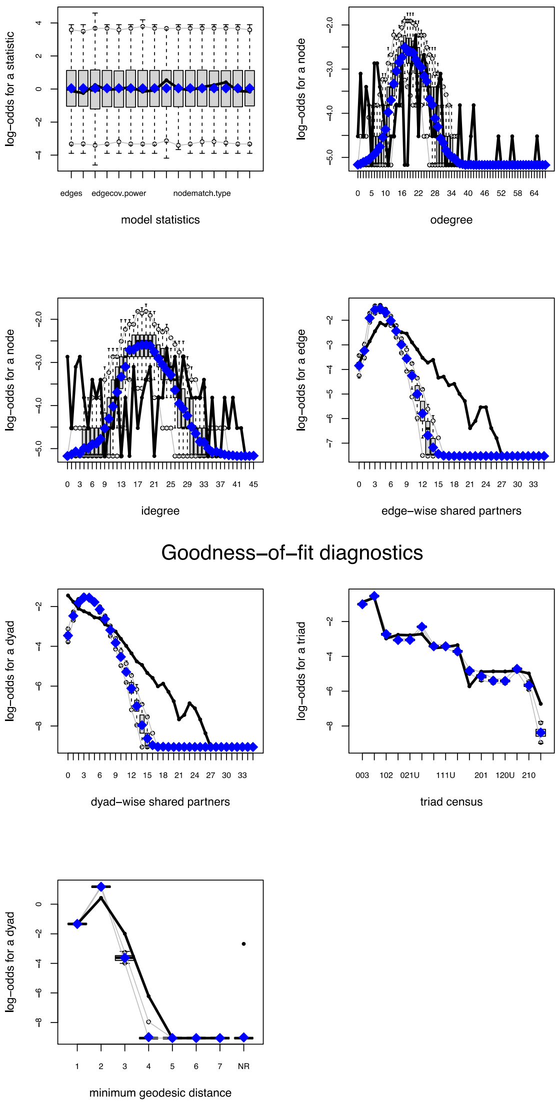


Case Rhein, hypothesis 3 & Case Maggia, hypothesis 1 (additional ERGM results and GOF statistics not included in the analysis)

	Estimate	Std. Error	MCMC %	Z value	Pr (>|z|)
edges	-5.28	1.24	0	-4.27	0
mutual	0.61	0.12	0	5.01	0
esp1	-0.87	0.09	0	-9.76	0
EC.H3_similarity	-0.04	0.16	0	-0.27	0.79
EC.power	0.32	0.09	0	3.5	0
NM.location	0.38	0.07	0	5.68	0
NF.location.inter-cantonal	0.17	0.05	0	3.51	0
NF.location.other	0.2	0.23	0	0.86	0.39
NF.location.St. Gallen	0.12	0.04	0	2.91	0
NM.response	-0.09	0.07	0	-1.17	0.24
NF.response.add_later_no_answer	1.65	0.62	0	2.66	0.01
NF.response.normal_answer	1.85	0.62	0	2.99	0
NF.response.normal_no_answer	1.77	0.62	0	2.87	0
NM.type	0.06	0.08	0	0.77	0.44
NF.type.Federal_Office	-0.48	0.11	0	-4.51	0
NF.type.Municipality	-0.29	0.07	0	-4.19	0
NF.type.NGO_organization_association	-0.38	0.06	0	-5.84	0
NF.type.Other	-0.46	0.07	0	-6.52	0



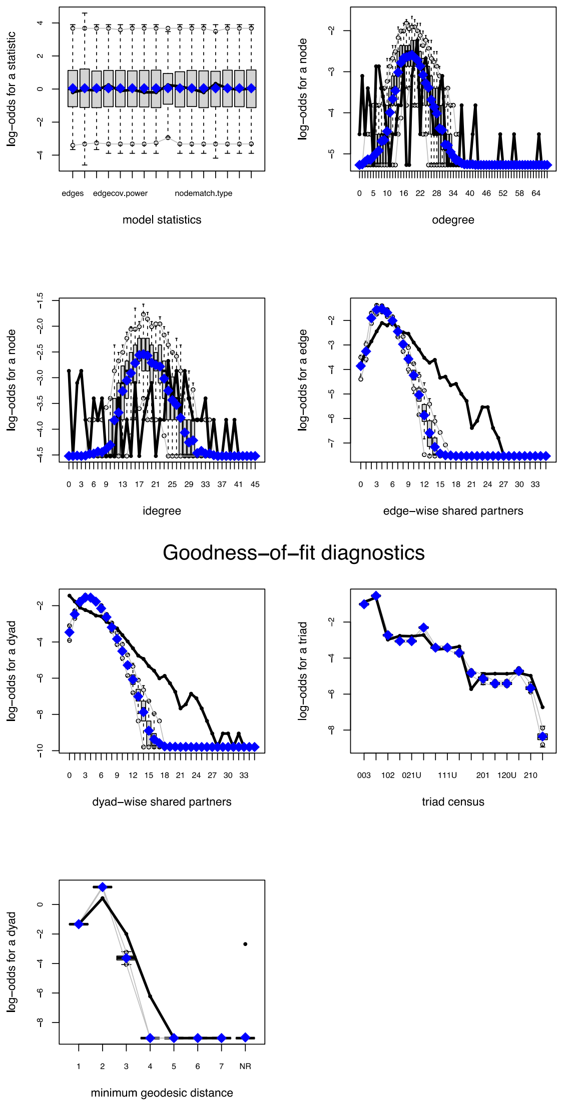
	Estimate	Std. Error	MCMC %	Z value	Pr (>|z|)
edges	-2.4	0.4	0	-6.03	0
mutual	0.23	0.09	0	2.6	0.01
esp1	-0.61	0.13	0	-4.79	0
EC.H1_length	0.04	0.1	0	0.4	0.69
EC.power	0.16	0.08	0	2.14	0.03
NM.location	0.17	0.12	0	1.39	0.17
NF.location.Tessin	-0.08	0.12	0	-0.71	0.48
NM.response	0.02	0.05	0	0.28	0.78
NF.response.add_later_no_answer	0.27	0.27	0	0.99	0.32
NF.response.normal_answer	0.88	0.18	0	4.93	0
NF.response.normal_no_answer	0.81	0.18	0	4.62	0
NM.type	-0.04	0.07	0	-0.56	0.58
NF.type.Federal_Office	-0.29	0.13	0	-2.35	0.02
NF.type.Municipality	-0.26	0.06	0	-4.18	0
NF.type.NGO_organization_association	-0.49	0.07	0	-7.38	0
NF.type.Other	-0.63	0.07	0	-9.01	0

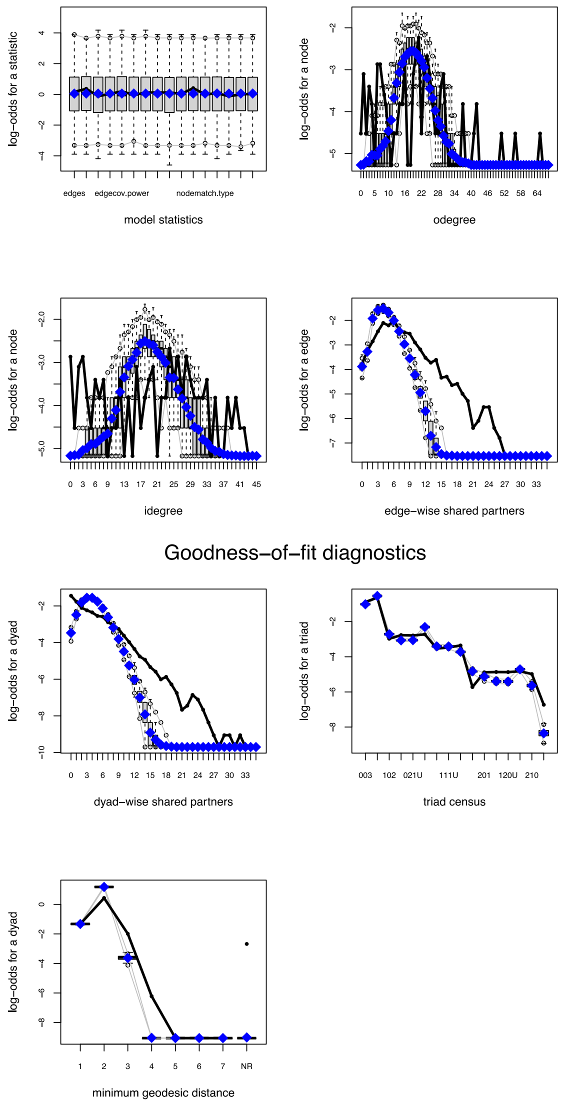


Case Maggia, hypotheses 2 & 3 (additional ERGM results and GOF statistics not included in the analysis)

	Estimate	Std. Error	MCMC %	Z value	Pr (>|z|)
edges	-2.4	0.41	0	-5.85	0
mutual	0.23	0.09	0	2.59	0.01
esp1	-0.62	0.13	0	-4.87	0
EC.H2_multiplexity	0.03	0.22	0	0.13	0.9
EC.power	0.17	0.08	0	2.18	0.03
NM.location	0.16	0.12	0	1.36	0.17
NF.location.Tessin	-0.08	0.12	0	-0.68	0.5
NM.response	0.02	0.06	0	0.39	0.7
NF.response.add_later_no_answer	0.26	0.27	0	0.95	0.34
NF.response.normal_answer	0.88	0.19	0	4.77	0
NF.response.normal_no_answer	0.81	0.18	0	4.4	0
NM.type	-0.04	0.07	0	-0.64	0.52
NF.type.Federal_Office	-0.3	0.12	0	-2.49	0.01
NF.type.Municipality	-0.27	0.06	0	-4.32	0
NF.type.NGO_organization_association	-0.49	0.07	0	-7.49	0
NF.type.Other	-0.64	0.06	0	-9.95	0

	Estimate	Std. Error	MCMC %	Z value	Pr (>|z|)
edges	-2.39	0.41	0	-5.83	0
mutual	0.24	0.09	0	2.6	0.01
esp1	-0.62	0.13	0	-4.75	0
EC.H1_length	0.01	0.1	0	0.07	0.94
EC.power	0.16	0.07	0	2.26	0.02
NM.location	0.17	0.12	0	1.44	0.15
NF.location.Tessin	-0.09	0.12	0	-0.78	0.44
NM.response	0.02	0.06	0	0.4	0.69
NF.response.add_later_no_answer	0.26	0.27	0	0.99	0.32
NF.response.normal_answer	0.89	0.18	0	4.86	0
NF.response.normal_no_answer	0.81	0.18	0	4.48	0
NM.type	-0.03	0.07	0	-0.47	0.64
NF.type.Federal_Office	-0.31	0.13	0	-2.45	0.01
NF.type.Municipality	-0.27	0.06	0	-4.14	0
NF.type.NGO_organization_association	-0.49	0.07	0	-7.33	0
NF.type.Other	-0.63	0.07	0	-9.13	0





Appendix C – Who is satisfied with their inclusion in polycentric sustainability governance? Network embedding, power and procedural justice in Swiss wetlands

Bayesian Analysis Reporting Guidelines list of key reporting points

BARG Reporting steps	
Step 1. Explain the model	
A. Data variables. Explain the dependent (predicted) variables and independent (predictor) variables.	Section: Variables and measurement (Satisfaction with inclusion in the governance process), Distributions: Figure A27
B. Likelihood function and parameters. For every model, explain the likelihood function and all the parameters, distinguishing clearly between parameters of primary theoretical interest and ancillary parameters. If the model is multilevel, be sure that the hierarchical structure is clearly explained, along with any covariance structure if multivariate parameter distributions are used.	Section: Model specification
C. Prior distribution. For every model, explain and justify the prior distribution of the parameters in the model.	Subsection: Prior distributions and predictive checks
D. Formal specification. Include a formal specification (mathematical or computer code) of the likelihood and prior, located either in the main text or in in publicly and persistently accessible online supplementary material.	Section: Model specification, equations 1, 2 and 3, computer code accessible in online repository
E. Prior predictive check. Especially when using informed priors but even with broad priors, it is valuable to report a prior predictive check to demonstrate that the prior really generates simulated data consistent with the assumed prior knowledge.	Subsection: Prior distributions and predictive checks, Figure A29
Step 2. Report details of the computation	
A. Software. Report the software used, including any specific added packages or plugins	Subsection: Computation
B. MCMC chain convergence. Report evidence that the chains have converged, using a convergence statistic such as PSRF, for every parameter or derived value.	Subsection: Computation

C. MCMC chain resolution. Report evidence that the chains have high resolution, using the ESS, for every parameter or derived value.	Subsection: Computation, Table A15
D. . If not MCMC.	not applicable
Step 3. Describe the posterior distribution	
A. Posterior predictive check. Provide a posterior predictive check to show that the model usefully mimics the data.	Subsection: Prior distributions and predictive checks, Figure A29
B. Summarize posterior of variables. For continuous parameters, derived variables and predicted values, report the central tendency and limits of the credible interval. Explicitly state whether you are using density-based values (mode and HDI) or quantile-based values (median and ETI), and state the mass of the credible interval (for example, 95%).	Figure A30 & Figure A31
C. BF and posterior model probabilities.	not applicable
Step 4. Report decisions (if any) and their criteria	
Step 5. Report sensitivity analysis	
A. For broad priors. If the prior is intended to be vague or only mildly informed so that it has minimal influence on the posterior, show that other vague priors produce similar posterior results.	Figure A29
B. For informed priors	not applicable
C. For default priors. If using a default prior, show the effect of varying its settings. Be sure that the range of default priors constitutes theoretically meaningful priors, and consider whether they mimic plausible empirically informed priors.	Figure A32 & Figure A33
D. BFs and model probabilites.	not applicable
E. Decisions	not applicable
Step 6. Make it reproducible	see online repository

Table A14: Bayesian Analysis Reporting Guidelines list of key reporting points, based on (Kruschke, 2021) and where these points are addressed in the article. We also include points and steps not applicable in order to be transparent about what we deemed not applicable. The requirements of step 6 (Reproducibility) are addressed in an online repository.

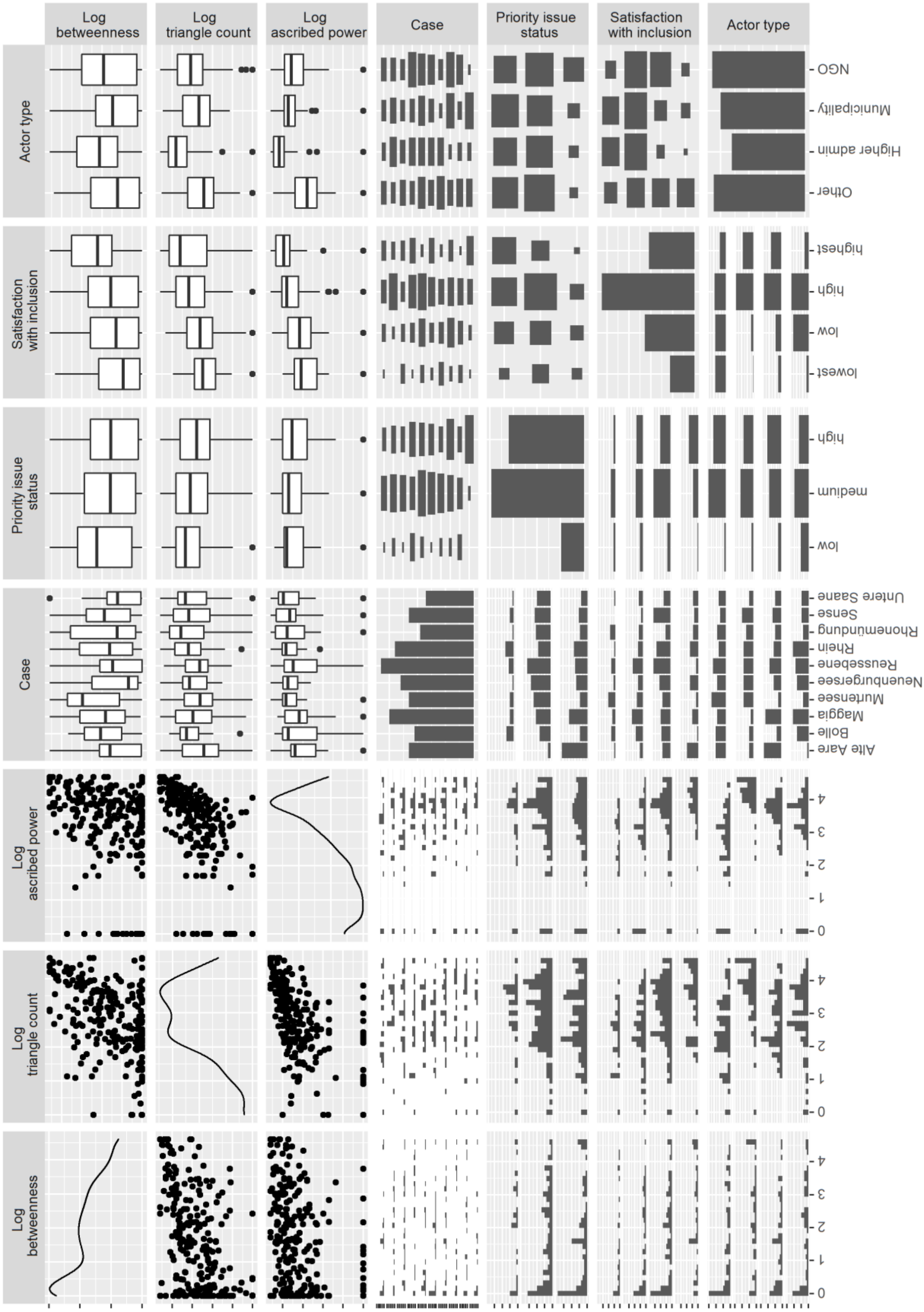


Figure A27: Distributions (diagonal) and pairwise interactions (off diagonal) for all variables used in modeling. Only complete cases (n = 243) are shown.

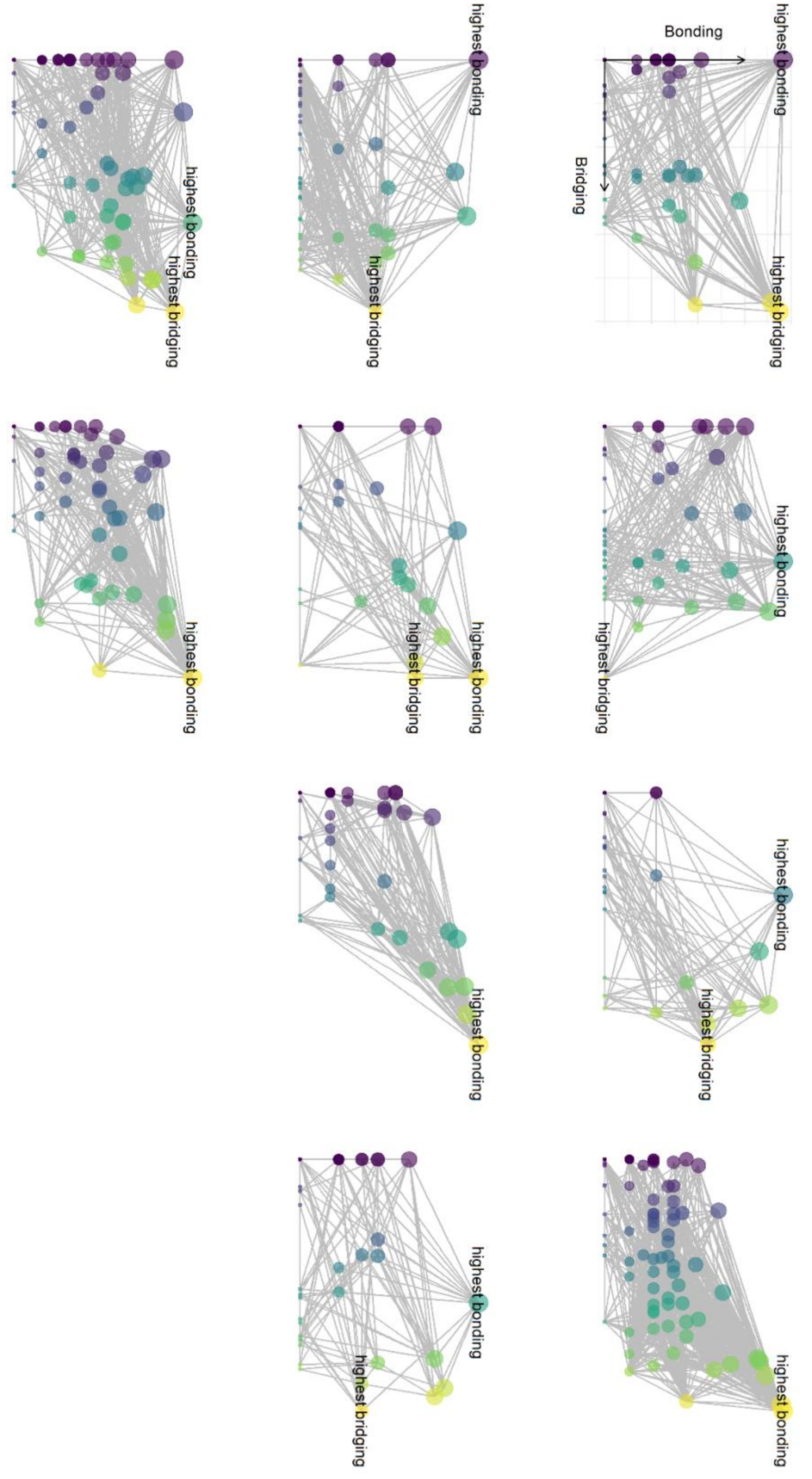


Figure A28: Network plots of undirected collaboration networks (combining positive, neutral and negative ties) across all ten cases with functional structure in terms of bridging versus bonding social capital emphasized in node placement. Isolates not shown. If only highest bonding is labeled, highest bonding equals highest bridging in the case.

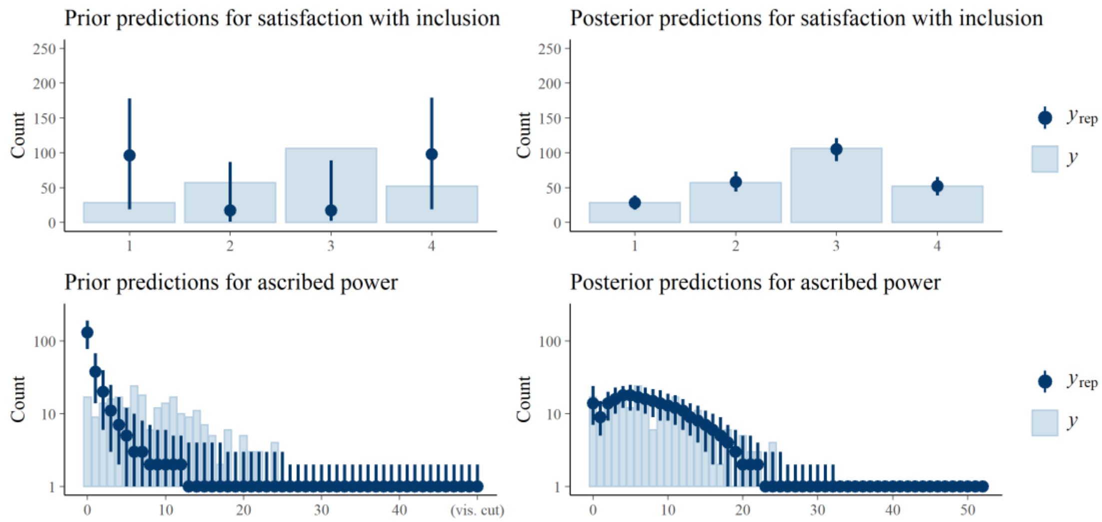


Figure A29: Prior (left panel) vs. posterior predictions (right panel) of regression model (y_{rep} versus empirical distribution y of outcome categories).

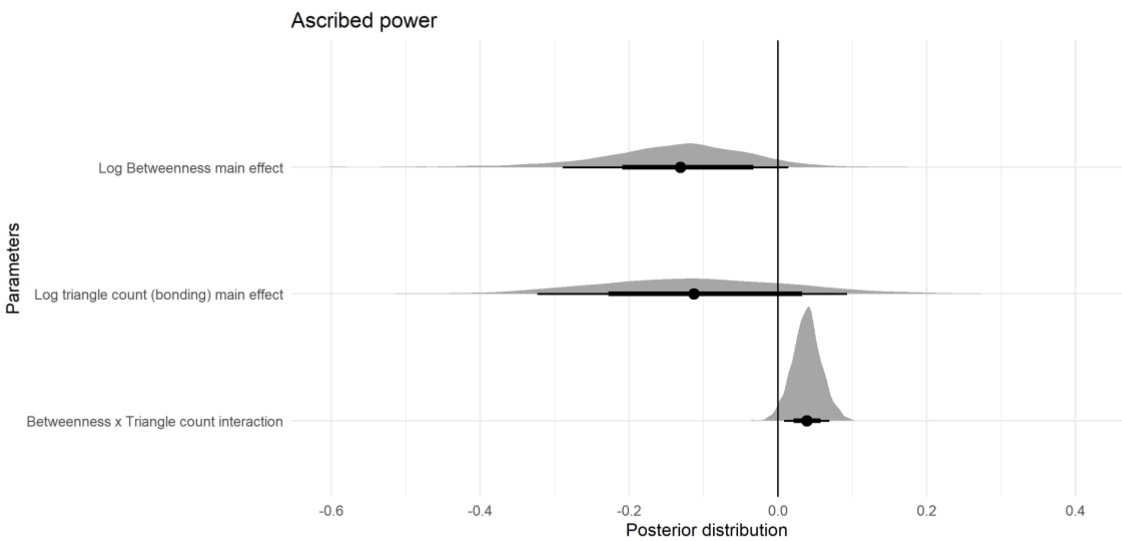


Figure A30: Posterior distributions of β model parameters for zero-inflated ordinal regression part of model (predicting ascribed power). Dots indicate median high posterior density interval values. Thick horizontal bars indicate 66% credible intervals, thin horizontal bars 88% credible intervals.

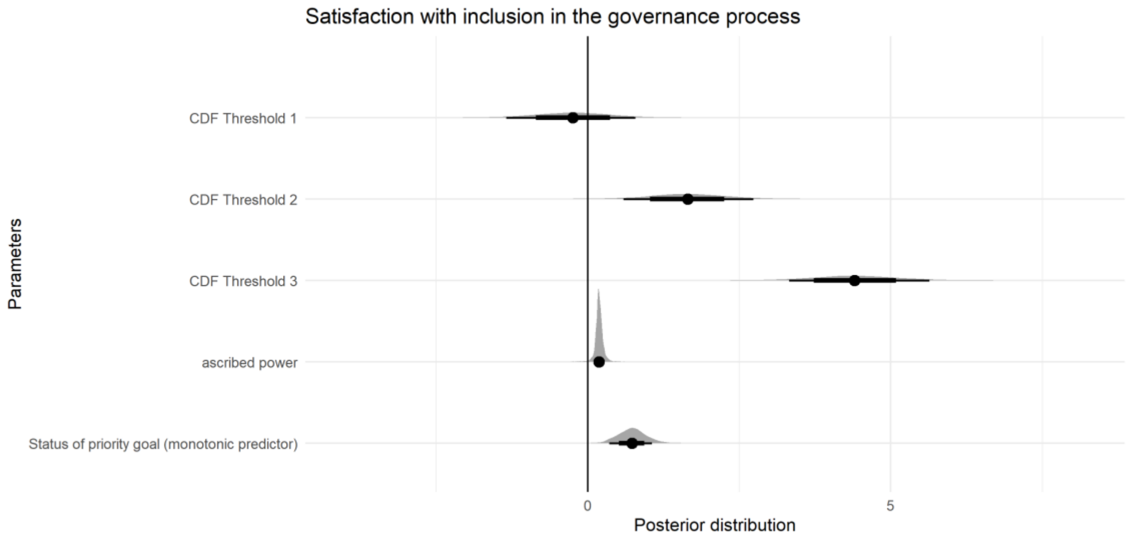


Figure A31: Posterior distributions of β and CDF threshold model parameters for zero-inflated ordinal regression part of model (predicting satisfaction with inclusion in governance process). Dots indicate median high posterior density interval values. Thick horizontal bars indicate 66% credible intervals, thin horizontal bars 88% credible intervals.

Table A15: Tail effective sample size for main model parameters

Parameter	***Tail ESS***
Satisfaction with inclusion model	
CDF threshold 1	*2432*
CDF threshold 2	*2540*
CDF threshold 3	*2397*
Ascribed power	*1534*
Status of priority goal (monotonic predictor)	*3250*
Ascribed power model	
Log betweenness	*1976*
Log triangle count	*1889*
Triangle count x Betweenness interaction	*2555*

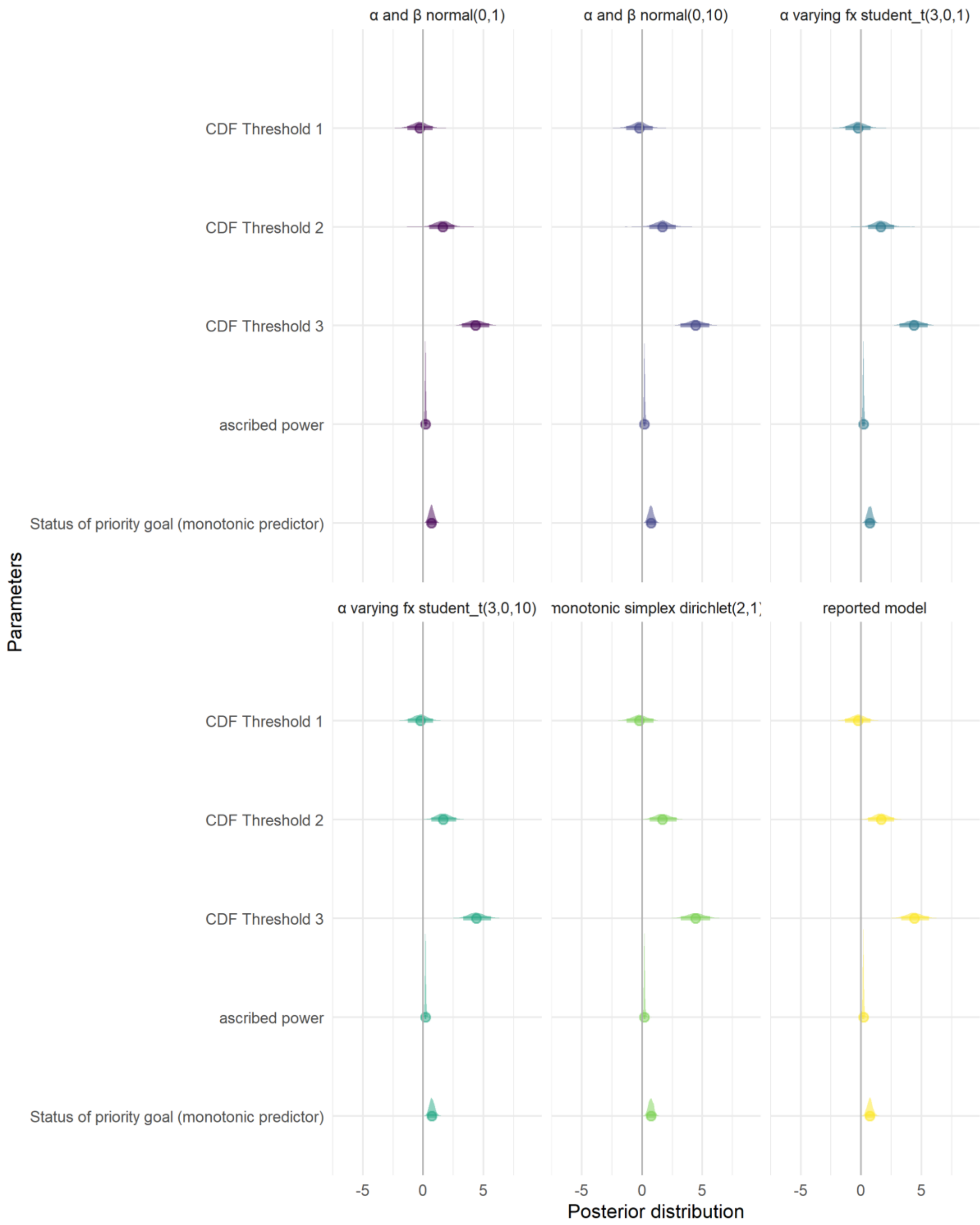


Figure A32: Sensitivity of posterior distribution of α and β parameters to different prior settings for ordinal regression model parameters. Variation to the reported model was introduced both by varying priors for weakly informative β and α parameters and by introducing variation on default parameters for the dirichlet distribution on the monotonic effect simplex parameter and for the student-t distribution on the varying intercept and slopes parameters of the multi-level model. The highest posterior density intervals are shown. Point estimates (dots) are medians. Thick horizontal lines indicate 88% credible intervals. Sensitivity was assessed on a model without imputation for computational efficiency.

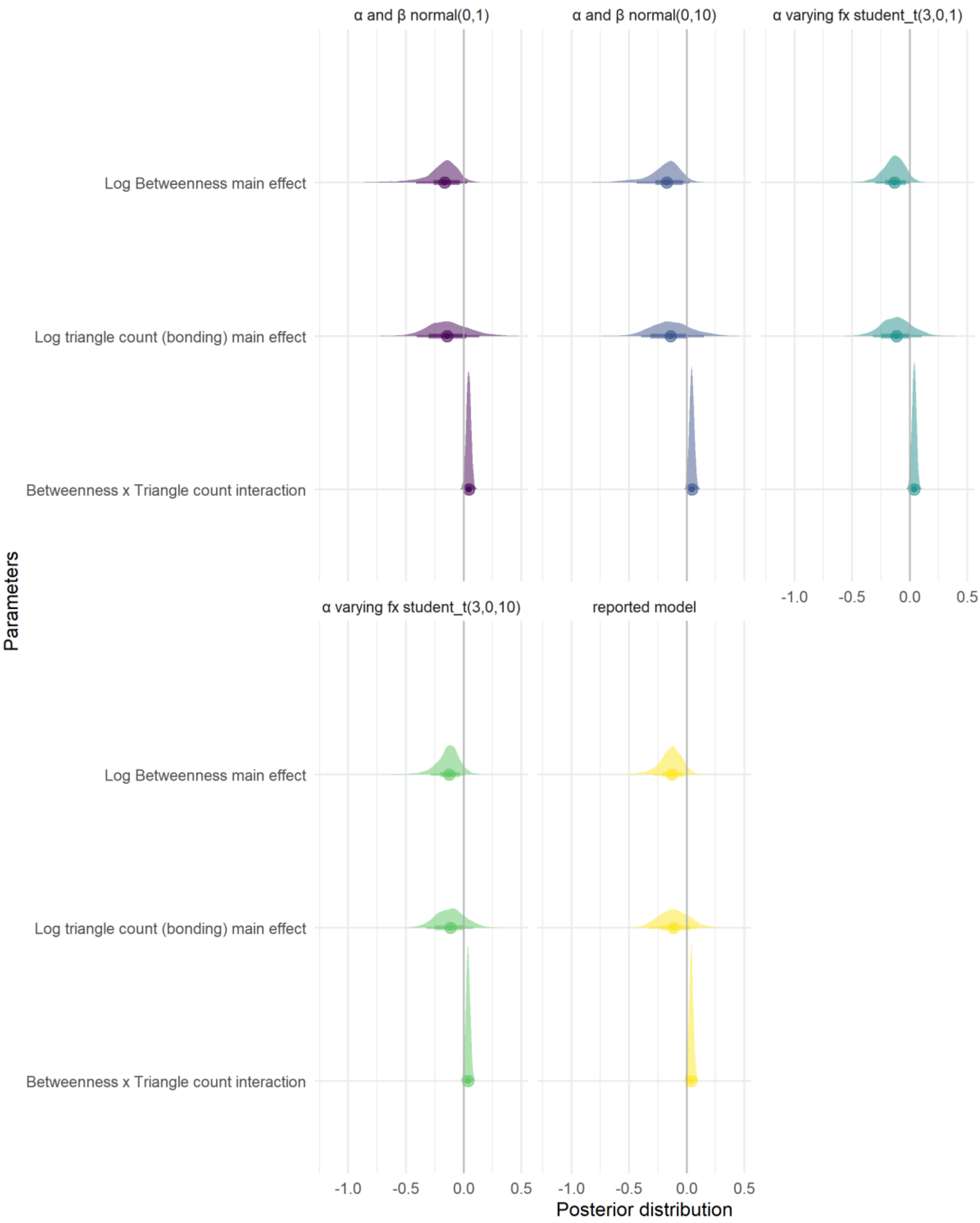


Figure A33: Sensitivity of posterior distribution of α and β parameters to different prior settings for zero inflated poisson model parameters. Variation to the reported model was introduced both by varying priors for weakly informative α and β parameters and for the student-t distribution on the varying intercept and slopes parameters of the multi-level model. The highest posterior density intervals are shown. Point estimates (dots) are medians. Thick horizontal lines indicate 88% credible intervals. Sensitivity was assessed on a model without imputation for computational efficiency.

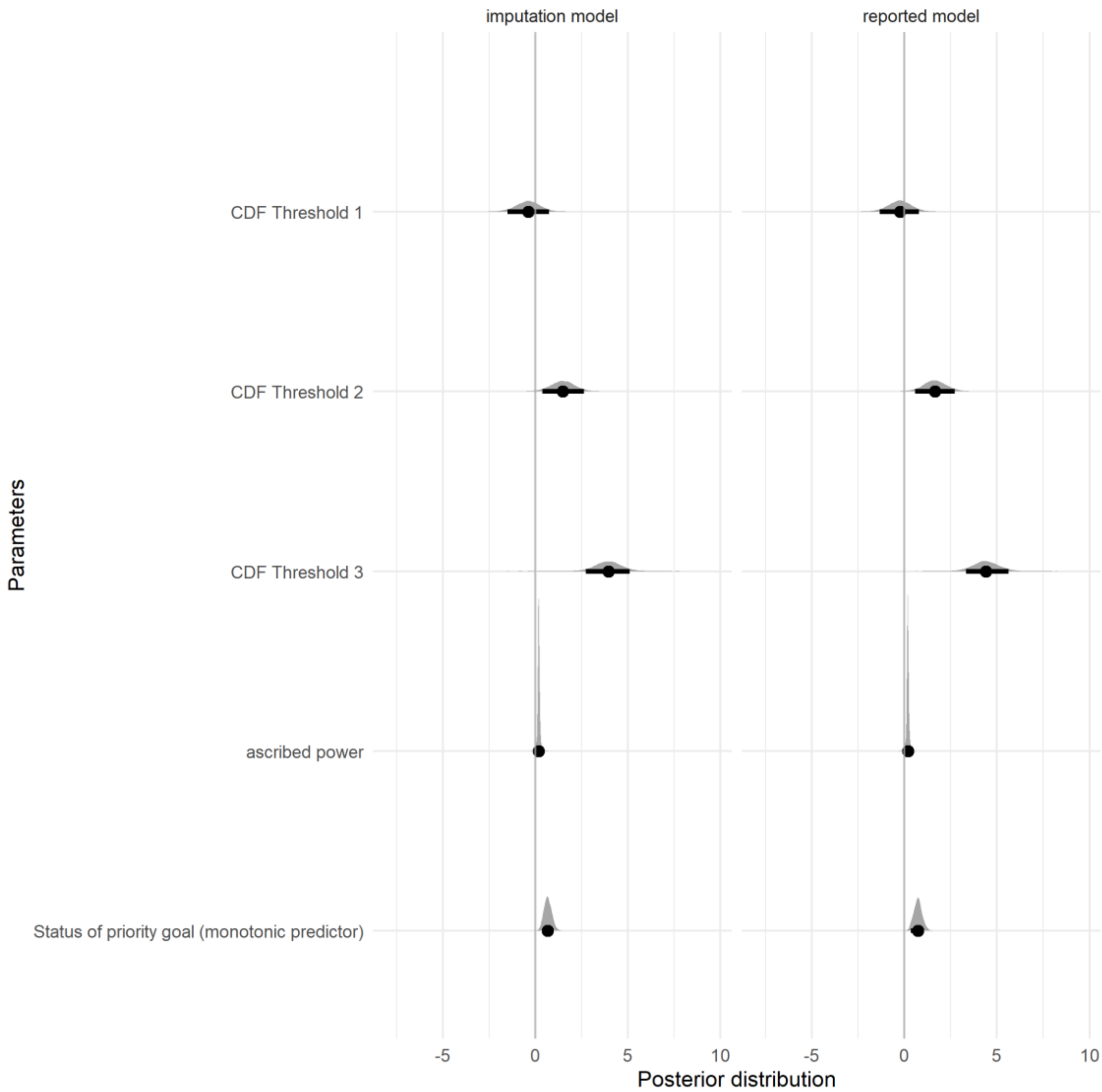


Figure A34: Sensitivity of posterior distribution to imputation approach, compared to row-wise deletion (reported model) for main ordinal regression model parameters. The highest posterior density intervals are shown. Point estimates (dots) are medians. Thick horizontal lines indicate 88% credible intervals.

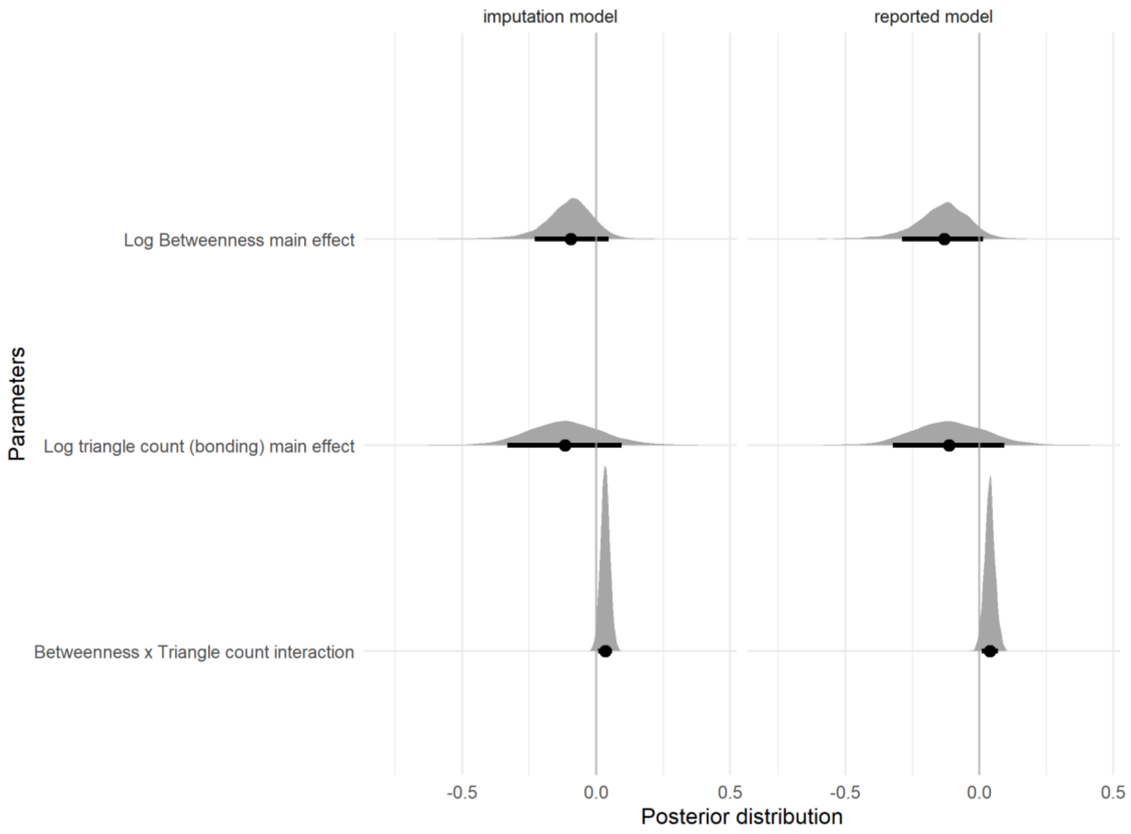


Figure A35: Sensitivity of posterior distribution to imputation approach, compared to row-wise deletion (reported model) main for zero inflated poisson model parameters. The highest posterior density intervals are shown. Point estimates (dots) are medians. Thick horizontal lines indicate 88% credible intervals.

Appendix D – The link between social-ecological network fit and outcomes: a rare empirical assessment of a prominent hypothesis

Table of key reporting points based on Bayesian analysis reporting guidelines (BARG)

BARG Reporting Step	**Article**
Preamble	
A. Why Bayesian. If the audience requires it, explain what benefits will be gleaned by a Bayesian analysis (as opposed to a frequentist analysis).	Section: Model specification
B. Goals of analysis. Explain the goals of the analysis. This prepares the audience for the type of models to expect and how the results will be described.	Section: Integration of outcomes in networks of social-ecological systems
Step 1. Explain the model	
A. Data variables. Explain the dependent (predicted) variables and independent (predictor) variables.	Section: Variables
B. Likelihood function and parameters. For every model, explain the likelihood function and all the parameters, distinguishing clearly between parameters of primary theoretical interest and ancillary parameters. If the model is multilevel, be sure that the hierarchical structure is clearly explained, along with any covariance structure if multivariate parameter distributions are used.	Section: Model specification
C. Prior distribution. For every model, explain and justify the prior distribution of the parameters in the model.	Section: Model specification & Figure A36
D. Formal specification. Include a formal specification (mathematical or computer code) of the likelihood and prior, located either in the main text or in in publicly and persistently accessible online supplementary material.	Section: Model specification
E. Prior predictive check. Especially when using informed priors but even with broad priors, it is valuable to report a prior predictive check to demonstrate that the prior really generates simulated data consistent with the assumed prior knowledge.	Section: Model specification & Figure A36
Step 2. Report details of the computation	
A. Software. Report the software used, including any specific added packages or plugins.	Section: Model specification
B. MCMC chain convergence. Report evidence that the chains have converged, using a convergence statistic such as PSRF, for every parameter or derived value.	Section: Model specification & Table A17
C. MCMC chain resolution. Report evidence that the chains have high resolution, using the ESS, for every parameter or derived value	Section: Model specification & Table A14

Step 3. Describe the posterior distribution A. Posterior predictive check. Provide a posterior predictive check to show that the model usefully mimics the data.	 Section: Model specification & Figure A36
B. Summarize posterior of variables. For continuous parameters, derived variables and predicted values, report the central tendency and limits of the credible interval. Explicitly state whether you are using density-based values (mode and HDI) or quantile-based values (median and ETI), and state the mass of the credible interval (for example, 95%).	Figure A37, Figure A38, Figure A39
Step 4. Report decisions (if any) and their criteria	Not applicable
Step 5. Report sensitivity analysis A. For broad priors. If the prior is intended to be vague or only mildly informed so that it has minimal influence on the posterior, show that other vague priors produce similar posterior results.	 Figure A40
Step 6. Make it reproducible	Section: Model specification (dataset)

Table A16: The BARG (Kruschke, 2021) supports the reproducibility of Bayesian analyses based on a list of key reporting points. Here we included the full list of all BARG key reporting points, regardless if applicable to our research design, to be transparent about what we deemed not applicable.

Table A17: Tail effective sample size (ESS) and potential scale reduction factor (PSRF) values for main model parameters

	PSRF	Tail ESS
CDF Threshold 1	1.00	13050
CDF Threshold 2	1.00	12707
Share closed triangles	1.00	14459
Share closed four-cycles	1.00	14537
Share closed triangles * Share closed four-cycles interaction	1.00	14914
Governance outcomes popularity	1.00	14779

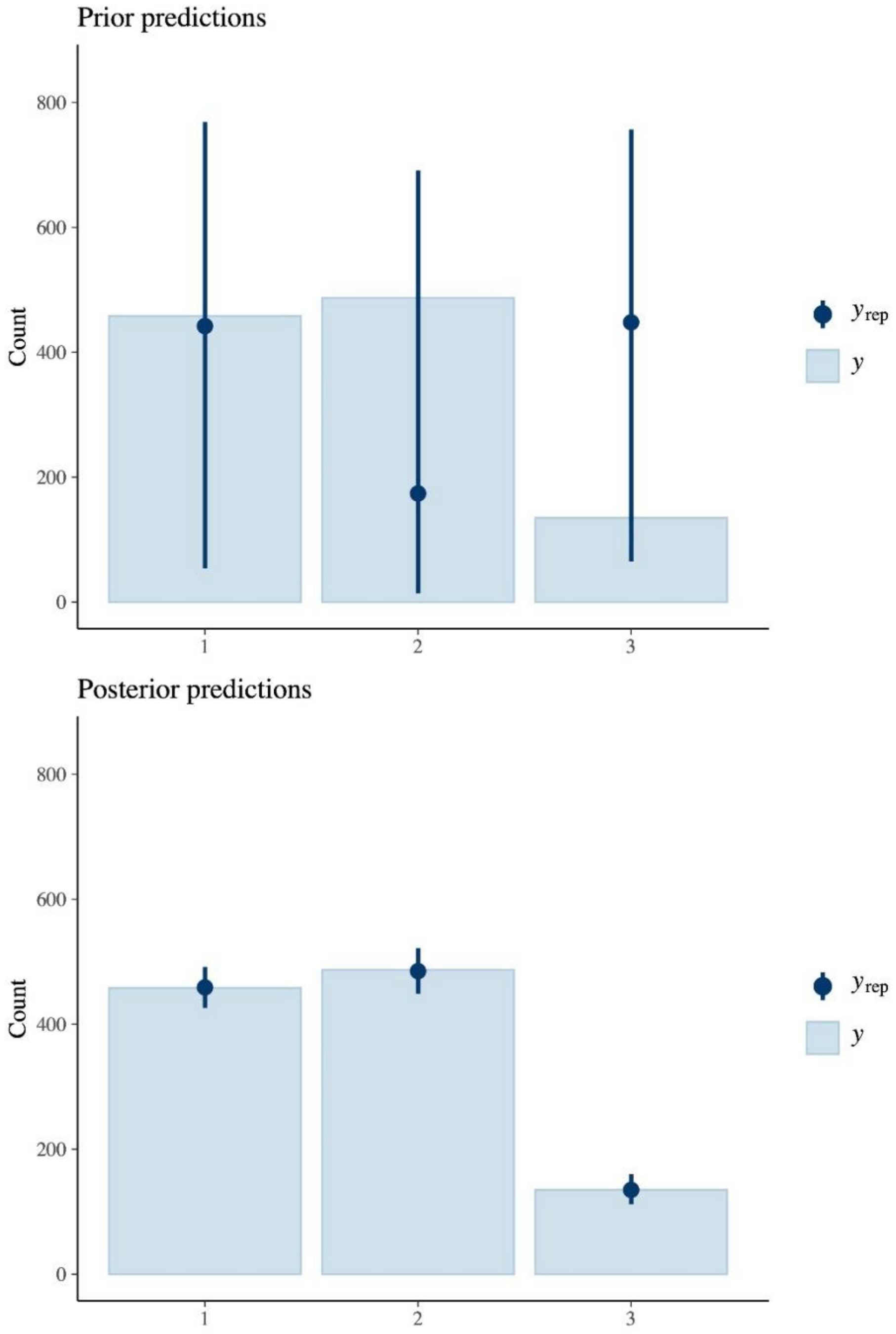


Figure A36: Prior (top) vs. posterior (bottom) predictions y_rep of the regression model compared to the empirical distribution of the outcome variable y (governance outcome assessment) [1 = good governance outcome, 2 = neutral governance outcome, 3 = poor governance outcome]

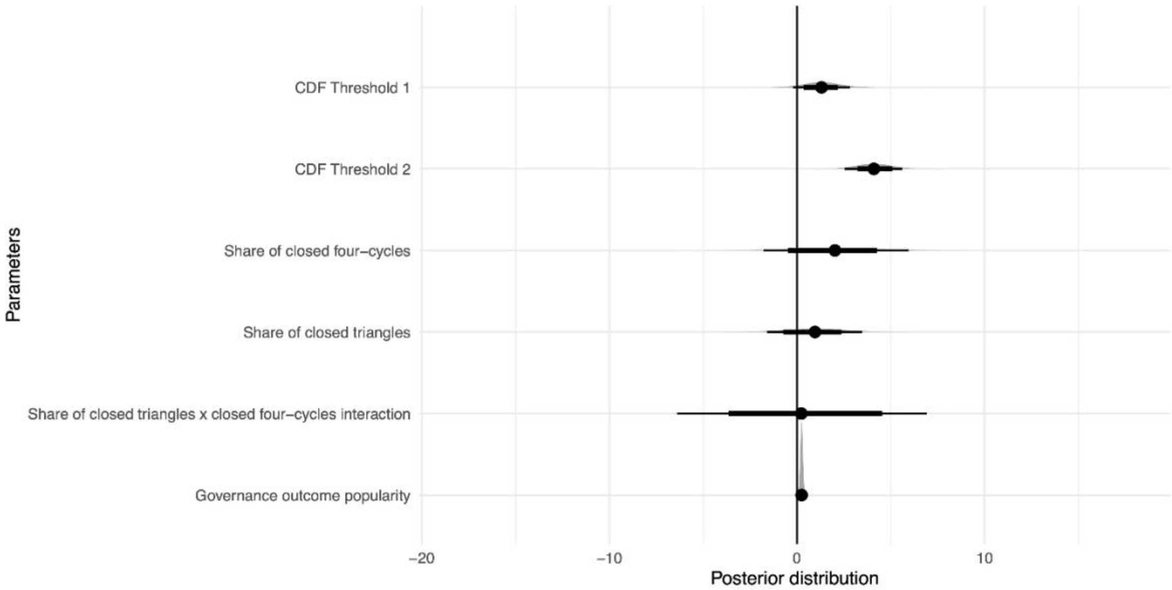


Figure A37: Posterior distribution for CDF Threshold and β parameters. The highest posterior density intervals are shown. Point estimates (dots) are medians. Thick horizontal bars indicate 66% credible intervals, thin horizontal lines indicate 88% credible intervals.

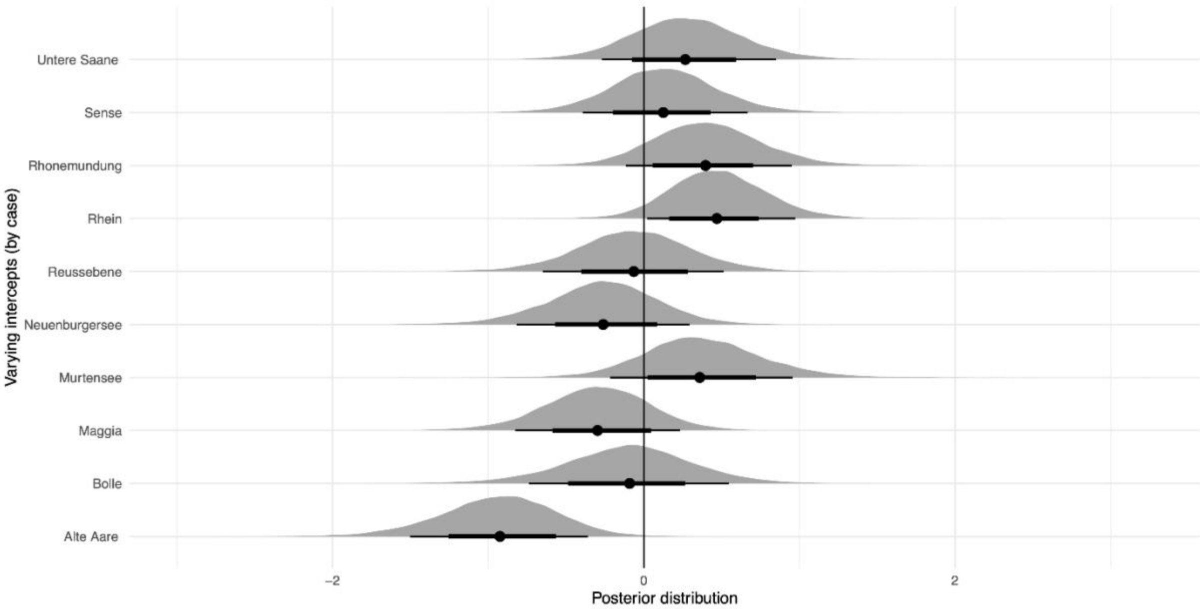


Figure A38: Posterior distribution of $\alpha_{[case]}$, varying intercept parameters by case. The highest posterior density intervals are shown. Point estimates (dots) are medians. Thick horizontal bars indicate 66% credible intervals, and thin horizontal lines indicate 88% credible intervals.

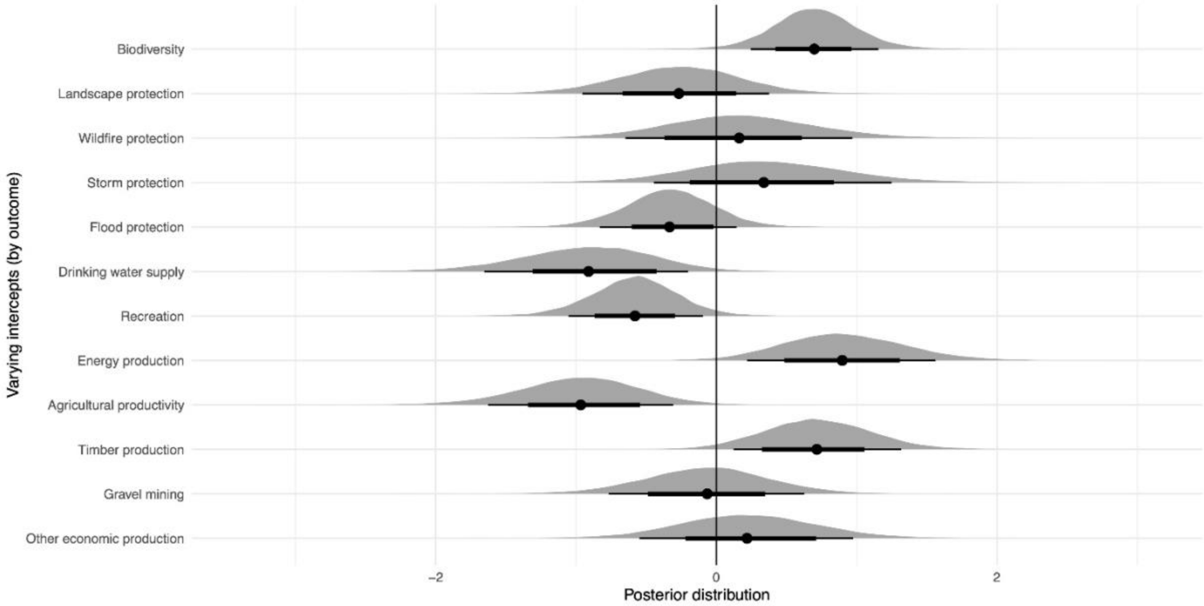


Figure A39: Posterior distribution of $\alpha_{[governance\ outcomes]}$, varying intercept parameters by governance outcomes. The highest posterior density intervals are shown. Point estimates (dots) are medians. Thick horizontal bars indicate 66% credible intervals, thin horizontal lines indicate 88% credible intervals.

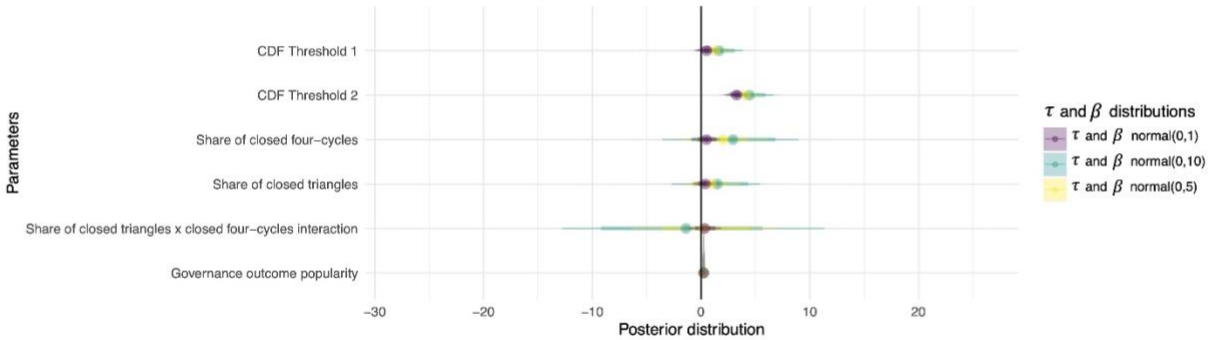


Figure A40: Variability of the posterior density of the MCMC distributions for different prior settings of α and τ (CDF Threshold). It can be seen that there is very little change in the posterior estimation when starting with wide priors such as normal (0,5) or normal(0,10), only for the comparably more restrictive prior normal(0,1) slight differences can be recognized. Point estimates (dots) are medians. Thick horizontal bars indicate 66% credible intervals, thin horizontal lines indicate 88% credible intervals.

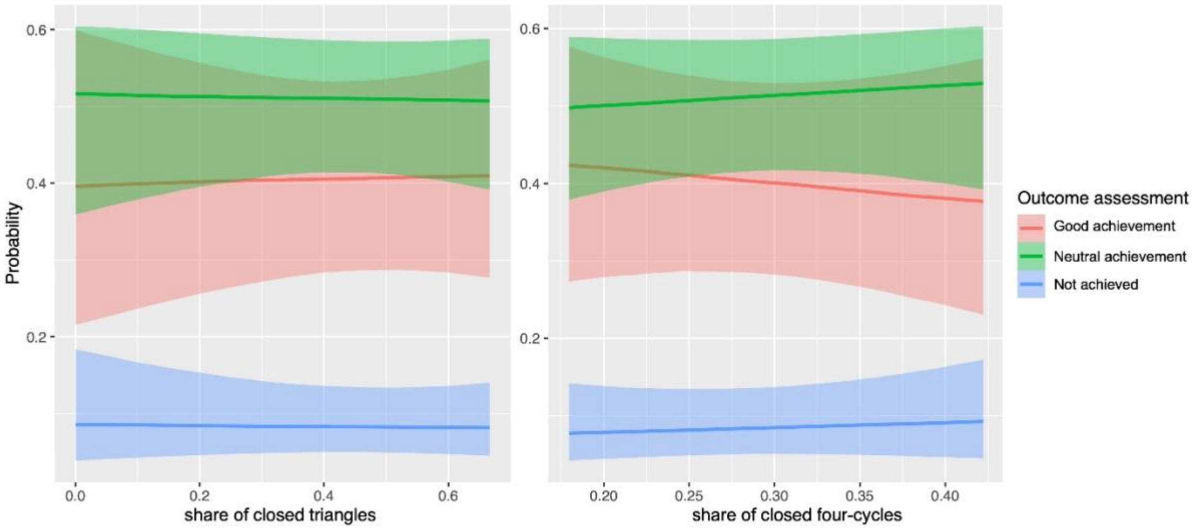


Figure A41: Marginal effects of the share of the closed triangle and four-cycle motifs on the state of governance outcomes for a network conceptualization where all activities are connected to each other. The probabilities of all three states of governance outcomes sum to one for every configuration of inputs. To interpret the figure, the likelihood of the state of a governance outcome falling within the highest versus the lowest category with an increasing share of closed versus open motifs of social-ecological fit can be compared. Compared to the standard model, the results show that differences between different governance outcomes remain. The effect of network motifs of social-ecological fit on the governance outcomes, however, disappears as all ecosystem management activities are connected.

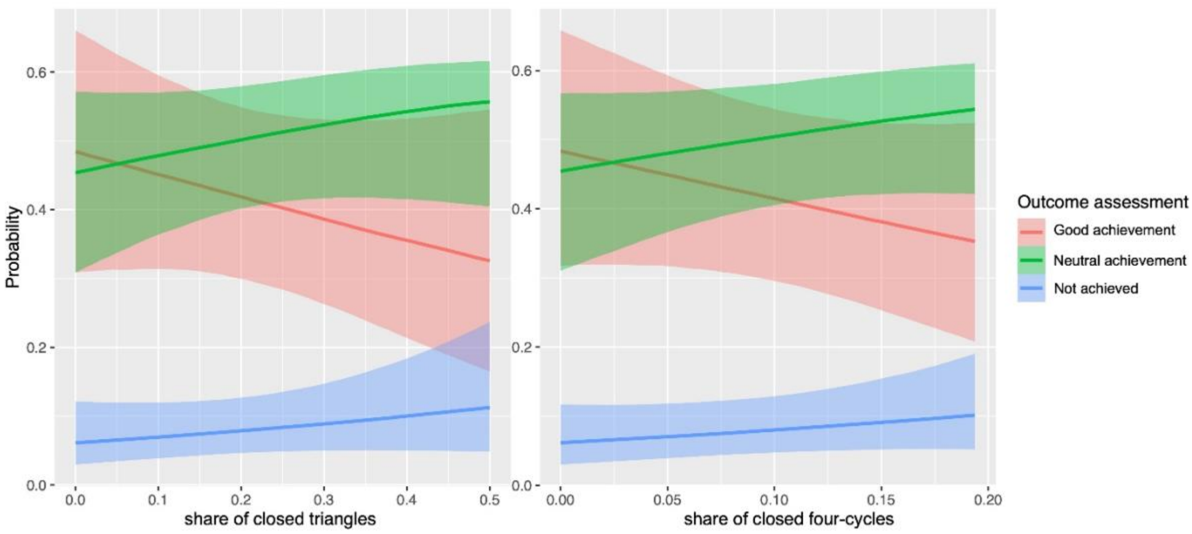


Figure A42: Marginal effects of the share of the closed triangle and four-cycle motifs on the state of governance outcomes for a network conceptualization using a more restrictive criterion for the symmetrization of the collaboration network where a tie between two actors only exists if both actors indicated collaboration. The probabilities of all three states of governance outcomes sum to one for every configuration of inputs. To interpret the figure, the likelihood of the state of a governance outcome falling within the highest versus the lowest category with an increasing share of closed versus open motifs of social-ecological fit can be compared.

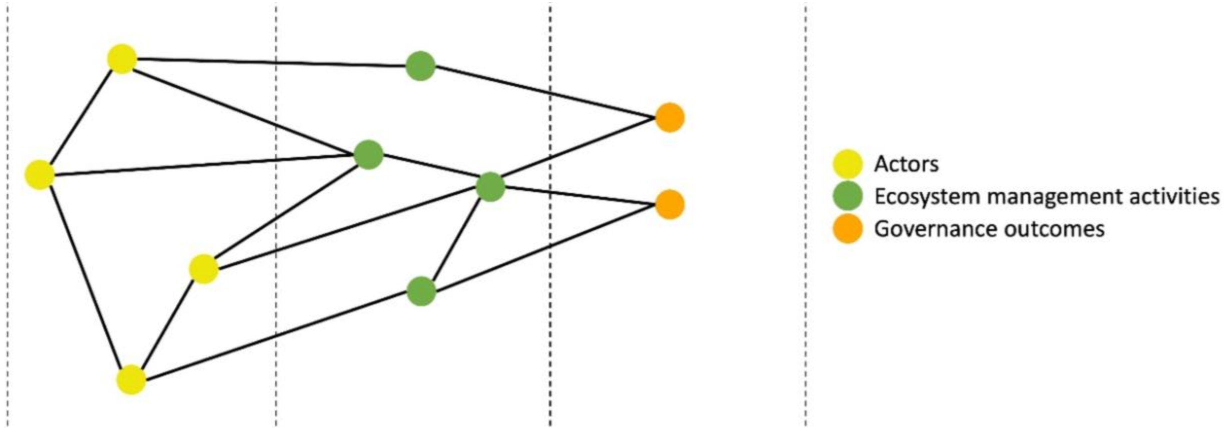


Figure A43: Illustration of the multi-level networks with actors, ecosystem management activities, and governance outcomes as nodes. Relevant motifs exist if two actors influence the same or two directly connected ecosystem management activities. The motifs are closed (fit) if the two actors in one motif collaborate, or the motifs are open (social-ecological misfit) if the two actors in one motif do not collaborate. Further governance outcomes are connected to these network motifs based on connecting environmental issues (not shown in the figure).

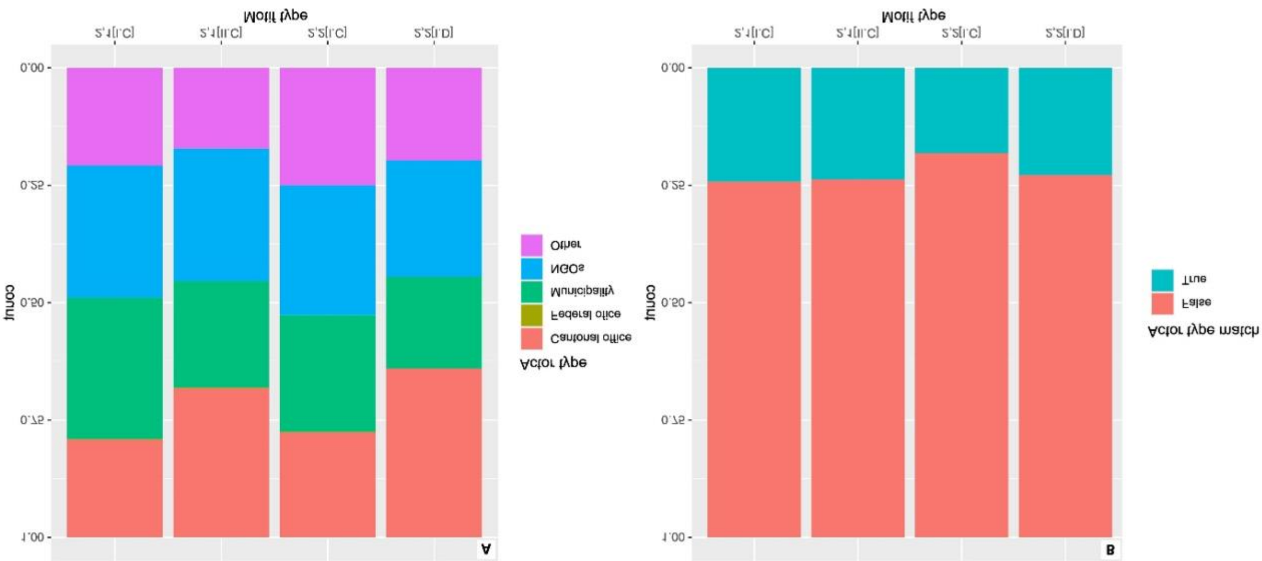


Figure A44: Additional robustness test for the role of actor types for the probability of open and closed triangle and four-cycle motifs (2,1[I.C]: open triangle, 2,1[II.C]: closed triangle, open four-cycle: 2,2[I.C], and 2,2[I.D]: closed four-cycle). The actor types are not included in the main model as the analysis focus is on how network motifs characterizing fit influence the probability of governance outcomes.
Illustration A shows that there exist differences between actor types, as cantonal offices are generally overrepresented in closed network representations. This indicates that the cantonal offices make an important contribution to increasing the level of fit. Other actor types, such as municipalities, are more often included in open network motifs compared to closed network motifs.
Illustration B shows that no big differences can be identified depending if actors from the same type or different types are connected based on one common or two connected ecosystem management activities. This indicates that actor type homophily does not play an important role in the emergence of network motifs characterizing fit.

List of key survey questions

Following the key survey questions used for this article are listed. For further information on the survey, including a complete list of all survey questions, see Huber et al. (2022b).

- Which of the organizations listed below have you regularly collaborated with in the past three years as part of your activities in the [case area]. Regular collaboration includes in-depth exchange of information and expertise (more than once a year) and joint planning, decision-making, implementation, and evaluation of projects.
  Survey participants could choose from a list of potentially relevant collaboration partners and add additional actors to this existing list of potentially relevant collaboration partners if needed.

- Which of the activities below has your organization been involved in over the past three years in the [case area]? By activity, we mean both planning, decision-making, implementation, and evaluation of projects.
  Survey participants could choose from a list of activities.

- Below are possible outcomes for floodplain areas in the [case area]. How well do you think these outcomes are being achieved?
  Survey participants could choose one of the three options: “goal achieved”, “goal partially achieved”, to “goal not achiev

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Selbständigkeitserklärung

Ich erkläre hiermit, dass ich diese Arbeit selbständig verfasst und keine anderen als die angegebenen Quellen benutzt habe. Alle Koautorenschaften sowie alle Stelle, die wörtlich oder sinngemäss aus Quellen entnommen wurden, habe ich als solche gekennzeichnet. Mir ist bekannt, dass allenfalls der Senat gemäss Artikel 36 Absatz 1 Buchstabe o des Gesetzes vom 5. September 1996 über die Universität zum Entzug des aufgrund dieser Arbeit verliehenen Titels berechtigt ist.

Zürich, 11. Februar 2023

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