



Investigating the risky dilemma of regional flood planning: The case of the Wolastoq | Saint John River Basin, Canada

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ABSTRACT

Adaptive approaches to flood governance are gaining attention as climate change is expected to alter historic flooding patterns around the world. Collaboration networks are essential to adaptive governance as they create a cohesive system of diverse actors functioning across different jurisdictions and spatial levels. This research investigates the network structure of the regional collaborative governance for flood planning in the Wolastoq | Saint John River Basin, Canada. A social network approach was employed to assess the extent and characteristics of adaptive flood governance in the region, specifically investigating network properties related to collective action dilemmas, organizational type, and geographic scale. The network displayed a diverse composition of organization types, a propensity for bonding structures, homophily among governmental organizations, and prominent brokerage activity of multi-basin actors. The presence of bonding structures in the network reflected the high-risk dilemma presented by flood planning, characterised by the presence of both government and non-governmental actors with diverse authority, resources, and organizational capacity. Transitioning to adaptive governance would benefit from increased connectivity among regions and enhanced brokerage activity amongst governmental organizations.

1. Introduction

Natural disasters are a longstanding concern with devastating consequences. Flooding (Cornwall, 2021; Davenport et al., 2021), wildfires (Burke et al., 2021; Wang et al., 2021; Abram et al., 2021) and droughts (IPCC, 2019; Fleck and Udall, 2021) are among some of the many disasters having catastrophic impacts on communities. The connection between disasters and anthropogenic climate change is now front and centre, with the report by the IPCC (2023) clearly establishing the unprecedented scale of recent climatic changes, the contributions of human influences to these changes, and their relationship with the frequency and intensity of observed extreme events. Governance choices and management actions are required to address present realities as well as alter future impacts of environmental change (IPCC, 2018; Fleck and Udall, 2021).

Governance must align with ecological processes in social-ecological systems if contemporary and future challenges related to extreme events are to be addressed (Young, 2002; Folke et al., 2007; Bodin and Tengö 2012; Guerrero et al., 2015a; Bodin, 2017). Consequently, this fit

between ecological and governance systems is being incorporated into assessments of disaster risks (e.g. Toosi et al., 2019; Dunn et al., 2020) as well as appraisals of disaster governance (e.g. Bodin et al., 2019). This coupled understanding in terms of ecological and governance processes is essential to understand and influence disaster situations because “hazards are jointly shaped by human and biophysical factors” (Hamilton et al., 2019, p. 114). In this study, we focus on the processes and structure of flood governance. Flood governance should correspondingly reflect the biophysical scale of the issue. Catchments or drainage basins have long been established as an appropriate scale for water resource management (McKinney, 1999; Savenije and Van Der Zaag, 2000; Savenije and Van der Zaag, 2008; Winz et al., 2009) and water governance (Niemczynowicz, 1999; Pahl-Wostl et al., 2012; Lebel et al., 2013). Governance should also be responsive at sub-catchment levels (Lebel et al., 2013; Rouillard and Spray, 2017), given their unique circumstances and issues (Norberg and Cummin, 2008; Savenije and Van der Zaag, 2008). The nature of flooding, in particular, requires that it is addressed at the appropriate spatial scale and level of decision making (Niemczynowicz, 1999; Merz et al., 2010). Flooding events and

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subsequent impacts do not adhere to jurisdictional boundaries; decisions and actions upstream can alter flooding impacts downstream (Dieperink et al., 2018; Seher and Löschner, 2018). Therefore, approaches that cross administrative and institutional borders are needed (Bracken et al., 2016; Cumiskey et al., 2019; Clegg et al., 2021).

Governance that is adaptive is essential for coping with uncertainty (Dietz et al., 2003; Pahl-Wostl, 2009), and this also applies to flooding. Fournier et al. (2016), for example, present a framework to assess flood mitigation effectiveness in European countries against criteria of multilevel governance, multi-actor networks, flexibility in arrangements, scale matching, and opportunities for experimentation and learning. This study has shown that adaptive flood response is strongly influenced by governance arrangements, but gaps in informal networks and a lack of capacity at the appropriate scale of the problem weaken this (Fournier et al., 2016). Analysis of other flooding regimes displayed an under emphasis on the role and impact of the governance network structure, such as the propensity for bonding or bridging relationships (Plummer et al., 2018).

An essential attribute of adaptive governance is the involvement of a variety of actors (Dietz et al., 2003; Folke et al., 2005; Armitage et al., 2009; Pahl-Wostl et al., 2012). The inclusion of relevant actors promotes transparent deliberation for rule development, increases the flow of information, and fosters trust-building (Dietz et al., 2003). Linking actors at different levels, i.e., multi-level governance networks, aids in addressing broader system dynamics while responding to problems at the appropriate level (Young, 2002; Armitage et al., 2009). The inclusion of local actors and diverse knowledge holders is also essential for subsequent action (Cosens and Williams, 2012; Plummer et al., 2013). Interactions among multiple groups can support continual learning (Folke et al., 2005; Huitema et al., 2009) and the diversification of flood risk management strategies (Hegger et al., 2014). However, integrating actors across both policy (Metz et al., 2020) and administrative domains (Becker, 2020) is challenging, and influenced by relationships among actor groups (Cumiskey et al., 2019).

Framed by the above imperatives – governance reflecting nested biophysical levels, adaptiveness, and multi-actor involvement – we examine governance for flood planning in the Wolastoq | Saint John River Basin, Canada. The Wolastoq | Saint John River Basin, the regional focus of this research, is a transboundary river located in Eastern North America, and one of many basins experiencing recent catastrophic flooding. The Wolastoq has experienced flooding throughout time, but floods are increasing in severity and frequency. The basin is one example of many where multiple, diverse actors from government, non-government, and industry are all involved in flood planning. Thus, this catchment provides an opportunity to explore questions of collaborative networks for the purpose of flood planning. We employ a network perspective to investigate collaborative arrangements for flood planning decisions. Our findings are discussed in light of scholarships on networks, flood governance, uncertainty, and coping with increasing and intensifying disasters.

1.1. Social network analysis

Social network analysis provides a basis to quantify the structure of actors' relationships and its impacts on the social processes being studied (Borgatti et al., 2009). As network structure impacts overall behaviour and function (Valente, 2012), not all networks are suitable for pursuing a desired outcome (Bodin, 2017). Hence, more empirical research is needed to understand the specific network properties and structures that contribute to fruitful governance arrangements that can address sustainability challenges (Bodin and Crona, 2009; Bodin et al., 2016; Baird et al., 2019; Berardo and Lubell, 2019; Guerrero et al., 2020; Bodin et al., 2020; Baudoin and Gittins, 2021).

Understanding how network structures, organizational roles, and actor attributes impact governance function in regional collaborative governance arrangements, particularly those with components of top-

down government, is of interest to scholars (Sayles and Baggio, 2017; Alexander et al., 2017; Hamilton and Lubell, 2018; Hamilton et al., 2020; Locatelli et al., 2020). For example, the balance between bridging structures (two actors connected through a common third actor) and bonding structures (three actors all connected to each other) in a network can indicate levels of trust and conflict (Berardo and Scholz, 2010; McAllister et al., 2017; Bodin et al., 2020). Since the relative involvement and relationship choices of different organization types at different levels will impact network structure (Fliervoet et al., 2016; Sayles and Baggio, 2017; Locatelli et al., 2020), there is also reason to investigate how organization type and relative jurisdictional level may impact transboundary flood planning.

The research is guided by the following objectives and accompanying supporting literature about networks in flood governance:

1.1.1. Objective one: identify the flood planning collaboration network

Understanding the flood planning collaboration network within the embedded institutional context was the first objective. As adaptive governance should involve a variety of actors (Baird and Plummer, 2021) operating at multiple levels (Rouillard and Spray, 2017; Dieperink et al., 2018), first identifying which organizations are involved and where they are located provides context for further analysis of flood planning efforts.

Canada appears to be in the early stages of the shift from traditional to more adaptive approaches to managing and governing flooding, including the involvement of a broader variety of actors (Henstra et al., 2019). However, reports on flood preparedness indicate that Canadian provinces and territories, as well as cities, remain unprepared for increases in severe flooding events (Feltmate et al., 2020; Feltmate and Moudrak, 2021). Multiple catastrophic floods have occurred throughout Canada in recent years (Insurance Bureau of Canada, 2019; Malbeuf, 2020) and are the greatest cause of natural disaster damages (CCA, 2019). Climate change is forecasted to further alter flooding patterns driven by both snowmelt and rainfall (Government of Canada, 2019).

1.1.2. Objective two: assess the tendency towards bonding and bridging structures

Bonding and bridging structures can indicate levels of trust and conflict in networks (Berardo and Scholz, 2010; McAllister et al., 2017; Bodin et al., 2020). Bonding structures include reciprocal relationships and as closed triads. Closed triads, also called network closure, refer to a structure of three links among three nodes, creating a closed triangle (Goodreau et al., 2009). It is commonly thought of as the tendency for actors to establish ties with friends of friends, although there are various rationales for the phenomenon (Bodin et al., 2019). Strong relationships from reciprocal or repeated interaction can build trust and be used to exert social pressure (Burt, 2005; Prell & Lo, 2016).

The propensity for bonding structures in a network is often compared to that for bridging structures (e.g. Bodin et al., 2020; Vantaggiato and Lubell, 2022). Bridging structures can represent access to more distant parts of the network, which can provide routes to new information (Burt, 2005). Bridging structures include open two paths (where two actors are connected through a common third actor) and stars (where three or more actors are connected through a central actor). The additional ties represented by bonding over bridging structures may contribute to network redundancies that are beneficial in allowing a network to persist and reorganize (Alexander et al., 2017).

Berardo and Scholz's (2010) risk hypothesis, which relates to social risk, argues that policy actors favour bridging capital in the early phases of network creation because extensive ties and centralization are beneficial for required information sharing to address low risk problems. However, this benefit diminishes for more complicated collaborative or complex problems that require trust and reciprocal relationships (Berardo and Scholz, 2010). Bonding network structures, such as closed triads, have been proposed to be prevalent when risk perception is high (Berardo and Scholz, 2010). Understanding the relative tendency to

form bridging and bonding structures provides insight into the difficulty and perceived risk of collaboration. As one sector or region's flood management actions can create the environment for increased flooding in other regions, flooding could present a context amplifying the consequences of defection.

1.1.3. Objective three: analyze the impact of geographic scale and organization type

Incorporating organizational attributes into network analysis can further reveal insights into multi-level governance (Guerrero et al., 2015b; Hileman and Lubell, 2018; Hamilton and Lubell, 2019). Collaboration among and between different organization types operating within different geographic levels may impact the functionality of a network (Fliervoet et al., 2016; Hileman and Lubell, 2018; Locatelli et al., 2020). Collaborative relationship choices may be impacted by organizational type, spatial jurisdiction, or formal authority (Bodin and Nohrstedt, 2016; Fischer and Jasny, 2017; Jasny et al., 2019; Hedlund et al., 2021), and these choices shape multi-level governance arrangements. Flood planning often involves a variety of organization types operating over different spatial levels and who may be impacted in different ways by the consequences of flooding. As levels of government often function differently in water governance networks (Hileman and Lubell, 2018; García et al., 2019), it is useful to understand how collaboration activity differs among groups based on both organization type and spatial level.

Homophily, the social process of actors disproportionately forming ties with actors who have similar characteristics (McPherson et al., 2001), can heavily influence network structure (McPherson et al., 2001; Barnes et al., 2016b). Shared attributes among actors can facilitate communicating complex information and mutual understanding (Prell et al., 2009). However, homophily can also lead to the development of distinct social groups, which can trap knowledge and behaviours in network communities (McPherson et al., 2001; Crona and Bodin, 2011). With flood governance shifting to include a broader variety of actors, identifying tendencies to collaborate or not across organization types or regions provides insight into the inclusiveness of the emerging governance network (Vidal-Hernández et al., 2019).

1.1.4. Objective four: assess the impact of geographic scale on brokerage

Relationships that join different actor types can facilitate connections across administrative levels (Hamilton et al., 2020), better coordinate emergency responses (Lind et al., 2008), and improve the diffusion of information (Levy and Lubell, 2018). This role of joining otherwise unconnected actors is known as brokerage, where intermediaries (brokers) facilitate transactions between actors lacking trust or access to each other (Marsden, 1982). Connecting dissimilar actors may provide different benefits compared to connecting similar type actors (Fernandez and Gould, 1994), influencing knowledge flows (Levy and Lubell, 2018; Locatelli et al., 2020) and management priorities (Hamilton et al., 2020). Brokerage is further impacted by the larger social context, as strong divides or a lack of trust between actor groups may reduce the benefits of brokers (Barnes et al., 2016a). Further, understanding the influences of geographic scale on brokerage roles can provide insights into connections across levels and informs interventions that facilitate greater connections among distinct groups (Hamilton et al., 2020). However, there is limited research on brokerage between actor groups (Hamilton et al., 2020) and how context impacts brokerage roles (Barnes et al., 2016a). As flood governance in a transboundary river basin involves actors of various types who operate over distinct scales and distinct parts of the basin, it is useful to know which actor types are facilitating connecting the basin as a whole.

1.1.5. Objective five: assess if municipalities are brokers in the network

Research has shown that government at local levels (i.e. municipalities) occupy unique roles in water governance. Municipalities are often situated within formal government hierarchies while also

engaging with community organizations, presenting unique challenges (García et al., 2019). Becker's (2020) network analysis of flood risk mitigation within the Høje Å catchment, Sweden, found that municipalities were connected to higher levels of government, but often connected to each other through non-governmental associations. Investigating if municipalities hold a unique role in this flood planning network provides a comparative in a Canadian context.

2. Methods

2.1. Study region

The Wolastoq | Saint John River Basin is a 673 km transboundary river in Eastern North America, located in the provinces of Québec and New Brunswick in Canada and the state of Maine in the United States of America. While existing in three separate political jurisdictions, discussion of environmental issues is often operationalized as three main basins defined by water flow (Kidd et al., 2011): Upper, Middle and Lower Basins. Flooding has been a historic and recent concern in the region with multiple catastrophic events in recent years (Woodhall-Melnik and Grogan, 2019). Both the 2018 and 2019 floods were 100-yr floods, with the 2018 flood costing the New Brunswick provincial government over \$74 million (Poitras, 2019). Future flood models forecast an increase in inundation extents under shared socio-economic pathway (SSP) 4.5 and SSP 8.5 scenarios for both one in 100-yr floods and one in 200-yr floods (Mohanty and Simonovic, 2021).

Slightly over half of the area covered by the Wolastoq | Saint John River Basin is located in the province of New Brunswick, where multiple provincial agencies and intergovernmental agencies, and partnerships with federal agencies have key water-related roles and responsibilities (Department of Environment and Local Government, 2018; Plummer et al., 2016). Purview with regards to flooding is distributed among provincial departments (specifically the Department of Environment and Local Government and the Department of Justice and Public Safety), and among regional governments (Regional Service Commissions) and municipalities (Government of New Brunswick, 2014). The Wolastoq | Saint John River Basin was chosen as an appropriate region to explore adaptive flood governance as it 1) has a history of flooding; 2) recently experienced drastic (intensifying frequency and severity) floods; and 3) is emblematic of the social (multi-jurisdictional) and biophysical (basin and sub-basin) complexities inherent in flood governance.

2.2. Data collection

Structured surveys were used to gather social network data. Research ethics was submitted to and approved by the [removed for review] Social Science Research Ethics Board ([removed]). First, the research team, in conjunction with key informants, identified 136 organizations throughout New Brunswick, Québec, and Maine, including multiple levels of government (federal, provincial, regional, and municipal), Indigenous self-government, non-governmental organizations, and industry. Individuals within each organization were identified with potential knowledge about their organization's flood planning activities, and multiple individuals were identified for large organizations (Fliervoet et al., 2016).

An online questionnaire was distributed via email to the identified individuals and was open from August 18th to September 30th, 2020. Respondents were asked to respond to the questionnaire on behalf of their organization and could respond in either English or French. To prompt non-responders, reminder emails were sent, and English-speaking individuals were also telephoned.

Using the list of pre-identified organizations, respondents were asked to select the organizations that they collaborated with when making flood planning decisions. Collaboration was defined as the regular professional sharing of human, financial and/or technical resources, engaging in joint activities, and organizing joint activities (Alexander

et al., 2017; Bodin et al., 2019). Respondents were encouraged to consider all flood planning activities conducted since 2018.

Completed questionnaires were received from 58 individuals responding on behalf of 53 invited organizations. Four organizations responded to the questionnaire invitation to indicate they were not within the network boundaries, reducing the number of possible responding organizations to 132. As such, the response rate for the network was 40%. Table S1 in Supplementary Material 1 provides the response rate by organization type and location.

2.3. Constructing the collaboration network

The collaboration network was constructed from responding organizations. Non-respondent network organizations were dropped and responses from multiple individuals in the same organization were coalesced into a singular response using all collaboration ties reported (Baird et al., 2016). Due to the inherently bidirectional nature of collaboration ties, only reciprocal ties were included and were treated as undirected (Fliervoet et al., 2016; Bodin et al., 2020).

Node attributes were created for basin location, basin level (to indicate level within the geographic scale), and organization type. The attribute basin location was defined as one of the three main basins or multi-basin for those operating within more than one of them. This was created from responses identifying organizational sub-sub basins for flood planning. Basin level indicated a binary single-basin or multi-basin actor. This distinction between single and multi-basin organizations attempted to account for the varying spatial levels of organizations (Alexander et al., 2017) while accounting for the nature of the trans-boundary watershed. Ties to non-respondents were also captured as a node attribute to control for their potential effect in the analysis.

2.4. Network analysis

2.4.1. Exponential random graph model

Exponential random graph models (ERGM) are a class of models that analyze overall network structure through smaller configurations within the network (Lusher et al., 2012). ERGMs analyze the empirical networks as the dependent variable, with the prevalence or absence of these smaller configurations, also called motifs, as the independent variables. Previous scholarship has associated many of the social processes and forces that impact network formation and structure with specific smaller configurations (Robins et al., 2007; Goodreau et al., 2009; Crona and Bodin, 2011; Lusher et al., 2012). ERGMs convey which motifs impact network structure and the results are used as a device to understand what social forces may affect the specific empirical network (e.g. homophily, centralization, closure). Node attributes can also be incorporated into the model to determine if they impart significant structural effects.

ERGMs compare motif occurrences in the observed network to those in purposefully generated random networks. Each motif is assigned a parameter and standard error, as in a regression analysis. However, ERGMs account for dependencies that are implicit in networks. The parameter value indicates if a motif occurs more or less often compared to generated random graphs, with significance determined by the standard error. The occurrence, or lack thereof, of a motif can be used to understand if the underlying associated social processes are enhanced or suppressed in the observed network. Motifs need to be interpreted in relation to each other, as simpler motifs can be nested in more complex configurations. For example, an open two-path is contained within a triangle, and the inclusion of the lower-order, or simpler, motif leads to more precise interpretations of the higher-order, or more complex, motif (Snijders et al., 2006). ERGMs are more robust to missing data from non-respondents than network descriptives (Robins et al., 2004).

ERGMs were fitted to the undirected collaboration network using Markov Chain Monte Carlo (MCMC) simulation in R v. 4.0.5 in the ergm package (Hunter et al., 2020) and checked for goodness of fit and

degeneracy (Supplementary Resource 2). Models were developed in an explorative manner, to ensure all motifs necessary for answering the propositions were included while finding the model with the best fit (Bodin and Nohrstedt, 2016). To minimize convergence challenges, models were fitted sequentially, adding new terms only after the previous model converged (Alexander et al., 2018; Barnes et al., 2019). Initial models included baseline structural mechanisms and then were expanded to include nodal attributes.

2.4.2. Brokerage analysis

A Gould-Fernandez (1989) brokerage analysis computes brokerage counts for each of their five brokerage roles: coordinators, itinerant brokers, gatekeepers, representatives, and liaisons (Fig. 1). Each brokerage chain is defined by the orientation of actors based on distinct actor subgroups. Coordinators join two nodes from their own subgroup. Itinerant brokers join two actors that belong to the same subgroup where the broker is of a different subgroup. Both gatekeepers and representatives join one actor from their own subgroup to an actor of a different subgroup but differ in node orientation. For undirected networks, the counts for gatekeepers and representatives are the same. Liaison brokerage chains connect three actors from different actor subgroups (Gould and Fernandez, 1989).

A Gould-Fernandez brokerage analysis was performed in the SNA package (Butts, 2020) in R. The analysis provides observed brokerage counts for all five roles for the overall network and for every node. Observed brokerage counts are compared to expected counts and variances from a null model of the same network size and density, with assumptions of normal distribution (Gould and Fernandez, 1989). Significance is determined through standardized scores and indicates brokerage activity substantially larger or smaller than expected in the null model, suggesting the presence of additional social forces. Two Gould-Fernandez analyses were performed; one used the categorical attributes of basin location, and the second used the attributes of government, municipalities, and other. Standardized scores were calculated for all five brokerage roles for each attribute category, and significance was determined, assuming a normal distribution with absolute standardized scores greater than 1.96 indicating significance (Gould and Fernandez, 1989).

3. Results and discussion

3.1. Objective one: identify the flood planning collaboration network

The majority of 53 responding organizations were located within the province of New Brunswick (N=47) (Table S1). Municipal governments, non-government organizations, and watershed organizations responded in the highest numbers. Fig. 2 shows the undirected, reciprocal collaboration network with a density of 0.065. The two fragments (nodes disconnected from the main network) are comprised of organizations based in Maine. The reciprocal collaboration network did not include any organizations based within Québec. As the response rates for Maine and Québec were low, this research cannot comprehensively address collaboration across provincial / international boundaries within the watershed. The largest portion of the watershed and questionnaire respondents are located within the province of New Brunswick, which serves as the primary institutional backdrop for much of the discussion.

The collaboration network displayed a range of organization types engaged in flood planning that have varying legislated roles and responsibilities (Fig. 2). Responsibility to address flooding in New Brunswick falls among the provincial, regional, and municipal levels of government. The provincial government in the current Flood Risk Reduction Strategy identified three primary objectives focused on the identification, inclusion, and mitigation of flood risk, with an emphasis on infrastructure (Government of New Brunswick, 2014). However, “continuing to update flood hazard maps” was the sole provincial action item to address flooding concerns in the 2020 Climate Change Action

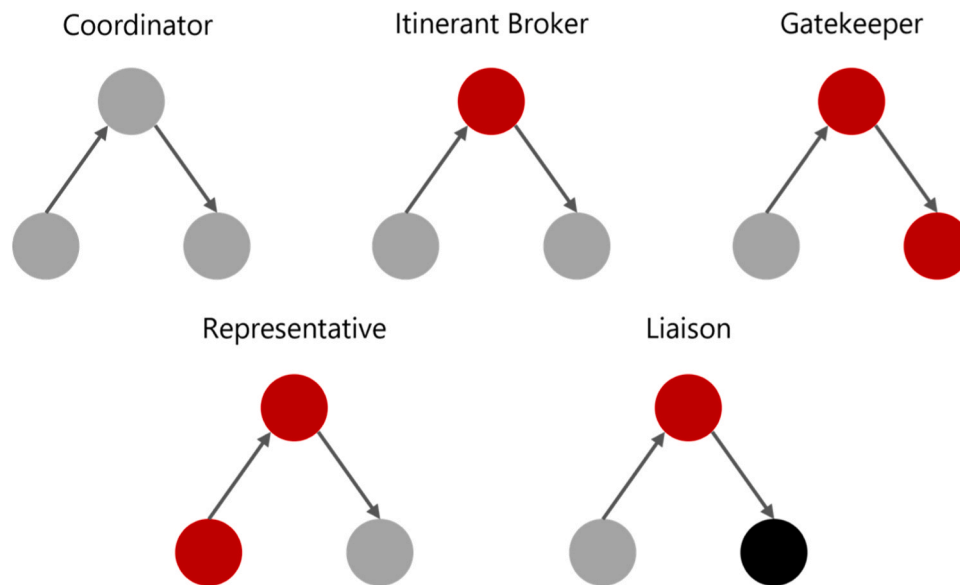


Fig. 1. Gould-Fernandez brokerage chains. Adapted from Gould and Fernandez (1989).

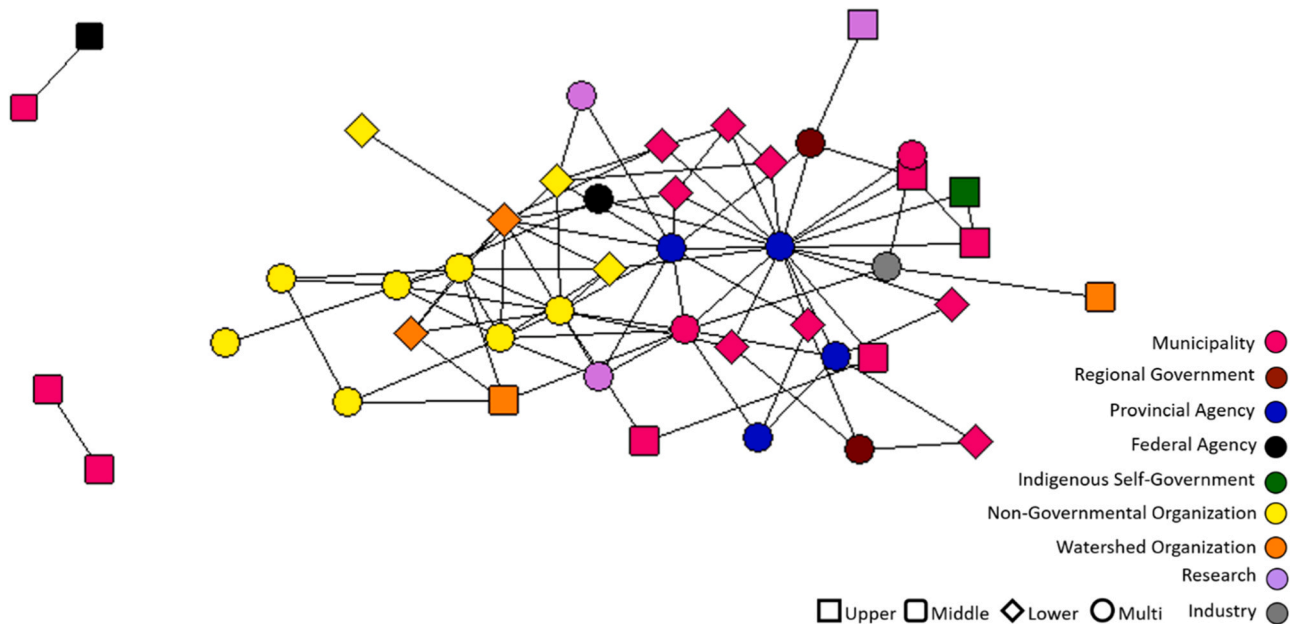


Fig. 2. Undirected collaboration network (N=44) with isolates (N=9) removed from the diagram. Colour indicates organization type and shape indicates basin location. Density = 0.065 (approximately 6.5% of all possible ties among responding actors were reported).

Plan Progress Report (Department of Environment and Local Government, 2020). There is ongoing work at regional and municipal levels to address flooding concerns. For instance, the Federal National Disaster Mitigation Program provided partial funding for four flooding mitigation projects for the City of Fredericton and the City of Saint John in 2019 (Public Safety Canada, 2019). There is also ongoing engagement between municipalities and non-governmental organizations in compiling and operationalizing climate change adaptation plans, which largely include flood planning (Brogan et al., 2020; City of Fredericton, 2020).

Prominent participation of New Brunswick based non-governmental organizations (NGOs) was observed within the collaboration network (Fig. 2). A lack of legislated authority to governmental or non-governmental bodies for purview over watersheds within New Brunswick has contributed to the ongoing involvement of small,

environmentally focused NGOs. The ongoing work of these NGOs, self-described as both NGOs and watershed organizations within the collected network, is supported in part through provincial and federal funding (e.g. through the New Brunswick Environmental Trust Fund). Funding allotments are often provided for specific projects with specific time frames and can be subject to necessary alignment with broader overarching priority concerns or areas.

The variety of organisations involved in the Wolastoq | Saint John River Basin is indicative of the contemporary shift from government to governance (Lebel et al., 2006; Howlett et al., 2009; Pahl-Wostl, 2009; Armitage et al., 2012). While government refers to state-centric, top-down hierarchical models of control, governance incorporates non-state actors, formal and informal institutions, and networks (Kooiman and Bavinck, 2005; Pahl-Wostl, 2009). Addressing problems in complex adaptive social-ecological systems requires adaptive governance which

incorporates and connects distinct groups beyond government (Dietz et al., 2003; Ostrom, 2005; Folke et al., 2005; Armitage et al., 2009). The active participation of non-governmental actors in the collaborative flood planning network collected here demonstrates this shift.

However, governments continue to be integral. Huntjens et al. (2010) argue large complex systems, like river basins, benefit from some degree of central authority to contribute to “facilitation of participatory processes, setting of standards, capacity building, conflict resolution, and cooperation across boundaries” (p. 276). Kuehne et al. (2020) noted government institutions may provide resource stability to build long-term bonding and bridging structures among diverse groups. As displayed by the network composition, the active role of government may be beneficial by contributing resource stability. However, the investigation into contextually beneficial roles of government in collaborative governance is still an ongoing area of research (Fliervoet et al., 2016; Kuehne et al., 2020).

3.2. Objective two: assess the tendency towards bonding and bridging structures

The ERGM analysis showed a strong negative coefficient for edges, meaning the network has a low density (Table 1). There was no significant impact for isolates, centralization, or two actors to be connected to a common third actor. However, network closure (i.e. three actors all connected), was significant in the network. Ties to non-respondents was included as a nodal covariate to control for the bias in the partial network due to the low response rate, and this was statistically significant.

The results for two-paths and network closure (Table 1) indicate that there is no meaningful impact of centralization on the network but a tendency for network closure. This result suggests the tendency for bonding structures over bridging structures in the network. The tendency for bonding structures in this context aligns with Berardo and Scholz's (2010) risk-hypothesis for a high-risk cooperation dilemma, where complex collaboration problems require trust and reciprocal relationships. While research is ongoing to better understand specific components of high-risk dilemmas (Bodin et al., 2020), the risk has been postulated to stem from potential partner defection (Berardo and Scholz, 2010), questionable benefits of a collaborative relationship (Nohrstedt and Bodin, 2019), or uncertain contexts where contestation about decisions is needed (McAllister et al., 2017).

The potential risk indicated by the tendency for network closure may be a product of network composition. As discussed in Objective One, there is a broad range of participating organizations in the flood planning network. With varying mandates and agendas, it is possible organizations require closed network structures to negotiate goals (McAllister et al., 2015). Furthermore, the prominent activity of NGOs in the network means many of the organizations conducting flood planning are subject to uncertain funding cycles for the capital to engage in additional climate adaptation or collaborative projects. As reported in analysis of this same system, organizations face financial and time constraints in collaborative relationships (McGlynn et al., 2023). It may be reasonable to conclude there is uncertainty if a collaborative relationship will be worthwhile to address flood planning problems when collaborating among differing organization types, and if the collaborative relationship can be sustained long enough to do so.

The impact of resource availability and consistency has been investigated for other collaborative arrangements for watershed governance. Koontz and Newig (2014) found access to resources, dedicated leaders, and local networks influenced differences in perceptions of the implementation and usefulness of collaborative planning activities, with available funding greatly impacting the ability to implement the collaborative plan. The San Francisco Bay Area's “bottom-up” approach to flood risk management, as discussed by Serra-Llobet et al. (2016), was limited by a lack of regulatory oversight to impose long-term plan updates and a lack of consistent and stable funding, both of which

Table 1
Collaboration ERGM parameter estimates.

ERGM term	Description	Parameter Estimates (Std. Error)
Density <i>Edges</i>	Propensity to form ties	-4.5896 (0.518) ***
Isolates <i>Isolates</i>	Propensity for isolates in the network	-0.2851 (1.235)
Anti-Centralization <i>Gwdegree (fixed, 0.5)</i>	Propensity away from centralization. A negative value indicates the centralization of edges.	-0.7871 (1.140)
Two-paths <i>Gwdsp (fixed, 0.5)</i>	Propensity to find to find two actors tied to a common third actor. Bridging structure.	0.0095 (0.039)
Network closure <i>Gwesp (fixed, 0.5)</i>	Three actors connected. Together, two-actor ties and network closure represent the tendency for network closure i. e. are triangles created by three actors connecting to one another or by two actors connecting to one another who happen to be connected to a common third actor. Bonding structure.	0.5961 (0.206) **
Ties to non-respondents <i>Nodcov</i>	Control parameter – accounts for the effect of ties to non-responding organizations	0.0598 (0.016) **
Activity by basin level <i>Nodefactor</i>	Single basin activity, compared to the propensity to form ties, baseline of multi basin organizations	-0.0925 (0.157)
Homophily for basin level <i>Nodematch</i>	Tendency to connect to actors working at the same basin level	0.2945 (0.253)
Activity by organization type <i>Nodefactor</i>	Government activity, propensity to form ties, compared to the baseline of non-government	-0.3301 (0.103) **
Homophily for organization type <i>Nodematch</i>	Tendency to connect to actors of the same organizational type	1.3562 (0.271) ***

Alpha values were fixed at 0.5

Number in parentheses represent standard errors and (***) $p < 0.001$, (**) $p < 0.01$, (*) $p < 0.05$, (.) $p < 0.1$

Names of the corresponding network configuration in the *ergm* R package in italics (Hunter et al., 2020)

contributed to a short-term focus. This work, along with others, argues for a need for a balanced inclusion of a centralized authority to complement a “bottom-up” governance approach (Pahl-Wostl, 2009; Huntjens et al., 2010, 2012; Guerrero et al., 2015a; Serra-Llobet et al., 2016).

3.3. Objective three: analyze the impact of geographic scale and organization type

We included terms for nodefactor (to capture activity) and node-match (to capture homophily) in the ERGM for broad level attributes for geographic scale and organization type (Table 1). The geographic scale attribute consisted of a binary single basin or multi-basin categorization based on flood planning activities. The ERGM displayed no significant effect for activity or homophily based on geographic scale (Table 1), which differed from other's findings (Sayles and Baggio, 2017; McAllister et al., 2017; Hamilton and Lubell, 2018; Hileman and Lubell, 2018).

To capture homophily and activity for organizational type, organizations were assigned a categorization of government or non-government. Although seven distinct organization types were categorized for the network (Fig. 1), the low number of respondents from some categories (Table S1) made including all seven categories impractical for modeling purposes. The categories were amalgamated into government and non-government following the primary network divide discussed by Fliervoet et al. (2016). The ERGM displayed that government organizations engaged in fewer ties than compared to non-government organizations (0.3301) and there was a strong tendency for homophily among both groups (1.3562) (Table 1). A tendency for homophily is common in social networks and has been seen along organizational divides in collaboration networks (Jasny et al., 2019; Locatelli et al., 2020).

The necessity for municipalities to interact with higher levels of government in this legislative context likely contributed to the evidence of government homophily in the network. Responsibility for emergency management in New Brunswick falls within the jurisdiction of the provincial government and requires active communication with municipalities. An extent of collaboration among all levels of government is embedded in the legislative context. The tendency for NGOs to be more active in the network may also stem from this distribution of responsibility. While government actors hold authority, NGOs may require collaboration to reach objectives (Warner and Van Buuren, 2009).

3.4. Objective four: assess the impact of geographic scale on brokerage

Among the top ten brokers by total brokerage counts, there was a mix of organization types: provincial agencies, municipal governments, non-governmental organizations, and watershed organizations (Table 2). This brokerage analysis further investigated the potential impact of geographic scale on the network, and in contrast to the activity measure in the ERGM, scale impacted brokerage role. All the organizations with the highest brokerage counts were either multi-basin or Lower Basin actors. When dividing organizations by basin location, there were significant coordinator, gatekeeper, representative, and liaison brokerage roles in the network (Table 3). When investigating group differences, the Upper Basin and multi-basin actors occupied significant brokerage roles. Upper Basin actors were coordinators, connecting fellow Upper Basin

Table 2
Top 10 brokers by total brokerage counts.

Organization	Basin	Total Brokerage Counts
New Brunswick Emergency Measures Organization	Multi	316
World Wildlife Fund - Canada	Multi	96
New Brunswick Climate Change Secretariat	Multi	68
City of Fredericton	Multi	54
Kennebecasis Watershed Restoration Committee	Lower	52
St. John River Society	Multi	46
Conservation Council of New Brunswick	Multi	34
ACAP Saint John	Lower	22
Nature NB	Multi	22
New Brunswick Department of Health	Multi	14

actors. As only four Upper Basin organizations responded, even the presence of two coordinator brokerage chains was significantly high. Multi-basin organizations also functioned as coordinators, connecting fellow multi-basin actors. Multi-basin organizations also had a positive significant total brokerage count, suggesting connections throughout the basin were likely impacted by the multi-basin actors. No categories of organizations were significantly unlikely to be in a brokerage position.

Regional governance systems need to be able to “engage effectively at multiple scales” (Lebel et al., 2006, p. 19). Important aspects of a regional governance system are connections among actors within the same levels (horizontal ties) and between different levels (vertical ties) (Berkes, 2002; Ostrom, 2005; Armitage et al., 2009; Alexander et al., 2017; Hileman and Lubell, 2018). Connections across spatial levels are a necessary component of adaptive governance to cope with inter-connected SES dynamics and uncertainties (Folke et al., 2005). Both horizontal and vertical ties are required for cohesive flood planning at the river basin scale (Benson and Lorenzoni, 2017; Becker, 2018).

Geographic scale impacted brokerage activity as Multi-basin organizations occupied significant brokerage positions, potentially impacting knowledge flows (Levy and Lubell, 2018; Locatelli et al., 2020), and management priorities or implications (Hamilton et al., 2020). Ties among actors operating over different spatial levels also may be connecting different organization types, which provide a possible mechanism to combine different types of knowledge (e.g. expert, local, traditional ecological knowledge) in stages of the collaborative process (van Tol Smit et al., 2015).

3.5. Objective five: assess if municipalities are brokers in the network

To assess if municipalities are brokers in the network, a second brokerage analysis separated municipalities from other government bodies. When dividing organization type into upper-level government (Regional, Provincial and Federal agencies, and Indigenous self-government), municipalities, and all non-government actors, there were significant coordinator and itinerant brokerage roles in the network (Table 4). Government actors occupied positive significant coordinator, itinerant, gatekeeper, and representative roles.

The analysis found no unique role of municipalities as brokers, despite likely occupying a unique functional role in flood planning (García et al., 2019; Becker, 2021). The broader government category occupied multiple significant brokerage roles. As coordinator brokers, the government actors are connecting two other government organizations. As itinerant brokers, the government actors are connecting to two organizations of a different categorization. While not explicitly contained within the analysis, the broader tendency for government homophily, as well as the regional context, would suggest the higher-level government organization were acting as itinerant brokers between two municipalities. In the role of gatekeeper or representative, which due to the undirected network are equivalent, the government broker was connecting another government organization to an organization of a different category. This prominent role of government actors as brokers is similar to the findings of Fliervoet et al. (2016) where government actors were prominent bridges in both the flooding and nature-focused networks.

4. Conclusion

Analysis of the flood planning collaboration network in the Wolastoq | Saint John River Basin revealed active roles of government agencies and NGOs. This active collaboration of multiple types of organizations emphasises the ongoing shift towards adaptive governance for addressing complex environmental challenges. The composition of the flood planning collaboration network, coupled with findings from Exponential Random Graph Models (ERGM), sheds light on potential emerging challenges associated with such a shift. These challenges underscore the importance of proactive measures to foster strategic

Table 3

Total brokerage counts by organizational location using Gould-Fernandez brokerage measures.

	Coordinator	Itinerant broker	Gatekeeper	Representative	Liaison	Total
Upper	2*	0	1	1	0	4
Middle	0	6	2	2	4	14
Lower	26	34	29	29	2	120
Multi Basin	162*	98	172	172	86	690*
Total	190***	138	204**	204**	92*	828***

The p-values are represented as significance codes (*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$)**Table 4**

Total brokerage counts by organizational subgroup using Gould-Fernandez brokerage measures.

	Coordinator	Itinerant broker	Gatekeeper	Representative	Liaison	Total
Municipalities	2	34	7	7	46	96
Upper-Level Government	20*	160**	84*	84*	70	418**
Other	150	10	72	72	10	314
Total	172***	204**	163	163	126	828***

The p-values are represented as significance codes (*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$)

collaboration that can enhance the capacity for adaptive flood governance.

The tendency towards bonding structures in the network may indicate flood planning presents a high-risk problem due to possible partner defection (Berardo and Scholz, 2010), questionable benefits of collaborative relationships (Nohrstedt and Bodin, 2019), or the need to negotiate goals and objectives (McAllister et al., 2015; McAllister et al., 2017). This tendency can be partially explained by the organizational and institutional composition of the network. Organizations engaged in flood planning in this context hold various roles, authorities, and jurisdictions and are subject to different resource availability and consistency, which can impact collaborative relationships. Governance systems with resource limitations may require stronger relationships and/or more repeated interactions to produce effective collaborations. However, while a tendency for bonding structures can facilitate repeated interactions and the trust essential for effective flood planning, the reinforcement of existing relationships can, over time, stifle the introduction of new perspectives and ideas, hindering the ability to innovate and adapt to evolving flood risks.

While the prominent brokerage role of a few NGOs in this network can help address the challenges posed by the tendency towards bonding structures, it also introduces a vulnerability. The strategic positioning of these NGOs can facilitate the exchange of information and resources between otherwise disconnected groups, fostering collaboration and innovation within the network. However, any decrease in capacity in any one organization may disrupt the brokerage links connecting other organizations, potentially compromising the network's effectiveness. Redundancy, to an extent, is critical to ensure function remains if relationships in the network disappear. There might be an opportunity to expand collaborative efforts within the basin while keeping in mind the existing tendency for closed network structures. Additional relationships that create links between cohesive groups, if manageable, may reduce part of the weakness of the current structure, and support increased learning and access to resources (McGlynn et al., 2023).

There are also opportunities for increased collaboration between municipalities. Municipalities often have similar mandates and deal with similar types of issues, making further collaboration among them potentially resource efficient and effective. Upper-level government, while currently acting as brokers between municipalities, may be able to formally support and provide mechanisms for increased collaboration between municipalities. Additionally, there are opportunities for NGOs to collaborate with more municipalities. These collaborations may provide unique expertise and knowledge, and support integrating the historic emergency management and the emerging flood planning networks.

This study highlights how the structure of the collaboration network can be enhanced to better support adaptive flood governance. However, structure alone is not sufficient. While flood planning requires connections across jurisdictions, sectors, and industries, and benefits from a multitude of approaches, recommendations for increased collaboration without adequate support to promote effective engagement throughout the basin will continue to be inadequate to comprehensively address increasing flood risks. Regional governance structures are often limited by conflicting priorities and limited resources, with impacts on resilience (Birchall et al., 2023; McGlynn et al., 2023). Upper-level government agencies have a role in supporting and guiding adaptive flood planning efforts. Flooding in a changing climate is a particularly complex phenomenon that will have different regional outcomes. Governance needs to be adaptive, involve the full constellation of actors, and simultaneously addressed at multiple levels, with careful attention to their interactions.

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CRedit authorship contribution statement

Angela M. Guerrero: Supervision, Writing – review & editing. **Julia Baird:** Conceptualization, Funding acquisition, Supervision, Writing – review & editing. **Ryan Plummer:** Conceptualization, Funding acquisition, Supervision, Writing – review & editing. **Bridget McGlynn:** Conceptualization, Data curation, Formal analysis, Writing – original draft, Writing – review & editing, Methodology.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Julia Baird reports financial support was provided by World Wildlife Fund - Canada. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at [doi:10.1016/j.envsci.2024.103795](https://doi.org/10.1016/j.envsci.2024.103795).

References

- Abram, N.J., Henley, B.J., Sen Gupta, A., et al., 2021. Connections of climate change and variability to large and extreme forest fires in southeast Australia. *Commun. Earth Environ.* 2 (1), 17. <https://doi.org/10.1038/s43247-020-00065-8>.
- Alexander, S.M., Armitage, D., Carrington, P.J., Bodin, Ö., 2017. Examining horizontal and vertical social ties to achieve social-ecological fit in an emerging marine reserve network. *Aquat. Conserv. Mar. Freshw. Ecosyst.* 27, 1209–1223. <https://doi.org/10.1002/aqc.2775>.
- Alexander, S.M., Bodin, Ö., Barnes, M.L., 2018. Untangling the drivers of community cohesion in small-scale fisheries. *Int. J. Commons* 12, 519–547. <https://doi.org/10.18352/ijc.843>.
- Armitage, D., de Loë, R., Plummer, R., 2012. Environmental governance and its implications for conservation practice. *Conserv. Lett.* 5, 245–255. <https://doi.org/10.1111/j.1755-263X.2012.00238.x>.
- Armitage, D., Plummer, R., Berkes, F., et al., 2009. Adaptive co-management for social-ecological complexity. *Front. Ecol. Environ.* 7, 95–102.
- Baird, J., Plummer, R., 2021. Water resilience: management and governance in times of change. Springer, Cham, Switzerland.
- Baird, J., Plummer, R., Bodin, Ö., 2016. Collaborative governance for climate change adaptation in Canada: experimenting with adaptive co-management. *Reg. Environ. Chang* 16, 747–758. <https://doi.org/10.1007/s10113-015-0790-5>.
- Baird, J., Plummer, R., Schultz, L., et al., 2019. How does socio-institutional diversity affect collaborative governance of social-ecological systems in practice? *Environ. Manag.* 63, 200–214. <https://doi.org/10.1007/s00267-018-1123-5>.
- Barnes, M.L., Bodin, Ö., McClanahan, T.R., et al., 2019. Social-ecological alignment and ecological conditions in coral reefs. *Nat. Commun.* 10, 2039. <https://doi.org/10.1038/s41467-019-09994-1>.
- Barnes, M.L., Kalberg, K., Pan, M., Leung, P., 2016a. When is brokerage negatively associated with economic benefits? Ethnic diversity, competition, and common-pool resources. *Soc. Netw.* 45, 55–65. <https://doi.org/10.1016/j.socnet.2015.11.004>.
- Barnes, M.L., Lynham, J., Kalberg, K., Leung, P., 2016b. Social networks and environmental outcomes. *Proc. Natl. Acad. Sci. USA* 113, 6466–6471. <https://doi.org/10.1073/pnas.1523245113>.
- Baudoin, L., Gittins, J.R., 2021. The ecological outcomes of collaborative governance in large river basins: Who is in the room and does it matter? *J. Environ. Manag.* 281, 111836. <https://doi.org/10.1016/j.jenvman.2020.111836>.
- Becker, P., 2020. The problem of fit in flood risk governance: regulative, normative, and cultural-cognitive deliberations. *Polit. Gov.* 8, 281–293. <https://doi.org/10.17645/pag.v8i4.3059>.
- Becker, P., 2018. Dependence, trust, and influence of external actors on municipal urban flood risk mitigation: the case of Lomma Municipality, Sweden. *Int. J. Disaster Risk Reduct.* 31, 1004–1012. <https://doi.org/10.1016/j.ijdr.2018.09.005>.
- Becker, P., 2021. Tightly coupled policies and loosely coupled networks in the governing of flood risk mitigation in municipal administrations. *Ecol. Soc.* 26, art34. <https://doi.org/10.5751/es-12441-260234>.
- Benson, D., Lorenzoni, I., 2017. Climate change adaptation, flood risks and policy coherence in integrated water resources management in England. *Reg. Environ. Chang* 17, 1921–1932. <https://doi.org/10.1007/s10113-016-0959-6>.
- Berardo, R., Lubell, M., 2019. The ecology of games as a theory of polycentricity: recent advances and future challenges. *Policy Stud. J.* 47, 6–26. <https://doi.org/10.1111/psj.12313>.
- Berardo, R., Scholz, J.T., 2010. Self-organizing Policy Networks: Risk, Partner Selection, and Cooperation in Estuaries. *Am. J. Pol. Sci.* 54, 632–649. <https://doi.org/10.1111/j.1540-5907.2010.00451.x>.
- Berkes, F., 2002. *Cross-Scale Institutional Linkages: Perspectives from the Bottom Up. The Drama of the Commons*. National Academies Press, pp. 293–321.
- Bodin, Ö., 2017. Collaborative environmental governance: Achieving collective action in social-ecological systems. *Science* (80-) 357, eaan1114. <https://doi.org/10.1126/science.aan1114>.
- Bodin, Ö., Baird, J., Schultz, L., et al., 2020. The impacts of trust, cost and risk on collaboration in environmental governance. *People Nat.* 2, 734–749. <https://doi.org/10.1002/pan3.10097>.
- Bodin, Ö., Crona, B.I., 2009. The role of social networks in natural resource governance: What relational patterns make a difference? *Glob. Environ. Chang* 19, 366–374. <https://doi.org/10.1016/j.gloenvcha.2009.05.002>.
- Bodin, Ö., Nohrstedt, D., 2016. Formation and performance of collaborative disaster management networks: Evidence from a Swedish wildfire response. *Glob. Environ. Chang* 41, 183–194. <https://doi.org/10.1016/j.gloenvcha.2016.10.004>.
- Bodin, Ö., Nohrstedt, D., Baird, J., et al., 2019. Working at the “speed of trust”: pre-existing and emerging social ties in wildfire responder networks in Sweden and Canada. *Reg. Environ. Chang* 19, 2353–2364. <https://doi.org/10.1007/s10113-019-01546-z>.
- Bodin, Ö., Robins, G., McAllister, R.R.J., et al., 2016. Theorizing benefits and constraints in collaborative environmental governance: a transdisciplinary social-ecological network approach for empirical investigations. *Ecol. Soc.* 21, art40. <https://doi.org/10.5751/ES-08368-210140>.
- Bodin, Ö., Tengö, M., 2012. Disentangling intangible social-ecological systems. *Glob. Environ. Chang* 22, 430–439. <https://doi.org/10.1016/j.gloenvcha.2012.01.005>.
- Borgatti, S.P., Mehra, A., Brass, D.J., Labianca, G., 2009. Network Analysis in the Social Sciences. *Science* (80-) 323, 892–895. <https://doi.org/10.1126/science.1165821>.
- Bracken, L.J., Oughton, E.A., Donaldson, A., et al., 2016. Flood risk management, an approach to managing cross-border hazards. *Nat. Hazards* 82, 217–240. <https://doi.org/10.1007/s11069-016-2284-2>.
- Brogan, B., McDonald, J., Lyons, B., et al., 2020. *Climate Change Adaptation Plan for Saint John*. Saint John.
- Burke, M., Driscoll, A., Heft-Neal, S., et al., 2021. The changing risk and burden of wildfire in the United States. *Proc. Natl. Acad. Sci.* 118, e2011048118. <https://doi.org/10.1073/pnas.2011048118>.
- Burt, R.S. (2005) *Brokerage and Closure: An Introduction to Social Capital*. Oxford University Press, Incorporated.
- Butts, C.T., 2020. *sna: Tools Soc. Netw. Anal.*
- CCA (2019) Canada’s top climate change risks: the expert panel on climate change risks and adaptation potential.
- City of Fredericton (2020) *City of Fredericton Climate Change Adaptation Plan*. Fredericton.
- Clegg G., Haigh R., Amaratunga D., Rahayu H. (2021) Transboundary River Governance Practices for Flood Risk Reduction in Europe: A Review. In: Amaratunga D., Haigh R., Dias N. (eds) *Multi-Hazard Early Warning and Disaster Risks*. pp 291–302.
- Cornwall W. (2021) Europe’s deadly floods leave scientists stunned. In: *Science* (80-). (<https://www.sciencemag.org/news/2021/07/europe-s-deadly-floods-leave-scientists-stunned>). Accessed 21 Jul 2021.
- Cosens, B.A., Williams, M.K., 2012. Resilience and water governance: Adaptive governance in the Columbia river basin. *Ecol. Soc.* 17.
- Crona, B., Bodin, Ö., 2011. Friends or neighbors? Subgroup heterogeneity and the importance of bonding and bridging ties in natural resource governance. *Social Networks and Natural Resource Management: Uncovering the Social Fabric of Environmental Governance*. Cambridge University Press, pp. 206–233.
- Cumisley, L., Priest, S.J., Klijn, F., Juntti, M., 2019. A framework to assess integration in flood risk management. *Implic. Gov., Policy, Pract.* 24.
- Davenport, F.V., Burke, M., Diffenbaugh, N.S., 2021. *Contrib. Hist. Precip. Change US flood Damages 118, 2017524118*. <https://doi.org/10.1073/pnas.2017524118/-/DCSupplemental>.
- Department of Environment and Local Government (2018) *A Water Strategy for New Brunswick 2018-2028*. Fredericton.
- Department of Environment and Local Government (2020) *Transitioning to a Low-Carbon Economy New Brunswick’s Climate Change Action Plan Progress Report 2020*.
- Dieperink, C., Mees, H., Priest, S.J., et al., 2018. Managing urban flood resilience as a multilevel governance challenge: An analysis of required multilevel coordination mechanisms. *Ecol. Soc.* 23. <https://doi.org/10.5751/es-09962-230131>.
- Dietz, T., Ostrom, E., Stern, P.C., 2003. The Struggle to Govern the Commons. *Science* (80-) 302, 1907–1912. <https://doi.org/10.1126/science.1091015>.
- Dunn, C.J., O’connor, C.D., Abrams, J., et al., 2020. Wildfire risk science facilitates adaptation of fire-prone social-ecological systems to the new fire reality. *Environ. Res. Lett.* 15. <https://doi.org/10.1088/1748-9326/ab6498>.
- Feltmate B., Moudrak M. (2021) And the preparedness of 16 major canadian cities to limit flood risk.
- Feltmate B., Moudrak M., Bakos K. (2020) Climate change and the preparedness of Canadian provinces and territories to limit flood risk. 97.
- Fernandez, R., Gould, R., 1994. A Dilemma of State Power: Brokerage and Influence in the National Health Policy Domain. *Am. J. Socio* 99, 1455–1491.
- Fischer, A.P., Jasny, L., 2017. Capacity to adapt to environmental change: Evidence from a network of organizations concerned with increasing wildfire risk. *Ecol. Soc.* 22. <https://doi.org/10.5751/ES-08867-220123>.
- Fleck, J., Udall, B., 2021. Managing Colorado river risk. *Science* (80-) 372, 885. <https://doi.org/10.1126/science.abj5498>.
- Fliervoet, J.M., Geerling, G.W., Mostert, E., Smits, A.J.M., 2016. Analyzing Collaborative Governance Through Social Network Analysis: A Case Study of River Management Along the Waal River in The Netherlands. *Environ. Manag.* 57, 355–367. <https://doi.org/10.1007/s00267-015-0606-x>.
- Folke, C., Hahn, T., Olsson, P., Norberg, J., 2005. ADAPTIVE GOVERNANCE OF SOCIAL-ECOLOGICAL SYSTEMS. *Annu. Rev. Environ. Resour.* 30, 441–473. <https://doi.org/10.1146/annurev.energy.30.050504.144511>.
- Folke, C., Pritchard, L., Berkes, F., et al., 2007. The problem of fit between ecosystems and institutions: Ten years later. *Ecol. Soc.* 12. <https://doi.org/10.5751/ES-02064-120130>.
- Fournier, M., Larrue, C., Alexander, M., et al., 2016. Flood risk mitigation in Europe: How far away are we from the aspired forms of adaptive governance? *Ecol. Soc.* 21. <https://doi.org/10.5751/ES-08991-210449>.
- García, M.M., Hileman, J., Bodin, Ö., et al., 2019. The unique role of municipalities in integrated watershed governance arrangements: A new research frontier. *Ecol. Soc.* 24. <https://doi.org/10.5751/ES-10793-240128>.
- Goodreau, S.M., Kitts, J.A., Morris, M., 2009. Birds of a feather, or friend of a friend? Using exponential random graph models to investigate adolescent social networks. *Demography* 46, 103–125. <https://doi.org/10.1353/dem.0.0045>.
- Gould, R.V., Fernandez, R.M., 1989. Structures of Mediation: A Formal Approach to Brokerage in Transaction Networks. *Socio Method.* 19, 89. <https://doi.org/10.2307/270949>.
- Government of Canada (2019) *Executive summary*. In: Bush E., Lemmen D. (eds) *Canada’s Changing Climate Report*. Ottawa.
- Government of New Brunswick (2014) *New Brunswick Flood Risk Reduction Strategy*. Fredericton.

- Guerrero, A.M., Barnes, M.L., Bodin, Ö., et al., 2020. Key considerations and challenges in the application of social-network research for environmental decision making. *Conserv. Biol.* 34, 733–742. <https://doi.org/10.1111/cobi.13461>.
- Guerrero, A.M., Bodin, Ö., McAllister, R.R.J., Wilson, K.A., 2015a. Achieving social-ecological fit through bottom-up collaborative governance: an empirical investigation. *Ecol. Soc.* 20, art41 <https://doi.org/10.5751/ES-08035-200441>.
- Guerrero, A.M., McAllister, R.R.J., Wilson, K.A., 2015b. Achieving Cross-Scale Collaboration for Large Scale Conservation Initiatives. *Conserv. Lett.* 8, 107–117. <https://doi.org/10.1111/cons.12112>.
- Hamilton, M., Fischer, A.P., Ager, A., 2019. A social-ecological network approach for understanding wildfire risk governance. *Glob. Environ. Chang.* 54, 113–123. <https://doi.org/10.1016/j.gloenvcha.2018.11.007>.
- Hamilton, M., Hileman, J., Bodin, Ö., 2020. Evaluating heterogeneous brokerage: New conceptual and methodological approaches and their application to multi-level environmental governance networks. *Soc. Netw.* 61, 1–10. <https://doi.org/10.1016/j.socnet.2019.08.002>.
- Hamilton, M., Lubell, M., 2018. Collaborative Governance of Climate Change Adaptation Across Spatial and Institutional Scales. *Policy Stud. J.* 46, 222–247. <https://doi.org/10.1111/psj.12224>.
- Hamilton, M.L., Lubell, M., 2019. Climate change adaptation, social capital, and the performance of polycentric governance institutions. *Clim. Change* 152, 307–326. <https://doi.org/10.1007/s10584-019-02380-2>.
- Hedlund, J., Bodin, Ö., Nohrstedt, D., 2021. Policy issue interdependency and the formation of collaborative networks. *People Nat.* 3, 236–250. <https://doi.org/10.1002/pan3.10170>.
- Hegger, D.L.T., Driessen, P.P.J., Dieperink, C., et al., 2014. Assessing Stability and Dynamics in Flood Risk Governance. *Water Resour. Manag.* 28, 4127–4142. <https://doi.org/10.1007/s11269-014-0732-x>.
- Henstra, D., Thistlethwaite, J., Brown, C., Scott, D., 2019. Flood risk management and shared responsibility: Exploring Canadian public attitudes and expectations. *J. Flood Risk Manag.* 12 (1), 10. <https://doi.org/10.1111/jfr3.12346>.
- Hileman, J., Lubell, M., 2018. The network structure of multilevel water resources governance in Central America. *Ecol. Soc.* 23 <https://doi.org/10.5751/ES-10282-230248>.
- Howlett, M., Rayner, J., Tollefson, C., 2009. Forest Policy and Economics From government to governance in forest planning? Lessons from the case of the British Columbia Great Bear Rainforest initiative ☆. *Policy Econ.* 11, 383–391. <https://doi.org/10.1016/j.forpol.2009.01.003>.
- Huitema, D., Mostert, E., Egas, W., et al., 2009. Adaptive water governance: Assessing the institutional prescriptions of adaptive (co-)management from a governance perspective and defining a research agenda. *Ecol. Soc.* 14 <https://doi.org/10.5751/ES-02827-140126>.
- Hunter, D., Handcock, M., Butts, C., et al., 2020. *ergm: Fit, Simula Diagn. Expon. -Fam. Models Netw.*
- Huntjens, P., Lebel, L., Pahl-Wostl, C., et al., 2012. Institutional design propositions for the governance of adaptation to climate change in the water sector. *Glob. Environ. Chang.* 22, 67–81. <https://doi.org/10.1016/j.gloenvcha.2011.09.015>.
- Huntjens, P., Pahl-Wostl, C., Grin, J., 2010. Climate change adaptation in European river basins. *Reg. Environ. Chang.* 10, 263–284. <https://doi.org/10.1007/s10113-009-0108-6>.
- Insurance Bureau of Canada (2019) Eastern Canada Spring Flooding Caused Close to \$208 million in Insured Damage. In: Media Release. (<http://www.abc.ca/nl/resources/media-centre/media-releases/eastern-canada-spring-flooding-caused-close-to-208-million-in-insured-damage>). Accessed 13 Apr 2021.
- IPCC (2019) Summary for Policymakers. In: Shukla P.R., Skea J., Buendia E.C., et al. (eds) *Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems*.
- IPCC (2023) Sections. In: *Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]*. IPCC, Geneva.
- IPCC (2018) Summary for Policymakers. In: Masson-Delmotte V., Zhai P., Pörtner H.-O., et al. (eds) *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change*. Geneva.
- Jasny, L., Johnson, M., Campbell, L.K., et al., 2019. Working together: The roles of geographic proximity, homophilic organizational characteristics, and neighborhood context in civic stewardship collaboration networks in Philadelphia and New York City. *Ecol. Soc.* 24 <https://doi.org/10.5751/ES-11140-240408>.
- Kidd S.D., Curry R.A., Munkittrick K.R. (2011) *The Saint John River: A State of the Environment Report*. Fredericton.
- Koolman, J., Bavinck, M., 2005. *The Governance Perspective*. In: *Fish for Life: Interactive governance for fisheries*. Amsterdam University Press, Amsterdam, pp. 11–24.
- Koontz, T.M., Newig, J., 2014. From Planning to Implementation: Top-Down and Bottom-Up Approaches for Collaborative Watershed Management. *Policy Stud. J.* 42, 416–442. <https://doi.org/10.1111/psj.12067>.
- Kuehne, L.M., Strecker, A.L., Olden, J.D., 2020. Knowledge Exchange and Social Capital for Freshwater Ecosystem Assessments. *Bioscience* 70, 174–183. <https://doi.org/10.1093/biosci/biz142>.
- Lebel, L., Anderies, J.M., Campbell, B., et al., 2006. Governance and the capacity to manage resilience in regional social-ecological systems. *Ecol. Soc.* 11 <https://doi.org/10.5751/ES-01606-110119>.
- Lebel, L., Nikitina, E., Pahl-Wostl, C., Knieper, C., 2013. Institutional fit and river basin governance: A new approach using multiple composite measures. *Ecol. Soc.* 18 <https://doi.org/10.5751/ES-05097-180101>.
- Levy, M.A., Lubell, M.N., 2018. Innovation, cooperation, and the structure of three regional sustainable agriculture networks in California. *Reg. Environ. Chang.* 18, 1235–1246. <https://doi.org/10.1007/s10113-017-1258-6>.
- Lind, B., Tirado, M., Petrescu-Prahova, M., Butts, C.T., 2008. Brokerage roles in disaster response: Organisational mediation in the wake of Hurricane Katrina. *Int. J. Emerg. Manag.* 5, 75–99. <https://doi.org/10.1504/IJEM.2008.019908>.
- Locatelli, B., Pramova, E., Di Gregorio, M., et al., 2020. Climate change policy networks: connecting adaptation and mitigation in multiplex networks in Peru. *Clim. Policy* 20, 354–372. <https://doi.org/10.1080/14693062.2020.1730153>.
- Lusher, D., Koskinen, J., Robins, G., 2012. *Exponential Random Graph Models for Social Networks*. Cambridge University Press, Cambridge.
- Malbeuf, J., 2020. Fort McMurray spring flood caused \$522 million in damage, insurance bureau says. CBC News, CBC News.
- Marsden, P.V., 1982. Brokerage Behavior in Restricted Exchange Networks. In: Marsden, P.V., Lin, N. (Eds.), *Social Structure and Network Analysis*. Sage, Beverly Hills, pp. 201–218.
- McAllister, R.R.J., Robinson, C.J., Brown, A., et al., 2017. Balancing collaboration with coordination: Contesting eradication in the Australian plant pest and disease biosecurity system. *Int. J. Commons* 11, 330–354. <https://doi.org/10.18352/ijc.701>.
- McAllister, R.R.J., Taylor, B.M., Harman, B.P., 2015. Partnership Networks for Urban Development: How Structure is Shaped by Risk. *Policy Stud. J.* 43, 379–398. <https://doi.org/10.1111/psj.12103>.
- McKinney, D.C., 1999. *Modeling Water Resources Management at the Basin Level: Review and Future Directions*. International Water Management Institute, Colombo, Sri Lanka.
- McGlynn, B., Plummer, R., Guerrero, A.M., Baird, J., 2023. Assessing social-ecological fit of flood planning governance. *Ecol. Soc.* 28 (1), art23 <https://doi.org/10.5751/ES-13842-280123>.
- McPherson, M., Smith-Lovin, L., Cook, J.M., 2001. *Birds of a Feather: Homophily in Social Networks*. *Annu. Rev. Socio* 27, 415–444.
- Merz, B., Hall, J., Disse, M., Schumann, A., 2010. Fluvial flood risk management in a changing world. *Nat. Hazards Earth Syst. Sci.* 10, 509–527. <https://doi.org/10.5194/nhess-10-509-2010>.
- Metz, F., Angst, M., Fischer, M., 2020. Policy integration: Do laws or actors integrate issues relevant to flood risk management in Switzerland? *Glob. Environ. Chang.* 61, 101945. <https://doi.org/10.1016/j.gloenvcha.2019.101945>.
- Mohanty, M.P., Simonovic, S.P., 2021. Changes in floodplain regimes over Canada due to climate change impacts: Observations from CMP6 models. *Sci. Total Environ.* 792, 148323. <https://doi.org/10.1016/j.scitotenv.2021.148323>.
- Niemczynowicz, J., 1999. Urban hydrology and water management - present and future challenges. *Urban Water* 1, 1–14. [https://doi.org/10.1016/S1462-0758\(99\)00009-6](https://doi.org/10.1016/S1462-0758(99)00009-6).
- Nohrstedt, D., Bodin, Ö., 2019. Collective Action Problem Characteristics and Partner Uncertainty as Drivers of Social Tie Formation in Collaborative Networks. *Policy Stud. J.* 0:1–27. <https://doi.org/10.1111/psj.12309>.
- Norberg, J., Cummin, G.S., 2008. *Complexity Theory for a Sustainable Future* (eds). Columbia University Press, New York.
- Ostrom, E., 2005. *Understanding Institutional Diversity*. Princeton University Press, Princeton.
- Pahl-Wostl, C., 2009. A conceptual framework for analysing adaptive capacity and multi-level learning processes in resource governance regimes. *Glob. Environ. Chang.* 19, 354–365. <https://doi.org/10.1016/j.gloenvcha.2009.06.001>.
- Pahl-Wostl, C., Lebel, L., Knieper, C., Nikitina, E., 2012. From applying panaceas to mastering complexity: Toward adaptive water governance in river basins. *Environ. Sci. Policy* 23, 24–34. <https://doi.org/10.1016/j.envsci.2012.07.014>.
- Plummer, R., Armitage, D.R., de Loë, R.C., 2013. Adaptive comanagement and its relationship to environmental Governance. *Ecol. Soc.* 18 <https://doi.org/10.5751/ES-05383-180121>.
- Plummer, R., Baird, J., Krievins, K., Mitchell, S.J., 2016. Improving river health: insights into initiating collaboration in a transboundary river basin. *Int. J. River Basin Manag.* 14, 119–132. <https://doi.org/10.1080/15715124.2015.1080717>.
- Plummer, R., Renzetti, S., Bullock, R., Melo Zurita, M. de L., Baird, J., Dupont, D., Smith, T., Thomsen, D., 2018. The roles of capitals in building capacity to address urban flooding in the shift to a new water management approach. *Environ. Plan. C: Polit. Space* 36 (6), 1068–1087. <https://doi.org/10.1177/2399654417732576>.
- Poitras, J. (2019) Is climate change causing the recent floods along the St. John River? CBC News.
- Prell, C., Hubacek, K., Reed, M., 2009. Stakeholder analysis and social network analysis in natural resource management. *Soc. Nat. Resour.* 22, 501–518. <https://doi.org/10.1080/08941920802199202>.
- Public Safety Canada (2019) Federal support for four New Brunswick flood mitigation projects. News Release.
- Robins, G., Pattison, P., Woolcock, J., 2004. Missing data in networks: Exponential random graph (p*) models for networks with non-respondents. *Soc. Netw.* 26, 257–283. <https://doi.org/10.1016/j.socnet.2004.05.001>.
- Robins, G., Snijders, T., Wang, P., et al., 2007. Recent developments in exponential random graph (p*) models for social networks. *Soc. Netw.* 29, 192–215. <https://doi.org/10.1016/j.socnet.2006.08.003>.
- Rouillard, J.J., Spray, C.J., 2017. Working across scales in integrated catchment management: lessons learned for adaptive water governance from regional experiences. *Reg. Environ. Chang.* 17, 1869–1880. <https://doi.org/10.1007/s10113-016-0988-1>.

- Savenije, H.H.G., Van der Zaag, P., 2008. Integrated water resources management: Concepts and issues. *Phys. Chem. Earth* 33, 290–297. <https://doi.org/10.1016/j.pce.2008.02.003>.
- Savenije, H.H.G., Van Der Zaag, P., 2000. Conceptual framework for the management of shared river basins; With special reference to the SADC and EU. *Water Policy* 2, 9–45. [https://doi.org/10.1016/S1366-7017\(99\)00021-5](https://doi.org/10.1016/S1366-7017(99)00021-5).
- Sayles, J.S., Baggio, J.A., 2017. Social-ecological network analysis of scale mismatches in estuary watershed restoration. *Proc. Natl. Acad. Sci.* 114, E1776–E1785. <https://doi.org/10.1073/pnas.1604405114>.
- Seher, W., Löschner, L., 2018. Balancing upstream–downstream interests in flood risk management: experiences from a catchment-based approach in Austria. *J. Flood Risk Manag* 11, 56–65. <https://doi.org/10.1111/jfr3.12266>.
- Serra-Llobet, A., Conrad, E., Schaefer, K., 2016. Governing for Integrated Water and Flood Risk Management: Comparing Top-Down and Bottom-Up Approaches in Spain and California. *Water* 8, 445. <https://doi.org/10.3390/w8100445>.
- Snijders, T.A.B., Pattison, P.E., Robins, G.L., Handcock, M.S., 2006. New specifications for exponential random graph models. *Sociol. Methodol.* 36, 99–153.
- Toosi, A.S., Calbimonte, G.H., Nouri, H., Alaghmand, S., 2019. River basin-scale flood hazard assessment using a modified multi-criteria decision analysis approach: A case study. *J. Hydrol.* 574, 660–671. <https://doi.org/10.1016/j.jhydrol.2019.04.072>.
- Valente, T.W., 2012. Network interventions. *Science* (80-) 336, 49–53. <https://doi.org/10.1126/science.1217330>.
- van Tol Smit, E., de Loë, R., Plummer, R., 2015. How knowledge is used in collaborative environmental governance: water classification in New Brunswick, Canada. *J. Environ. Plan Manag* 58, 423–444. <https://doi.org/10.1080/09640568.2013.860017>.
- Vantaggiato, F.P., Lubell, M., 2022. Functional differentiation in governance networks for sea level rise adaptation in the San Francisco Bay Area. *Soc. Netw.* 75, 16–28. <https://doi.org/10.1016/j.socnet.2022.02.010>.
- Wang, D., Guan, D., Zhu, S., et al., 2021. Economic footprint of California wildfires in 2018. *Nat. Sustain* 4, 252–260. <https://doi.org/10.1038/s41893-020-00646-7>.
- Warner, J., Van Buuren, A., 2009. Multi-stakeholder learning and fighting on the river scheldt. *Int. Negot.* 14, 419–440. <https://doi.org/10.1163/157180609X432888>.
- Winz, I., Brierley, G., Trowsdale, S., 2009. The use of system dynamics simulation in water resources management. *Water Resour. Manag* 23, 1301–1323. <https://doi.org/10.1007/s11269-008-9328-7>.
- Woodhall-Melnik, J., Grogan, C., 2019. Perceptions of mental health and wellbeing following residential displacement and damage from the 2018 St. John river flood. *Int. J. Environ. Res. Public Health* 16. <https://doi.org/10.3390/ijerph16214174>.
- Young, O.R., 2002. *The institutional dimensions of environmental change: fit, interplay, and scale*. MIT Press, Cambridge, Mass.