



Research

How the qualities of actor-issue interdependencies influence collaboration patterns

Martin Nicola Huber^{1,2}

ABSTRACT. Environmental governance is complex because it addresses challenges anchored in different sectors and concerns multiple interdependent issues. Managing those complex interdependencies through collaboration is vital for efficient long-term environmental governance. However, because 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 homogeneous 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. Although 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.

Key Words: *collaboration; exponential random graph model (ERGM); natural resource governance; social-ecological networks (SEN); social-ecological systems (SES)*

INTRODUCTION

Collaboration among actors is seemingly imperative for the successful governance of environmental systems (Bodin and Crona 2009, Prell et al. 2009, Lubell 2013). 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 because of 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 because of the number of interdependent actors and environmental issues (Adkin et al. 2017, Brandenberger et al. 2022). The environmental issues and actors are interdependent because 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. Because interdependencies between environmental issues are often vastly complex, it may be challenging for actors to understand their activities' full impact on specific environmental issues (Crona and Bodin 2006, Bergsten et al. 2019). Additionally, interdependencies between environmental issues are complex because they are not

binary—either present or absent—but rather can have different qualities (Sayles et al. 2019, Jasny et al. 2021). 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 and Tengö 2012, Bodin et al. 2019). The concept of SEN emerged more than a decade ago to describe and analyze SES using multilevel networks (Cumming et al. 2006, 2010, Janssen et al. 2006, Bodin and Tengö 2012). SEN studies often focus on collaboration among resource users and the resilience of interdependent SESs (Janssen et al. 2006, Bodin et al. 2014, Dakos et al. 2015, Guerrero et al. 2015). Although 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

¹Department of Environment and Social Sciences, Eawag, Dübendorf, Switzerland, ²Institute of Political Science, University of Bern, Bern, Switzerland

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 (Sayles et al. 2019, Vasudeva et al. 2020, Jasny et al. 2021). Accounting for the quality of dependencies can help explain why many environmental problems entail conflicts of interest (Herzog and Ingold 2019, Bodin et al. 2020). Although 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 (Guerrero et al. 2015, Treml et al. 2015, Sayles and Baggio 2017, Enqvist et al. 2020). The literature on fit claims that the alignment of collaboration patterns with the structure of the ecosystem enhances governance effectiveness (Ostrom 2007, Epstein et al. 2015, 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 because the achievement of fit depends not only on the existence but also on the quality of actor-issue paths. Although 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 that existed in 1850 in Switzerland have disappeared because of 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 by 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 (SESs)

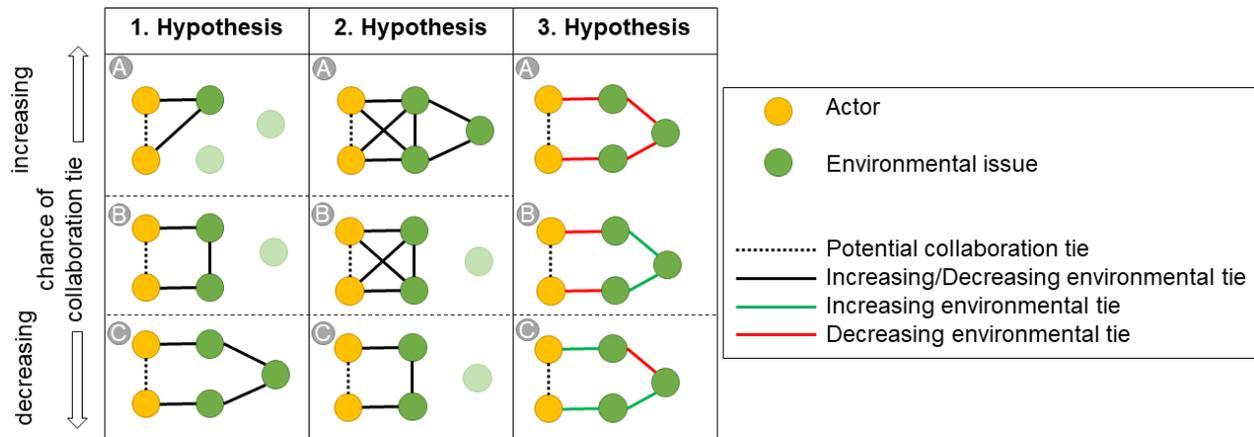
Previous research in ecosystem governance established the importance of governing ecological and social systems in an integrated manner (Berkes and Folke 1998, Ostrom 2007, Bodin and Crona 2009, Prell et al. 2009, Lubell 2013). The integration of social and ecological aspects is important because processes 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 and Ostrom 2014).

I build on the SES framework by Ostrom (2007) that holistically conceptualizes and analyzes governance structures of ecosystems (Gerber et al. 2009, Ostrom 2009, McGee and Jones 2019). The SES framework emphasizes the importance of aligned social and ecological systems to resolve policy issues and achieve sustainability of SESs (Ostrom 2009, Lubell et al. 2014, Epstein et al. 2015). To achieve an alignment of social and ecological systems and manage SES successfully, the importance of actor collaboration is often stressed in research building on the SES framework (Pittman and Armitage 2017, Ingold et al. 2018, Hedlund et al. 2020). I define collaboration here as an interaction between two actors to govern environmental issues. Although collaboration is generally assumed to be beneficial, it is also associated with certain costs (Hileman and Bodin 2019). The costs of collaboration ties are also a matter of interest in the ecology of games framework (EoG; Lubell et al. 2014, Berardo and Lubell 2019). 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 and 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 SES and exploring different forms of dependencies (e.g., collaboration) between actors (Robins et al. 2012, Dragicevic and Shogren 2017). However, the concept of networks is not limited to actor interactions (Janssen et al. 2006, Scott and Ulibarri 2019) but can equally include other forms of dependencies between any

Fig. 1. 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).



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). Because the SEN concept is still relatively new, only a few attempts exist to standardize the conceptualization of SENs (Bodin et al. 2019, Sayles et al. 2019, Felipe-Lucia et al. 2022). Research using SENs often focuses on analyzing the governance of ecosystems based on single case studies (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 and Baggio 2017, Widmer et al. 2019). The concept of social-ecological fit implies that the social systems should be aligned with the ecosystems (Ostrom 2007, Epstein et al. 2015, 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 (Folke et al. 2007, Lebel et al. 2013, Bodin et al. 2014, Widmer et al. 2019) that can be categorized as ecological fit, social fit, and social-ecological system fit (Epstein et al. 2015). I refer to the latter 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 (Moss 2003, Epstein et al. 2015). 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 (Lubell et al. 2014, Bodin et al. 2016), 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 1. 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 1 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.

When the probability of a collaboration tie forming is assessed, this is often done based on the shortest network connection between two actors (Berardo and Scholz 2010, Moon et al. 2019). In the literature

on fit, the path length plays a minor role because only very limited motifs of fit with only a small number of nodes are analyzed (Guerrero et al. 2015, Pittman and Armitage 2017, Enqvist et al. 2020). 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 (Lubell et al. 2014, Hileman and Bodin 2019). 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. 2015, 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 (Widmer et al. 2019, Guimarães 2020). 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. 2021). 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 1983, 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. 2021). Typical applications of similarity explaining actor collaboration are based on shared beliefs (Calanni et al. 2015) or occupational similarity (Cepić and 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 (Werth et al. 2012). However, 10 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).

Although 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. Also, 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 km²) 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 socioeconomic 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 1, 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 1, 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 2, 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 was lower because some actors present in multiple areas (mostly those 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 filled out the survey (response rate: 70%). The two most important survey questions for this paper were “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 3, 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 1983, Jones 2003, Widmer et al. 2019). Governance complexity has a hypotheses generating character for this paper because it potentially influences the actors’ decision to collaborate based on actor-issue paths.

The governance complexity is characterized using four conditions (see Table 1): (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: (i) cases

that cut across cantonal borders, and (ii) 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.

Table 1. 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).

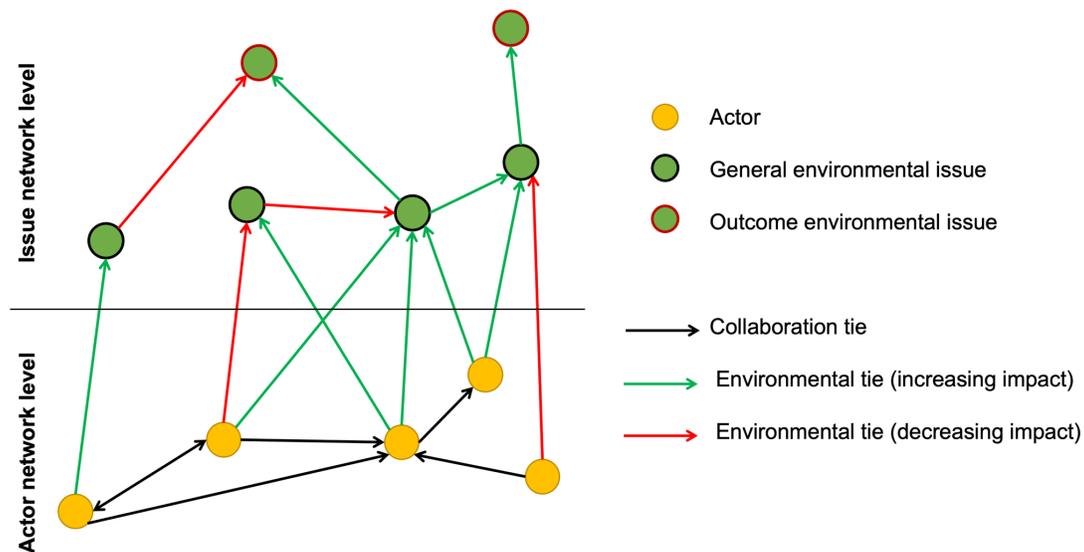
Cases	Network endogenous		Network exogenous	
	Number of actors in actor network	Number of ties in issue network	Case area structure	Existence of cantonal borders
Alte Aare	59	105	0.7	No
Bolle	74	80	-0.2	No
Sense	67	103	-0.1	Yes
Murtensee	59	92	-0.7	Yes
Reussebene	72	111	0.4	Yes
Untere Saane	61	85	-1.6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

Methods

The survey data of the wetlands was analyzed using ERGMs. I used 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 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 2020) to estimate the models for each case and hypothesis. All exogenous variables of the ERGM models were 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 used 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

Fig. 2. 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.



variances. As an indicator of the variances of the ERGM results, I used the associated p-values with smaller p-values indicating smaller variances of the results. The p-values are used as the weights (weight = $|1 - p\text{-value}|$) 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 conceptualized the data as actor-issue networks (for further details, see Appendix 1, Detailed conceptualization of the actor-issue networks). More specifically, the actor network level was conceptualized as the dependent network in the ERGMs. The issue network as well ties across network levels were included as dyad-level covariates, one for each hypothesis. Because the same actor-issue paths can be relevant for the operationalization of the dyad-level covariates for all three separate hypotheses, I calculated separate ERGMs for each of the three hypotheses (for further details, see Appendix 4, Aggregated covariance table for hypotheses). This was 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 was that the dyad-level covariates were all partially based on the same actor-issue paths but differed in how they were operationalized. The variables of

path length and multiplexity, for example, both depended on the same shortest actor-issue path connecting an actor pair. The difference is that 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.

The actor-issue network consisted of two interdependent network levels that characterize the interdependencies between actors, between issues, and between actors and issues (see Fig. 2). The nodes of the actor network were actors, and the directed ties represented a collaboration between those actors. The nodes in the issue network were environmental issues. Environmental issues were aggregated features of ecosystems (e.g., water quality or population of beavers) or issues that had an impact on them (e.g., amount of trash). Directed, increasing/decreasing ties between environmental issues existed if one could 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 because of 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, ties between the two network levels were also possible. Similar to ties between environmental issues, such ties that connect the two network levels were also directed and had either an increasing or

decreasing impact. A tie between the two network levels existed if actors directly impacted the state of an environmental issue by executing their activities or if environmental issues influenced the execution of the activities of actors. A “park ranger” who was responsible for the cleaning of the area, for example, had a decreasing impact on the “amount of trash”; therefore, a decreasing tie from the “park ranger” to the issue “amount of trash” existed. Environmental issues were 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 was based on information on the length of the actor-issue paths (see Fig. 1). A triangle network motif of two actors and one environmental issue indicated a shorter actor-issue path than, for example, a square or hexagon motif with two actors and multiple environmental issues. The second hypothesis relied on information on the multiplexity of the actor-issue paths. The focus here was on the amount of parallel actor-issue paths between actors. The shortest of those actor-issue paths connecting two actors had the strongest weight; the longest actor-issue paths had the smallest weight for calculating the multiplexity index.

The operationalization of the third hypothesis was based on the increasing or decreasing impact of actors on the two outcome environmental issues: local biodiversity and recreational value. Both were selected because they were mentioned as most relevant in the expert interviews across all cases. Actors’ influence on outcome environmental issues was based on actors’ actor-issue paths. In this particular case, actor-issue paths were 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” decreased the “amount of trash.” Further, the “amount of trash” decreased “habitat quality” and consequently also the “biodiversity.” Therefore the presence of a “ranger” had overall a positive impact on the “biodiversity” based on the actor-issue path. Each actor had multiple such paths connecting them with outcome environmental issues. The aggregated impact of actors on outcome environmental issues based on their actor-issue paths was 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 had a similar, either positive or negative, effect on the biodiversity and recreational value of the wetlands, and were more likely to collaborate (for further details, including examples for the operationalization of all hypotheses, see Appendix 1, Detailed examples for the operationalization of the independent variables).

I also included several established explanatory factors for actor networks as control variables for the tie formation process (Bodin and Crona 2009, Prell et al. 2009). First, I controlled for the power of actors because actors perceived to be powerful were attractive

collaboration partners (Fischer and Sciarini 2015). Second, I controlled 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 were more likely to collaborate because they shared organizational logic and were active within the same functional areas (Ingold 2011). Third, actors who did not respond to the survey were also included in the analysis. Therefore, controlling for the response of individual actors was needed as the information available to construct the actor-issue network was less complete for actors who did not respond to the survey. Non-response also had an impact on their ego network, which was sparser compared to other actors. Fourth, I adjusted for endogenous network processes (Handcock et al. 2019). Therefore, I included an edges term in the model, which was conceptually similar to an intercept in conventional regression models, establishing a baseline probability for a tie to occur in the network. Additionally, I controlled for triadic closure (the tendency of an actor pair with a common tie to also have a common partner in the network) by including ergm terms for edgewise and/or dyadwise shared partners (Hunter 2007).

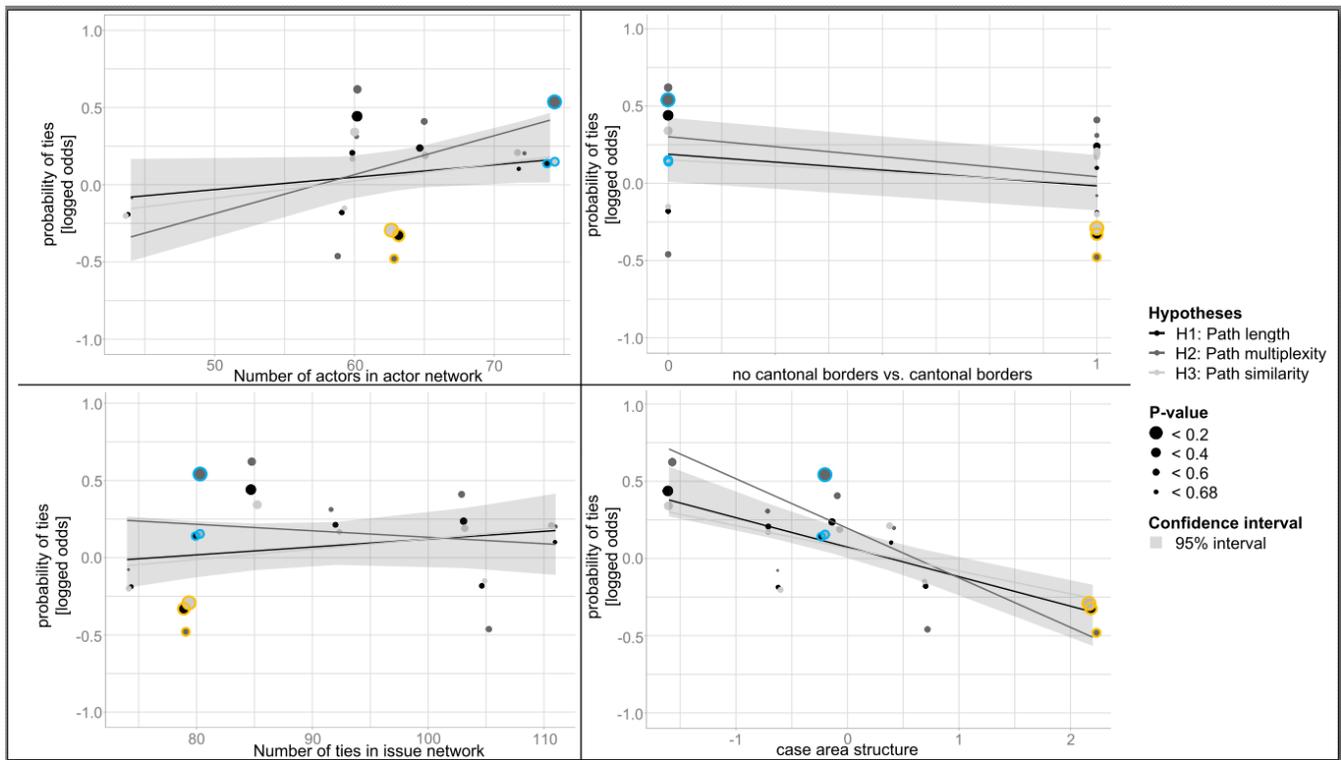
RESULTS

I calculated separate ERGMs for each case and each hypothesis. Based on the goodness of fit (GOF) statistics analysis, ERGMs of all cases provided 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 4, ERGM results and GOF statistics). Two cases for which I had data are not included in the analysis because of poor GOF statistics (for result tables and GOF statistics, see Appendix 4, Additional ERGM results and GOF statistics not included in the analysis).

Overall, the results (see Table 2) indicated a certain effect for all three hypotheses. However, although 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 ranged from positive to negative. Further, many of the results of the ERGMs were associated with relatively high levels of uncertainties because the sample sizes of the individual cases were relatively small (for further information on the influence of sample sizes on statistical tests, see Wasserstein et al. 2019, Foulley 2020). To overcome this uncertainty on the case level and to characterize the cases where the hypotheses are supported, I relied on a qualitative meta-regression analysis (see Figure 3). The qualitative meta-regression analysis pooled together the results across cases, which helped 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 3. 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

Fig. 3. 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.



across cases. Although 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, multiplicity, and similarity.

The most robust trend for the influence of the independent variables—and in particular the variable of the multiplicity of actor-issue paths—on the probability of collaboration ties appeared 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 was on average positive for homogenous cases and negative for more heterogeneous and complex cases. A similar but less accentuated trend appeared for the second exogenous complexity condition based on the existence of cantonal borders. Further, the regression lines slopes were 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, multiplicity, and similarity to cause a collaboration tie was on average higher in situations of high complexity. Finally, the number of ties in the issue network did 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 because 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, other mechanisms also 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

Table 2. 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 4.

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 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 of which might be favorable to collaborate with (Dörner 1983, 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 analyzed two of the cases in depth: one where the hypotheses were supported and another case where the results did not support the hypotheses. The two selected cases did not reflect the proportions of cases that support or reject the hypotheses but rather illustrated how different local governance situations influence the results.

The first case was a wetland system along the shore of the lake Neuchatel (see dots marked yellow in Fig. 3). Results for this case did 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 made 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 because of 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 dots marked blue in Fig. 3), 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 and attract many visitors, but they are also surrounded by large industrial areas. 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 because of 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 because of a simple case area structure but also because of 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 (Crona and Bodin 2006, Bergsten et al. 2019). 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.

Because 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. 2021). 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 because of 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 toward 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. Although the impact of complexity on the achievement of fit has been discussed in some articles (Bergsten et al. 2014, Epstein et al. 2015, 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 (Guerrero et al. 2015, Treml et al. 2015, Sayles and Baggio 2017, Enqvist et al. 2020), 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 because 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 develop 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 (Wasserstein et al. 2019, Foulley 2020). 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.

Responses to this article can be read online at:
<https://www.ecologyandsociety.org/issues/responses.php/13536>

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Data Availability:

The data that support the findings of this study are available on request from the corresponding author, MH. None of the data are publicly available because they contain information that could compromise the privacy of research participants. The code that supports the findings of this study is in Appendix 5.

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