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Indigenous nations at the confluence: water governance networks and system transformation in the Klamath Basin

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ABSTRACT. Collaborative approaches to complex water quality problems can facilitate collective action across large watersheds with multiple, overlapping political jurisdictions, including Indigenous territories. Indigenous nations are increasingly engaging in collaborative water governance, in part, as a response to colonial legacies that have excluded Indigenous peoples from watershed management. This study uses social network analysis to explore emerging Klamath water governance networks. We seek to understand ongoing system transformation in contemporary water governance through tribal engagement in multi-jurisdictional water governance networks, from a system of Indigenous dispossession and exclusion (late 1800s-1980s) toward a yet unrealized system that centers Indigenous peoples. To envision the meaningful inclusion of Indigenous peoples in adaptive water governance, we first draw on criteria established by Indigenous water governance scholars. Then, we examine a snapshot of Indigenous participation in water quality governance in the Klamath Basin that focuses on the Karuk Tribe from 2018-2019. Specifically, Karuk tribal managers identified 21 different science-policy coalitions that they worked with on a range of water quality issues. We then used social network analysis methods to generate a network in which 210 different organizations were linked through co-membership in one or more coalitions. Our findings indicated that the Karuk and other Klamath Basin tribes play a central role in Klamath water quality governance and were not relegated to "stakeholder status." Using a community detection algorithm, we found that tribes were key players in the central technical working group that emerged through network connections. Applying a log-linear statistical model, we also observed a high level of mixing in the network across all types of organizations, including tribes. Finally, through a multi-membership model, we found that tribes were more strongly connected to influential network actors than NGOs, despite environmental NGOs being more numerous. These analyses demonstrate how tribal engagement can activate key mechanisms for water quality governance transformation, e.g., shifting information flows and changing system structures to more effectively center Indigenous nations. In addition to insights from social network analysis, we also highlight the limitations of technical water management in supporting the deep connections held between Indigenous peoples and their waters that are central to Indigenous water governance.

Key Words: *collaborative management; collective action; environmental governance; Indigenous water governance; Karuk Tribe; log-linear models; multimembership model; polycentric governance; social network analysis; walktrap community detection; water quality*

INTRODUCTION

The Klamath River has experienced a long history of water governance challenges, with Indigenous nations now playing a key role in creating new, basin-level science and policy (Pierce 1998, Doremus and Tarlock 2008, Reed 2014, Sarna-Wojcicki et al. 2019). Despite a long history of Indigenous communities being excluded from water governance decisions and “fish versus farms” contestations, Indigenous leaders from multiple tribes have remained deeply committed to ongoing negotiations toward Klamath Basin restoration (Jenkins 2008, Gosnell and Kelly 2010, Smith 2019). In the past two decades, collaborative and adaptive governance approaches to complex water quality problems in the Klamath have become increasingly prominent in water management decisions (Gosnell and Kelly 2010, Chaffin et al. 2016a). This is illustrated by recent progress with multi-sector agreements to remove four large dams on the Klamath that do not provide significant hydropower benefits yet create significant problems for threatened salmon and salmon-dependent Indigenous communities (KRRC 2020, KVAL News 2020).

Using social network analysis, we examined the emergent structures of Klamath collaborative water governance, given increased tribal participation and leadership in water quality networks. We consider the potential for these water quality networks to advance system transformation for water governance, from a system of Indigenous dispossession and exclusion (late 1800s-1980s) toward a yet unrealized system that centers Indigenous peoples and their knowledge systems. Similar to the confluence or junction point of two rivers, we view tribal engagement in Klamath collaborative water governance networks as a meeting place for multiple knowledge streams, including western scientific management approaches and place-based Indigenous management systems.

Indigenous watershed restoration approaches in the Klamath are embedded in place-based management traditions based on deeply held caretaking responsibilities (Lake et al. 2010, Reed and Norgaard 2010, Karuk DNR 2011, Tripp 2020). Indigenous knowledge and leadership are therefore an important part of salmon protection and restoration efforts in the Klamath (Fricke et al. 2019, Sarna-Wojcicki 2019). Although some of these efforts are specific to the Klamath, this speaks to a broader body of literature describing how a wide range of Indigenous nations and their allies are leveraging Indigenous knowledge, law, science, and activism to forward water protection and restoration, despite ongoing struggles (e.g., Holtgren et al. 2014, Chief et al. 2016, Whyte 2017, Middleton-Manning et al. 2018, Wilson and Inkster 2018, Yazzie and Baldy 2018, Estes and Dhillon 2019, Chief 2020).

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Indigenous struggles for water protection emphasize how collaborative water governance is connected to particular histories of racialized violence and dispossession (e.g., Norton 1979, 2014, Norgaard et al. 2011, Madley 2016), which continue to play out in contemporary water management (e.g., Reed 2014, Sarna-Wojcicki et al. 2019). Research has demonstrated the systematic exclusion of Indigenous communities from watershed collaborations, and in cases in which progress has been made, decades-long negotiations, and lawsuits and have been required to build meaningful co-governance institutions with Indigenous nations (Isely et al. 1970, Cronin and Ostergren 2007, Diver 2012, von der Porten et al. 2016). Despite these challenges, many tribal leaders have built tribal and inter-tribal natural resource management programs to enable tribal participation in water quality policy decisions (Cronin and Ostergren 2007, Diver 2012, Norman 2012, Holtgren et al. 2014, Chief et al. 2016, Wilson et al. 2018).

Although tribes may be invited to participate in decision making, a primary concern is that they are not invited to participate on their own terms. Through the "rendering technical" of complex Indigenous knowledge systems, dominant decision-making processes often negate the deeply held reciprocal relationships between Indigenous peoples and the places they come from (e.g., Borrows 1997, Lake et al. 2010, McGregor 2012, Whyte et al. 2016, Behn and Bakker 2019, Diver et al. 2019a). Examples include techno-bureaucratic applications using Indigenous knowledge to provide empiric measurements for policy makers without considering the place-based context of Indigenous knowledge, and without involving Indigenous peoples in decision-making processes to interpret their own knowledge systems (Kovach 2009, McGregor 2014, Diver 2017, Arsenault et al. 2019). Furthermore, science and policy experts often engage with Indigenous knowledge in a validation capacity, and thereby continue to privilege western science as the final authority (Agrawal 1995, Nadasdy 1999, 2003, Matsui 2015, Arsenault et al. 2019). Scholars have extensively critiqued the bureaucratic and scientific management processes that can dominate collaborative decision-making forums for their reduction of Indigenous knowledge systems to discrete numerical analyses (Martello 2001, Weir 2009, Norman, 2012), and for relegating sovereign tribes to "stakeholder status" (e.g., Smith 1996, von der Porten et al. 2016).

Responding to these challenges, a number of Indigenous communities are engaging in contemporary management decisions in part by leveraging scientific tools and data, building their own science and policy teams, and participating in a wide array of scientific and bureaucratic management forums (Diver 2012, 2018, McGregor 2012, Chief et al. 2016, Gosnell et al. 2017). Such technical capacity is not available to all tribes, especially those that remain unrecognized by state and federal governments. However, for those tribes that are engaging with techno-science, this work typically involves representing Indigenous knowledge systems in a bureaucratic management context. Working within dominant management structures also places tribes alongside state and federal organizations that have historically driven water governance decisions as well as numerous environmental NGOs that can compete with tribes for influence in collaborative decision making. When Indigenous representatives are a significant minority in water governance forums, this raises questions about bridging multiple knowledge systems, especially given the dominance of western scientific management (Ranco and Suagee 2007, Whyte 2013, Vaughan et al. 2016, Arsenault et al. 2019, Diver et al. 2019b). Despite such knowledge hierarchies, a number of Indigenous communities are finding ways to foreground Indigenous ways of knowing and are creating novel Indigenous water governance institutions (e.g., Ranco 2009, Napoleon 2013, Diver 2017, 2019a, Smith 2019, Confederated Tribes of the Umatilla Indian Reservation 2020). This may include taking a "two-eyed seeing" approach, in which Indigenous communities learn from one eye with the strengths of Indigenous knowledge and ways of knowing, and from the other eye with the strengths of western knowledge and ways of knowing (e.g., Denny and Fanning 2006, Arsenault et al. 2018, Reid et al. 2020, Smith et al. in press).

In our analysis, we examine the Klamath water quality networks as an exemplar case of tribal engagement in highly technical collaborative governance spaces (e.g., Chaffin et al. 2016a, Gosnell et al. 2017). We specifically consider how Klamath Basin tribes are engaging in water quality networks to address a wide array of intersecting water quality issues and diverse coalitions that include and extend beyond dam removal, i.e., fish disease, toxic algae, nutrient loading, cannabis, sediment, and other issues. Addressing Klamath water quality issues through diverse science and policy coalitions is part of strategies taken by the Karuk Tribe and others to enhance tribal participation in this complex, collaborative governance landscape (Chaffin et al. 2016a, Horangic et al. 2016).

Although research has established the policy impacts of tribal participation with Klamath dam removal (Chaffin et al. 2016a, Gosnell et al. 2017, KRRC 2020), the significance of increased tribal leadership in a broader set of water quality issues has not yet been addressed in the literature. Examining this trend provides an opportunity to investigate ongoing system transformation in the Klamath from a longstanding system of exclusion toward a system of meaningful tribal engagement in water governance. Following existing frameworks for adaptive and transformative governance (e.g., Walker et al. 2004, Chaffin et al. 2016b), we refer to system transformation as the deliberate, human-driven creation of new water governance institutions and structures that center Indigenous peoples and their knowledge systems. We refer to adaptive capacity as the ability of tribes to participate in current water governance decision-making structures, and existing processes for adaptive water governance.

Conducted from 2018-2019, this study asks whether and how emerging water quality networks can advance Indigenous self-determination in Klamath water governance. To address this, we use social network analysis to provide a snapshot of tribal engagement in complex water quality coalitions. This includes examining changes in tribal access to decision makers relative to other governments and NGOs.

We first discuss the literature on collaborative and adaptive management in relation to research on Indigenous water governance and social network analysis. Here, we draw on water governance scholarship to provide a meaningful benchmark for what it means to center Indigenous knowledge and self-determination in water governance institutions. We then use social network analysis to explore the structure of emerging Klamath water governance networks. To better understand tribal participation in water governance, we examine network heterogeneity, or the level of mixing. We also evaluate novel communities of organizations that emerge through network structures. We then consider the ability of tribes to access influential actors in the network, compared to a larger number of environmental NGOs. Finally, we juxtapose social network theory with insights from Indigenous water governance scholarship to analyze both opportunities and limitations for system transformation that more fully centers Indigenous peoples and their knowledge systems in water governance.

LITERATURE REVIEW

Collaborative governance and Indigenous self-determination

Collaborative governance refers to a devolved and participatory decision-making process that connects a broad set of stakeholders to understand, deliberate over, and negotiate solutions to complex environmental problems (Sabatier et al. 2005). It is thought to improve governance process and outcomes by including local knowledge in decision making, enhancing social learning opportunities among diverse stakeholders, and encouraging inclusive and democratic decision making (Pinkerton 2003, Carlsson and Berkes 2005, Diver 2016) as key elements of adaptive water governance (e.g., Gunderson et al. 2006, Chaffin et al. 2016b).

Collaborative water governance arrangements are often polycentric, involving “multiple centers” of authority operating across overlapping jurisdictions (Ostrom et al. 1961, McGinnis 1999, Schlager and Blomquist 2008). Polycentric, collaborative governance structures reflect more democratic and diverse approaches that transcend top-down management (McGinnis and Ostrom 2012, Gupta and Pahl-Wostl 2013). Such governance arrangements are increasingly studied through social network methods that analyze multilevel relationships and interactions among actors (Bodin and Prell 2011, Lubell et al. 2014, Bodin 2017).

Previous studies have documented the exclusion of tribes from collaborative water governance processes (Lubell and Leach 2005, Sarna-Wojcicki 2019). Despite claims to inclusivity, collaborative governance initiatives are often unaware of the particular needs, interests, and legal-political status of tribes (e.g., Reo et al. 2017, Long and Lake 2018). Scholars have described the problem of dominant groups avoiding opportunities to expand a collaborative process to include minority groups, because this can slow down or prevent consensus-based decisions (Foster 2002).

In the U.S. context, engaging with tribes as sovereign governments in devolved, collaborative processes can also present particular challenges. Non-governmental organizations in collaborative management forums often have limited knowledge of Federal Indian Law and legal requirements for federal agencies to consult directly with tribal governments (Ranco and Suagee 2007). In contrast to direct government-to-government engagement, collaborative processes can also relegate sovereign tribes to “stakeholder status” in which group members engage with sovereign tribes similarly to NGOs or community groups (c.f., Smith 1996). When such assumptions of equivalency occur, collaborative institutions overlook the self-governance authority of tribal nations that maintain longstanding, reciprocal relationships with the places that they come from (von der Porten and de Loë 2013, McGregor 2014, Simpson 2014, Diver et al. 2019a).

Social networks and natural resource governance

Our study draws on social network analysis of natural resource governance, which is premised on the understanding that natural resource management relies on social relationships (Bodin et al. 2006, 2011, Bodin and Prell 2011). Considering the importance of effective institutions for managing complex social-ecological systems (Ostrom 1990), networked governance has become a powerful approach for bringing together diverse stakeholders in pursuit of shared or coordinated conservation action at multiple scales, e.g., across geographic scales, multiple jurisdictions, or different levels of government (Gupta and Pahl-Wostl 2013, Jedd and Bixler 2015, Scarlett and McKinney 2016). Recognizing that social relationships and ecological systems can both be modeled as webs of interconnections, network analysis has gained traction as a tool for analyzing complex social-ecological dynamics (Bodin and Crona 2009, Bodin et al. 2017). This includes using social network analysis to reveal power asymmetries in natural resource management negotiations, as well as highlighting how position within the network can empower particular actors to control resources, information flows, and the dissemination of new ideas (Crona and Bodin 2010). Bodin et al. (2014, 2017) further emphasized the importance of social connectivity for fostering successful collaboration, noting that denser networks with more connections work to intensify communication channels and build mutual agreement over natural resource management strategies and decisions.

Network analysis can be used to evaluate resource dilemmas at different levels, e.g., whole network (web of interconnected actors), dyadic (relationship between two actors), and individual nodal levels (individual actors who interact through ties in a network; see Table 1). At the whole network level, network structure plays a key role in determining information flows between individual actors or nodes as well as policy coordination among actors (Lubell et al. 2014). Strategic positioning of nodes can be represented by network centrality measures used to generate different kinds of “importance scores” for actors within a network. For example, “betweenness” relates to brokerage ability in which an actor functions as a key “go between” for different communities in a network. An additional measure is “degree centrality,” which relates to the number of connections an actor holds and is sometimes used as an indicator of “popularity” (Scott 2001, Borgatti et al. 2018). High centrality is also linked to social or political attributes, such as social capital and influence.

As demonstrated by Chaffin et al. 2016a, network scholars may analyze a particular governance process to detect nodes or actors who are information brokers in a governance network. When network actors engage with the same organizations multiple times in multiple contexts, this can dismantle barriers to communication and information sharing and drive system change (Ernstson 2011). In this way, "institutional SNA [social-network analysis] can provide benchmarks for tracing the continued evolution of governance networks of SESs [social-ecological systems] in transition” (Chaffin et al. 2016a:120).

Table 1. Glossary of selected network terms. Adapted from Borgatti et al. (2018).

Network	Webs of interconnected entities or actors
Nodes/Entities/Actors	A node can be an individual, an organization, a household, or a location, among other things. These are the entities or actors who interact through ties in a network.
Links/Ties/Edges	The connections between entities in a network. A link or tie might indicate that the two nodes talked on the phone, shared vehicles with one another, attended the same event, or were patron and client. Some ties can be weighted, for example, when there are multiple connections or links between actors. This is useful where you want to not only understand if a relationship exists, but also the relative strength of the relationship or ties.
Dyad/Dyadic	A pair of actors or nodes and the link between them.
Degree	Number of ties attached to a node, that connects it to other nodes. Used as a measure of node centrality/importance in a network. Degree is sometimes thought of as a measure of "popularity."
Betweenness	How often a node falls on the shortest path between any two other nodes in the network. Used as a measure of node centrality/importance in a network. Betweenness is sometimes thought of as a measure of "brokerage."
Strength	The sum of weighted links connected to a given node. Used as a measure of node centrality/importance in a network. Note: this usage is specific to nodes and distinct from "strength of ties" or the number of interactions or weighted links between two actors or entities.

Network structure can also influence a group of stakeholders' abilities to successfully organize through collective action. Bodin et al. (2017) described the challenge of collaboration as the goal of achieving collective action, despite divergent interests. Different network structures, whether densely connected, or more modular with looser connections among subgroups, can influence collective action outcomes. With tighter connections, greater communication and reduced transaction costs for information sharing among network members is assumed to follow. At the same time, maintaining a high number of contacts is not always feasible for all actors in large networks. Thus, maximizing strategic links can be key. Network researchers also consider the level of heterogeneity of actors and cross-scale links across geographic scales or different levels of government as an indicator of problem-solving potential for complex issues (Bodin et al. 2017). Heterogeneous connections can also resist a common tendency toward homophily, in which social actors are more likely to connect with those who are most similar to themselves (McPherson et al. 2001, Prell 2012).

Similarly, social networks research has identified power asymmetries and top-down command and control as factors that limit the transformational potential of a governance system (Crona and Bodin 2010, Westley et al. 2013). When examining power dynamics, natural resource governance scholars are also concerned with the level of legitimacy, or stakeholder acceptance, of emergent networks in terms of "fairness, correctness, or rightfulness of power relations" (Sandström et al. 2014:61). For example, using networks for stakeholder analysis can determine groups that are left out of a decision-making process (Prell et al. 2009). These elements of social networks analysis relate directly to our study, considering whether and how water governance systems can better include Indigenous peoples in decision making.

Current research gap: Indigenous water quality governance and social networks

Filling a research gap, social network studies offer a significant opportunity for understanding the potential for system transformation in contemporary water governance that is occurring, in part, through Indigenous-led movements. In an earlier social networks study, Chaffin et al. (2016) conducted an institutional analysis of Klamath water governance focusing on 2001-2010 dam removal negotiations, approximately 10-20 years prior to this study. Their approach illustrated the polycentric nature of Klamath Basin management as well as the central role of a diverse set of actors in Klamath dam removal (Chaffin et al. 2016a).

Although Chaffin et al. (2016a) acknowledged Native American tribes as one water governance actor among many in dam removal negotiations, more recent events have demonstrated the centrality of Indigenous peoples in water protection efforts. Indigenous-led protests against the Dakota Access Pipeline that continue to reverberate around the world through the anthem: *Mní wičhóni* ("Water is life") is a case in point. Although network studies to date have not sufficiently addressed the role Indigenous nations play in contemporary natural resource governance, network analysis is well positioned to explore system transformation in water governance from earlier exclusion toward a system that centers Indigenous nations.

Indigenous water governance scholarship provides important guidance for what it means to center Indigenous knowledge and self-determination within complex, adaptive water management processes. For example, these scholars broadly consider how Indigenous knowledge and water relations are built into Indigenous law and corresponding governance systems that guide water protection (Borrows 1997, McGregor 2012, 2014, Wilson 2014, Hallenbeck 2015, Whyte et al. 2016, Craft 2017, Arsenault et al. 2018, Todd 2018). Additionally, scholarship critiques the political economy of extractive water management decisions that disproportionately affect Indigenous communities, and examines Indigenous resistance movements (Whyte 2017, Behn and Bakker 2019, Curley 2019, Estes and Dhillon 2019, Neville and Coulthard 2019). Researchers further analyze collaborative water governance initiatives attempting to center Indigenous knowledge and leadership, despite uneven power dynamics (Weir 2009, Holtgren et al. 2014, Vaughan et al. 2016, Diver 2018, 2019, Vaughan 2018, Arsenault et al. 2019, Norman 2019). This body of scholarship also involves the evaluation of water governance problems on Indigenous lands by biophysical scientists, many of whom are themselves Indigenous scholars or tribal managers (Middleton et al. 2019, Bulltail and Walter 2020, Chief 2020, Conroy-Ben and Crowder 2020, Kozich et al. 2020, Martin et al. 2020; N. Bartolome et al. 2019, *unpublished manuscript*).

Indigenous water governance literature suggests that true system transformation involves significant shifts in environmental policy that centers Indigenous peoples, their knowledge systems, and self-determination. This includes making changes in research methodologies (Wilson 2008, Kovach 2009, Craft 2017, Arsenault et al. 2018, Donkersloot et al. 2020), legal frameworks (Borrows 2009, Napoleon 2013, MacGregor 2014), and research management approaches (Arsenault et al. 2019; https://sites.google.com/alaska.edu/ism/). Indigenous scholars and their allies have outlined meaningful steps toward realizing such system transformation that include:

- Removing structural barriers to increase Indigenous access to land, accommodate Indigenous governance institutions, transfer resources and authority to enable more equitable benefit sharing and self-representation, and cultivate respect for Indigenous knowledge sovereignty (Latulippe and Klenk 2020);
- Supporting holistic frameworks for including Indigenous knowledge systems and Indigenous science in decision making, including "the importance of being on the land and water," as well as frameworks for centering Indigenous sovereignty, in which Indigenous nations are understood to be making policy decisions "as an order of government" (McGregor et al. 2019:8);
- Adopting a critical coexistence approach that invites non-Indigenous peoples to learn about the cross-cultural and cross-situational divides that are inherent to environmental governance, and also attend to ongoing colonial legacies that create environmental injustices for Indigenous communities (Whyte 2013); and
- Appreciating value differences and multiple ways of knowing: for Indigenous communities, "water is understood to be a living entity with duties and obligations to ensure the well-being of life, which is in direct contrast to water as a resource/property and commodity" (McGregor et al. 2020:36).

METHODS

To explore the role Indigenous communities play in advancing system transformation for water quality governance, we examine a case study involving the Karuk Tribe in the mid-Klamath Basin (Northern California) from 2018-2019. We do this through an academic-community research collaboration. Diver and Eitzel are interdisciplinary environmental scientists and community engaged scholars, who have worked with Indigenous communities from an allied position, with Diver partnering with the Karuk Tribe since 2009. Reed is a Karuk community member and traditional dip net fisherman, who previously served as a cultural biologist for the Karuk Tribe for over 20 years. Fricke is a former tribal manager with Karuk water quality programs, who represented the tribe in watershed policy and science forums from an allied position from 2005-2021. Hazel and Brown are ecological and social anthropologists using quantitative social network analysis and ethnographic methods in their research.

We used interviews and archival data to construct a two-mode (bipartite) network representing organizations' participation in coalitions. The network structure and cross-scale linkages emerged from water quality coalitions and member organizations that the Karuk Tribe worked with during the study period, a time period characterized by relatively high levels of collaborative engagement. We define coalitions as groups that bring together multiple science and policy organizations to work on Klamath Basin water quality problems. Following network research emphasizing the strength of weak ties (Granovetter 1973), we analyzed how emerging network connections via these coalitions can reorganize collaborative governance structures. Such reorganization creates additional opportunities for information flow and relationship building across diverse groups, and across different levels of government (federal, state, tribal) as well as non-governmental entities.

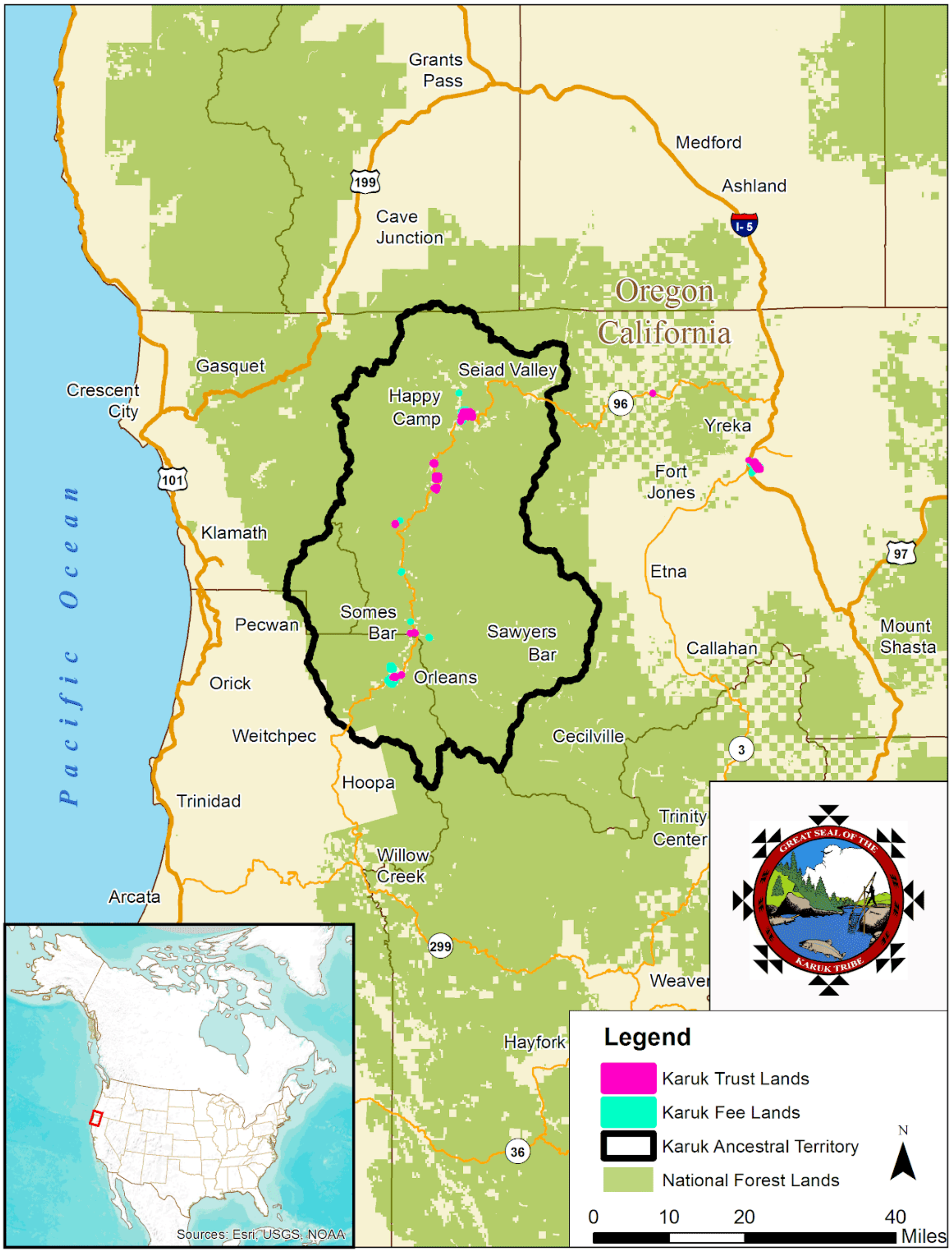
Study system: Karuk water quality governance in the mid-Klamath

This study is based on a collaboration with the Karuk Tribe, the second largest federally recognized tribe in California with 3754 members as of 2020 (Karuk Tribe 2020). Karuk ancestral territory includes the middle section of the Klamath River and covers approximately 1.48 million acres in California and Oregon (Fig. 1). Karuk people are salmon people: intimate relationships between the tribe and salmon inform Karuk culture, identity, spiritual beliefs, and tribal law. For the Karuk, the ability to fish comes with an inherent responsibility to take care of the salmon and the watersheds they come home to (Kroeber and Gifford 1949, Lake et al. 2010, Reed and Norgaard 2010, Karuk DNR 2011). Karuk caretaking practices include tribal watershed restoration initiatives and World Renewal ceremonies held by the Karuk Tribe every fall (Karuk DNR 1995).

The starting point for Karuk collaborative management initiatives is a long history of violence, dispossession, and distrust (Diver 2016, Norgaard 2019; http://karuktimeline.wordpress.com.). In contrast to other nearby tribes, the Karuk do not have a reservation (although they do have a number of trust parcels), and the U.S. federal government has designated most of Karuk territory as National Forest (Bower 1978, Salter 2000). This is because the U.S. government never ratified treaties negotiated in good faith with the Karuk people (Heizer 1972, Hurtado 1988, Johnston-Dodds 2002, Karuk DNR 2011). In California history, state sanctioned violence and racialized dispossession targeting Indigenous peoples in California was accompanied by intensive natural resource extraction (Norgaard 2014, Madley 2016, Vinyeta 2022; http://karuktimeline.wordpress.com.); a history that continues to affect the Karuk Tribe today (Bowers and Carpenter 2011, Norgaard 2014, Marks-Block et al. 2019). Because of limited tribal land ownership and other forms of dispossession, collaborative management is arguably an unavoidable component of contemporary Karuk land, water, and resource management.

For many years, the Karuk Tribe was excluded from land and water management decision making affecting Karuk ancestral territory (Norgaard 2005, 2019, Diver 2014, 2016, Vinyeta 2022). Despite ongoing barriers to entry, formal tribal participation in agency-driven management decisions started with the creation of Karuk fisheries departments in 1989. Tribal leadership has since extended into a range of natural resources protection issues, with the Karuk Tribe now participating in scientific collaborations and coalitions on water quality, forestry, fire, and other issues (Diver 2016, Norgaard and Worl 2019, Sarna-Wojcicki et al. 2019). The tribe has also played a leadership role in creating a number of new water quality coalitions, such as the Klamath Tribal Water Quality Consortium and the Klamath Basin Monitoring Program. Given increased tribal capacity and supportive policy

Fig. 1. Map of Karuk ancestral territory, including locations of trust and fee lands, by Jill Beckmann. Courtesy of the Karuk Department of Natural Resources.



changes on tribal self-determination endangered species at the state and federal level, there has been a substantial increase in tribal engagement in water governance since the late 1990s and early 2000s, as exemplified by studies of tribal impact on Klamath dam removal (Gosnell and Kelly 2010, Chaffin et al. 2016a, Gosnell et al. 2017).

From a systems perspective, a critical "release" point for Klamath water governance was the 2002 fish kill in the lower mainstem; a tragic crisis that catalyzed a shift in adaptive capacity for tribal participation Klamath water governance, as well as some level of system reorganization (Chaffin et al. 2014, Chaffin and Gunderson 2016). The fish kill crisis was triggered when upper basin irrigators protested water allocations for salmon, which led federal agencies to approve water diversions for agriculture in a drought year, despite scientific recommendations suggesting this decision would have significant negative impacts on threatened fish species (Doremus and Tarlock 2008, Reed 2014, Sarna-

Table 2. Water quality issue and numbers of coalitions involved in each.

Water-quality issue	Description	Number of coalitions†	Number of organizations‡	Network density§
Toxic algae blooms	Cyanobacteria, which proliferate in warm nutrient-rich waters held in dam reservoirs, can release a liver toxin that poses public health risks.	5	94	0.144
Dam removal	Large dams on the Klamath are associated with a range of water-quality problems and prevent fish passage to key salmon spawning habitat.	8	88	0.074
Fish disease	Fish disease outbreaks are associated with warm water temperatures, flow regimes that lead to parasite proliferations, and lack of spawning access above dam sites.	4	76	0.119
High nutrient loading	Excess nutrients coming from upstream agricultural uses and land management practices create non-point source pollution problems.	6	84	0.127
High sediment loading	Excess sediment delivery associated with slope failures and runoff from severe wildfire burn areas, unmaintained logging roads, and other road systems harms water quality.	1	18	0.007
Bacteria levels	Community water treatment systems are used to remove bacteria from drinking water, although minimal to no infrastructure is provided in rural areas.	1	14	0.004
Cannabis cultivation	State-sanctioned cannabis cultivation and illicit cultivation on federal lands is associated with pesticide and fecal coliform contamination to local waters as well as solid waste problems.	1	21	0.010

†Some coalitions are involved in more than one water-quality issue (21 distinct coalitions in total).
‡Some organizations are involved in more than one water-quality issue (210 distinct organizations in total).
§Number of links associated with that water-quality concern out of all possible links in a network with 210 nodes. For all issues taken together, network density is 0.248.

Wojcicki et al. 2019). In the fall of 2002, these diversions and resulting poor water quality conditions culminated in a fish disease outbreak, with 34,000-78,000 adult salmon and steelhead dying without spawning in the lower Klamath (Belchik et al. 2004, CDFG 2004). Occurring the day after Yurok tribal members conducted their World Renewal ceremonies, the fish kill forced federal agencies to hear tribal perspectives and engage with tribal concerns at a new level, and also sparked new tribal water quality initiatives.

The 2002 fish kill event further prompted increased tribal engagement and greater cross-scale interactions in Klamath water quality governance among multiple interest groups (Most 2006, 2007, Doremus and Tarlock 2008, Gosnell and Kelly 2010, Chaffin and Gunderson 2016). The Karuk Tribe's responses ranged from engagement in complex total maximum daily load (TMDL) planning processes to limit non-point source pollution affecting the mid-Klamath, to increased fisheries monitoring programs and habitat restoration, to advocating for dam removal within Federal Energy Regulatory Commission (FERC) dam relicensing processes. Shifts in the policy landscape, including legal and policy decisions that supported Indigenous water rights and endangered species protection, further accelerated tribal participation (Gosnell and Kelly 2010, Gosnell et al. 2017). At the same time, many tribal members report their voices were not consistently heard through dam removal and associated restoration planning processes (Norgaard 2019).

In this way, the fish kill was a key moment setting the stage for the current transitional moment. For example, the fish kill brought attention to Indigenous water protectors who continue to advocate for Klamath River restoration through direct action (Baily 2004, Greenson 2021). It also laid the groundwork for Klamath tribal leaders to create new water governance coalitions (Gosnell and Kelly 2010, Chaffin et al. 2016a, Sarna-Wojcicki et al. 2019). These coalitions play a key role in mid-Klamath collaborative water quality management today and connect Karuk tribal managers with hundreds of organizations. This sets the case context for our study, using social network analysis to evaluate structural shifts in emerging Klamath water governance networks.

Network Construction

Assessing tribal participation in water quality coalitions

Through semi-structured interviews with tribal water quality managers, we created a list of water quality issues and coalitions (groups of science and policy organizations coming together to address issues of common concern) that the Karuk Tribe engages with on water quality science and policy. Participation by Karuk tribal managers in relevant coalitions therefore defines our network boundary for Karuk water quality governance. We assessed coalition membership for the time period of January 2018 through March 2019. We view this dataset as a useful snapshot representing Karuk participation in a complex, polycentric set of water quality governance processes in the Klamath Basin.

In collaboration with tribal managers, we identified the Karuk Tribe's primary issues of concern for water quality: toxic algae blooms, dam removal, fish disease, high nutrient loading, high sediment loading, bacteria levels, and cannabis cultivation. We then worked with tribal partners to identify coalitions that were actively addressing these water quality problems, with some coalitions addressing more than one water quality issue (Table 2). This list included coalitions that the tribe worked with on water quality, even when the tribe was not a coalition member.

For each coalition, we identified member organizations, and their attributes (Table 3). Coalition membership was identified through publicly available membership lists and also through lists provided by tribal managers. For each water quality issue, we noted organizations that tribal managers identified as being a decision-

Table 3. Categories of organizations in Klamath water quality network.

Category	Description	Examples	Count
Federal	Federal-level agencies	U.S. Forest Service	13
State	State-level agencies	California EPA	22
Regional	County governments or regional irrigation districts	Humboldt County, Klamath Irrigation District	35
Municipal	City governments or municipal agencies	Orleans Community Services District	2
Tribal	Tribal governments	Karuk Tribe, Yurok Tribe	14
Consultant	Consulting companies	Riverbend Sciences	20
Environmental	Environmental non-governmental organizations	Salmon River Restoration Council	72
Industry	Industry associations or businesses	PacifiCorp, Upper Klamath Water User Association	18
University	Colleges or universities	Oregon State University	14

maker or funder. We then created a decision-making index based on the number of water quality issues that an organization was a decision maker for (ranging from zero to three) and also a funding index based on the number of water quality issues that an organization was a funder for (ranging from zero to four).

Projecting a bipartite network for water quality governance

To characterize tribal water quality coalition connections, we created a bipartite or two-mode network of coalitions and the organizations that belong to them. In this case, links represented organization membership in particular coalitions. We then projected our bipartite network to visualize organization-level connections occurring through coalitions. In other words, we removed one kind of node (coalitions), then recreated network links based on whether two organizations both appeared in the same coalition. Thus, organizations were linked through co-membership in a coalition, and sometimes in multiple coalitions. Based on the number of coalitions each organization had in common with other organizations, we created weighted links in the projected network, with link weights ranging from 1 to 12.

Network Analysis

We used social network analysis to identify whether and how tribes were participating in the collaborative water quality governance network. We were particularly interested in how tribes like the Karuk were engaging in highly technical collaborative water governance networks in relation to state and federal governments and environmental NGOs. To consider tribal engagement, we evaluated the heterogeneity of network connections, including the level of mixing across different organization types (for multiple levels of government as well as non-governmental entities). We used a walktrap community detection algorithm to analyze emergent subgroups in network structure. We also evaluated tribal access to influential actors (funders and decision makers) compared to the relatively larger number of environmental NGOs. Here, we describe the specific analyses undertaken.

Log-linear models to evaluate mixing across organization categories

To test whether organizations tended to enter coalitions with same-category organizations, i.e., whether indirect homophily drives coalition formation, we conducted a log-linear analysis of mixing among organization categories via coalition connections (using glm in R; R Core Team 2020). The presence of strong homogeneity in those categories would indicate that organizations are self-sorting into like groups (e.g., groups of environmental NGOs or federal agencies). In other words, we used log-linear analysis to evaluate how often each category of organization (e.g., environmental NGOs) was connected to all other organization categories, including its own category, via coalitions held in common. Homogeneous tie formation among like groups could support organizing within an established interest group, but it could also limit information exchange for problem solving among multiple types of organizations. A thorough description of the use and application of these methods is available in Appendix 1.

Algorithmic community detection

We used several algorithms from the igraph (Csardi and Nepusz 2006) package in R to detect communities of nodes that emerged from within the broader network. We compared results from walktrap, fastgreedy, spinglass, edge betweenness, leading eigenvalue, and Louvain algorithms. Of these, walktrap produced communities that best reflected our qualitative understanding of the system based on tribal manager interviews. We then examined the characteristics of detected communities. See Appendix 2 for additional details.

Nodal network centrality statistics

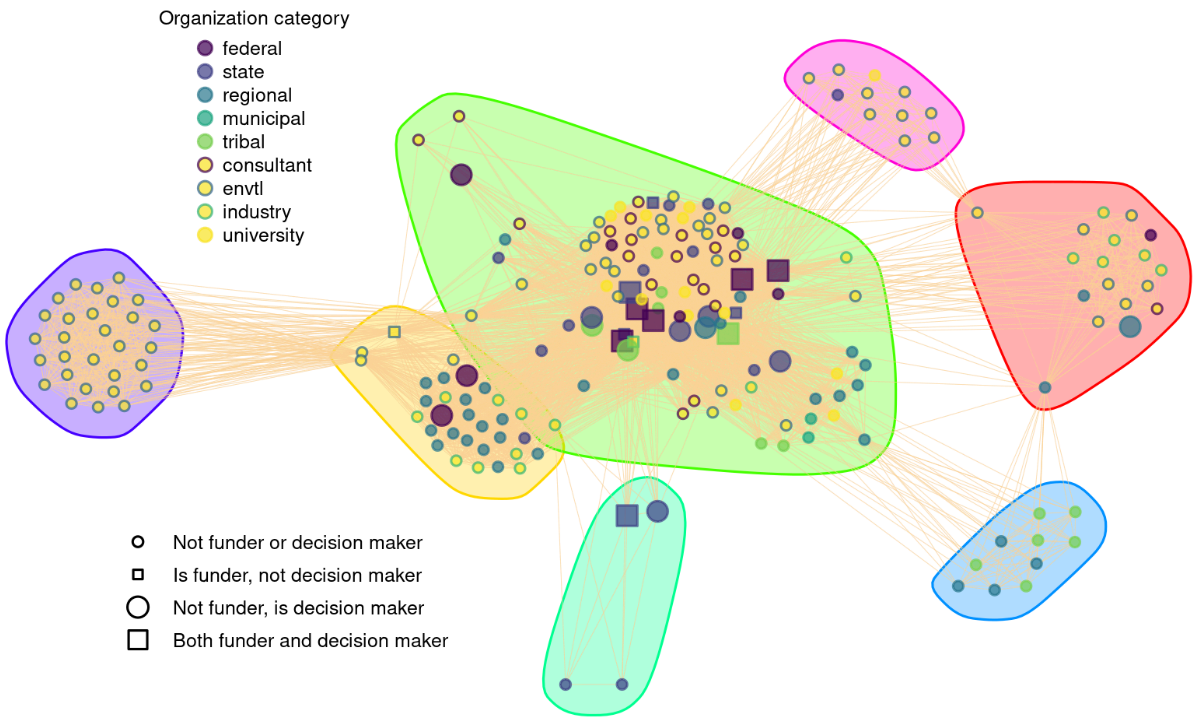
For all organizations or nodes, we used igraph to calculate degree, i.e., number of links that connect one organization to another, not using link weights; betweenness, i.e., how often an organization falls on the shortest path between any two other organizations (paths are treated as "shorter" when pairs of organizations have a higher link weight, i.e., more coalitions in common); and strength, i.e., the sum of weighted links connected to a given organization. We compared the average centrality measures for nodes in key organization categories.

Note that the Karuk Tribe centrality statistics are higher than all other nodes because they form our network boundary. Therefore, we calculate the centrality statistics of tribal organizations both with and without the Karuk Tribe's centrality statistics to evaluate the positioning of tribal nodes in the network without the outlier of the Karuk Tribe. The Karuk Tribe's links to other tribal nodes are still included in the centrality statistics of those organizations.

Multimembership models to test link strength of tribes versus other organization categories

Although we used log-linear models to check for the level of mixing across organization categories versus homogeneity in connections, we also examined the strength of dyadic relationships between organization categories and influential nodes. Specifically, we used multimembership models (Boyland

Fig. 2. Projected network of organizations through their coalition connections. Nodes are colored according to their category, are larger if they are decision makers on any water-quality issue, and are represented as a square if they are a funder on any water-quality issue. The seven communities detected by the walktrap algorithm are shown in the colored shapes surrounding the nodes. One diverse central technical working group contains the majority of the decision makers and funders, although smaller satellite groups are often more homogeneous (see Table 4). See Appendix 3 for a larger version of the figure with the nodes labeled and links colored by the number of coalition connections in common (mean 1.3, range 1-12).



et al. 2016) to test how an organization's category influenced how strong its links were to state and federal organizations, as influential entities in Klamath water quality governance. For each link in our projected network, we created a data table noting: (1) the organization category of the node on one side of the dyad, (2) whether the node on the other side was a state or federal node, and (3) the link weight (number of coalitions the two organizations had in common). We then used the MCMCglmm package (Hadfield 2010) in R to fit a multimembership model that tested how link weight (number of coalitions in common between the two nodes) varied for each node type (e.g., tribal, NGO, regional, state) when it connected to a state or federal agency. Note that federal and state agencies often connect with other federal and state agencies, so these connections are also checked. As with the centrality statistics, we conducted this analysis both with and without the Karuk Tribe as the network boundary.

RESULTS

Through our analysis, we examined the emergent structures of Klamath water quality networks and then interpreted findings in terms of ongoing system transformation centering tribes in water governance. In our interviews, Karuk tribal managers identified seven water quality issues of concern (Table 2) and 21 distinct coalitions that they engage with on water quality issues. Our bipartite network contained 231 nodes (210 organizations and 21 coalitions) and 423 links representing membership of organizations in one or more coalitions. After projecting the organizations onto each other based on coalitions held in common (Fig. 2), we had 210 nodes with 5433 links, weighted by the number of coalitions in common (ranging from 1 to 12). See Appendix 3 for full networks.

We examined data separately by water quality issue as well as in aggregated form (all water quality issues combined, i.e., all-issues network). Of the seven water quality issues, three had only one coalition each (sediment, bacteria, and cannabis) with a correspondingly smaller number of participating organizations. The other four issues had multiple coalitions with many more organizations involved (toxic algae, dam removal, nutrients, and fish disease). As expected, edge density (the proportion of links observed out of all possible links) was greater for issues bringing together more organizations, indicating a greater number of links and tighter connections among organizations. However, among the larger issue groups, dam removal was substantially less dense than for the other three issues (Table 2).

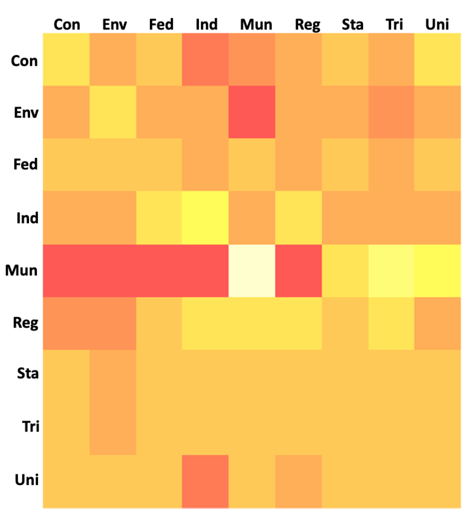
Multi-level links in a heterogeneous network

The coalitions themselves varied by diversity of organization category and size (see Appendix 4 for a list of coalitions and their composition). The projected network was similarly heterogeneous, containing a wide range of organization types (Table 2). Although environmental NGOs were the largest group, tribal governments, and all levels of U.S. government were represented in the network as well as other non-governmental entities such as universities, industry groups, and consultants.

Log-linear models show heterogeneous tendencies (mixing between organization categories) with discrete instances of self-sorting

Generally, the log-linear models revealed heterogenous tendencies in the network. Analysis of separate water quality issues confirmed the overall trend with the exception of dam removal; organizations tended to form heterogeneous associations with ties occurring across different organization categories via coalition connections. Although the all-issues network did exhibit a low level of homogeneous ties (Fig. 3), further analysis showed that this homogeneity was driven primarily by the dam removal coalitions having more homogenous membership, largely from strong ties among environmental organizations. Issue-specific analysis also showed that homogeneous ties were significantly more common than heterogeneous ties in some cases, but only for a limited set of organization categories: consultants, environmental, industry, municipal, and regional governments. Heterogeneous ties indicated that different organization types can access each other by mixing across organization categories in the emergent network. See Appendix 1 for details.

Fig. 3. Heatmap demonstrating how likely organizations of the same type or category are to connect with one another through coalition membership. Darker (red) cells indicate fewer connections than expected; lighter (white) cells indicate more. The lack of a strong light-colored diagonal shows low overall homogeneity in coalition membership and therefore higher mixing across organization categories. See Appendix 3 for issue-specific heatmaps, which all show low likelihood of same-category membership. Con=consultant; Env=environmental; Fed=federal; Ind=industry; Mun=municipal; Reg=regional; Sta=state; Tri=tribe; Uni=university.



Community detection reveals a central technical working group with issue-specific satellite groups

To further explore emergent structures in the network, we used community detection algorithms to identify new groupings of organizations. In contrast to other algorithms, walktrap identified distinct satellite communities working on specific water quality issues, rather than grouping them all together. These distinct satellite communities most closely reflected ethnographic information shared by tribal managers without overly generalizing connections across diverse interest groups, e.g., groups working on cannabis cultivation issues were not likely to be working with groups working on fire related water quality issues. See Appendix 2 for more details.

Based on the co-membership ties across 21 coalitions, walktrap found an emergent structure of 7 core and satellite subgroups with different characteristics (Table 4). The largest community contained 107 nodes or around 51% of all nodes in the network. This was identified as a central technical working group because it contained the vast majority of funders and decision makers and engaged with the highest number of water quality issues as well as with all forms of organizational types. Organizations in the central technical working group primarily involved those working on fish disease, nutrient loading, and toxic algae. In addition, most federal and state agencies participated in water quality governance through this central group.

By contrast, other detected communities were more homogenous in organization type as well as the number of issues they engaged with. These peripheral communities contained a smaller number of organizations that were typically focused on a primary water quality issue, such as wildfire-related sediment loading or cannabis cultivation. These smaller, peripheral communities represented diverse interest groups, alternately composed of upper basin irrigation districts, mainstream environmental NGOs, cannabis industry groups, community wildfire protection organizations, North Coast tribes as well as city and county governments.

Further, the full range of Klamath Basin tribes participating in the network (i.e., Karuk, Yurok, Hoopa, the Klamath Tribes, and Quartz Valley Indian Reservation) were located within the central technical working group. Additional Northern California tribes, not based on the Klamath, were positioned in more peripheral subgroups, engaging primarily through the Northcoast Resource Partnership's work on integrated regional water management. A diverse array of environmental NGOs and other non-governmental entities were distributed across all network communities.

Centrality of key node types: tribal, federal or state governments, and decision makers/funders

Building from community detection findings, we evaluated the centrality (i.e., betweenness, strength, and degree) of key node types. The Karuk Tribe, as our network boundary, had the largest betweenness, strength, and degree; therefore, we calculated average centrality statistics for tribal nodes both with and without the Karuk Tribe. We then compared the centrality statistics for tribal nodes (with the Karuk Tribe excluded) to the centrality of state and federal organizations, i.e., influential entities that have historically driven water governance processes. We further compared tribal centrality to that of environmental NGOs, as entities that can compete with tribes for influence in collaborative

Table 4. Emergent network subgroups identified with walktrap community detection algorithm. Findings indicate a central technical working group as the largest entity, as well as smaller satellite subgroups connecting around shared water quality issues.

ID	Size: N nodes (% total nodes)	Influence: N decision makers & funders	Issue diversity: N issues (mean per node)	Member diversity: N org. categories (out of 9)	Community description (for subgroups). This description interprets detected community subgroups based on ethnographic understandings of organization connections.
A	107 (50.95)	16 & 11	7 (2.80)	9	Central technical working group: nodes in this group are on average involved in the greatest number of water-quality issues and represent all 9 node categories. This is the largest, most heterogeneous community detected and represents a diverse group of organizations involved in multiple water-quality issues.
B	31 (14.76)	2 & 1	3 (1.13)	5	Irrigation focused: these nodes are all focused on irrigation issues and represent diverse governance categories.
C	29 (13.81)	0 & 0	1 (1.00)	1	Hydro focused: nodes in this group are all environmental non-governmental organizations connecting through dam removal.
D	18 (8.57)	1 & 0	3 (1.11)	5	Cannabis focused: nodes in this group are connecting through cannabis issues and represent a diversity of node categories.
E	11 (5.24)	0 & 0	1 (1.00)	3	Wildfire focused: most nodes are environmental NGOs, in which all nodes connect through wildfire issues that intersect with sediment concerns.
F	10 (4.76)	0 & 0	2 (1.20)	2	North coast focused: nodes in this community are tribal and regional groups connecting around integrated regional water management processes that include bacteria issues.
G	4 (1.90)	2 & 1	2 (1.50)	1	KRRC[†] state-focused: nodes in this community are all state government entities that connect through dam removal and fish disease issues.

[†]Klamath River Renewal Corporation.

management processes. Findings indicated that tribes, including the Karuk and other tribes, play a central role in Klamath water quality governance. These tribes were far from being relegated to “stakeholder status” in this case. This suggests an important shift from historical governance relations with state agencies excluding tribes from management toward greater tribal participation and self-determination.

Based on mean degree and strength, we found that tribes as a category were more central than environmental NGOs. Environmental NGOs exhibited higher betweenness (acting as a broker between groups) compared to the tribal category when analyzed without the Karuk Tribe (Fig. 4). This result was driven by the high betweenness of strategically positioned fisheries conservation organizations, such as California Trout or Trout Unlimited.

As expected, federal and state agencies were highly central in the network. In general, tribes as a category (with or without the Karuk Tribe) had higher average strength and comparable average degree than observed for the network as a whole (Fig. 4). Tribes based on the Klamath, with a history of engaging with Klamath River restoration, were all highly central (i.e., Karuk, Yurok, Hoopa, the Klamath Tribes, and Quartz Valley Indian Reservation). Of this group, several tribes were designated as decision makers for specific water quality issues. Additional Northern California tribes, not based on the Klamath, engaged more peripherally in the network, which is reflected in their lower centrality statistic.

We observed the highest centrality measures for organizations designated by tribal managers as decision makers and especially funders. Federal and state nodes made up 75% of all decision makers (with additional decision makers coming from tribal and regional organizations), and 77% of all funders (with additional funders including environmental NGOs, tribes, and industry). We did note that a small number of decision-making and funding entities were not centrally located in the network, i.e., having low centrality measures and being located outside the central technical working group community. See Appendix 5 for a list of organizations, their centrality measures, and decision-making/funding indices.

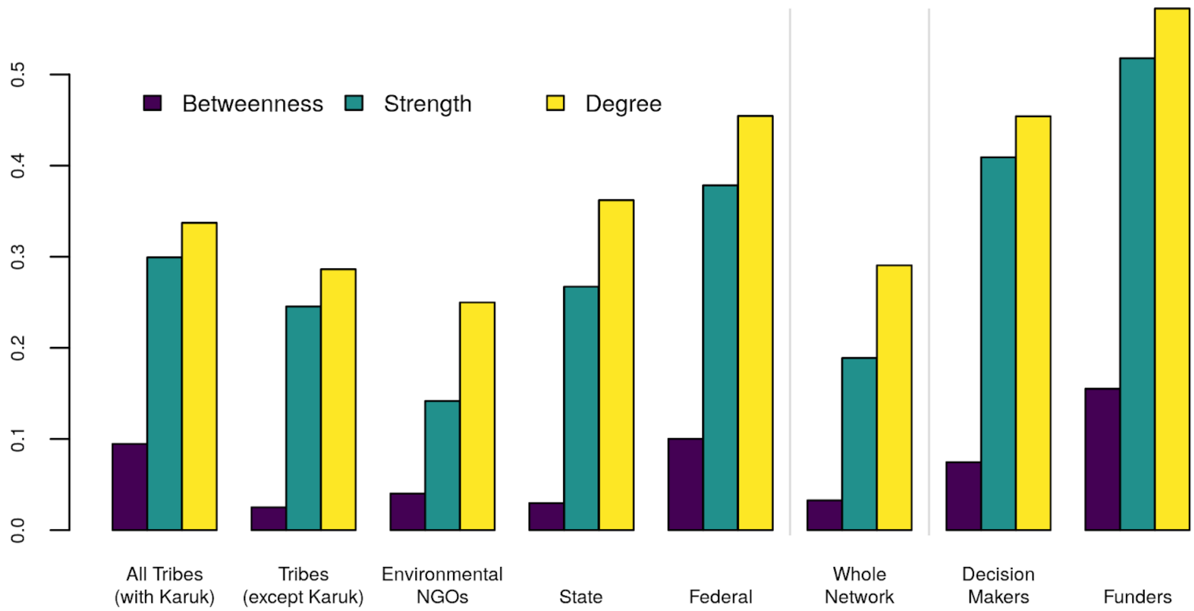
Strong tribal connections to state and federal organizations

Using the multimembership models, we found that tribal nodes had significantly stronger links (more coalitions in common) with state/federal nodes than with other types of nodes (excluding the Karuk Tribe's links). The model predicts the number of coalitions in common between tribal and state or federal nodes to be 1.63, as opposed to 1.06 between tribal and other kinds of nodes, $p < 0.001$; see Fig. 5. The only other category of organization that had a similar number of coalition connections to state/federal nodes was other federal nodes (a predicted number of coalitions of 1.64 for state/federal nodes as opposed to 1.15 for non-state/federal nodes). All other dyad pairings with different organization types connecting to state/federal organizations had significantly smaller predicted link weights, e.g., environmental NGOs had a predicted number of coalition connections to state/federal nodes of 1.06 as opposed to 1.03 for non-state/federal nodes. See Appendix 6 for the complete table of predicted effects for all categories and detailed results of the multimembership models.

DISCUSSION

Based on an exemplar case of broad tribal engagement in technical and bureaucratic collaborative water governance processes, our study explores how Indigenous communities like the Karuk Tribe are strategically placing themselves at the confluence of intersecting water governance decision-making forums, while still acknowledging tensions around meaningful tribal engagements in highly technical governance institutions. Building on Chaffin et al.'s (2016) analysis of Klamath dam

Fig. 4. Comparing mean centrality measures for key organization categories. We stratified our findings in two ways: (1) by key organizational types (tribe, state, federal, environmental NGO) and (2) by decision maker or funder status. Mean values of the whole network (all categories combined and including the Karuk Tribe) are also shown. To visualize all network centrality measures simultaneously, we rescaled the measures, i.e., by dividing a centrality measure such as betweenness, by the maximum value of betweenness for any node in the network. We then averaged rescaled centrality measures for key organization categories. See Appendix 5 for more details.



removal, we evaluated Indigenous participation in a broader set of water quality network structures. In this case, social network analysis demonstrates how tribes like the Karuk are inserting themselves in collaborative water quality governance, despite uneven distribution of resources. Given a desired trajectory of system transformation toward meaningful inclusion, we discuss the significance of increased tribal engagement in technical management structures for Klamath water governance. We also note challenges to full tribal representation in technical management processes that temper meaningful tribal engagement and self-determination.

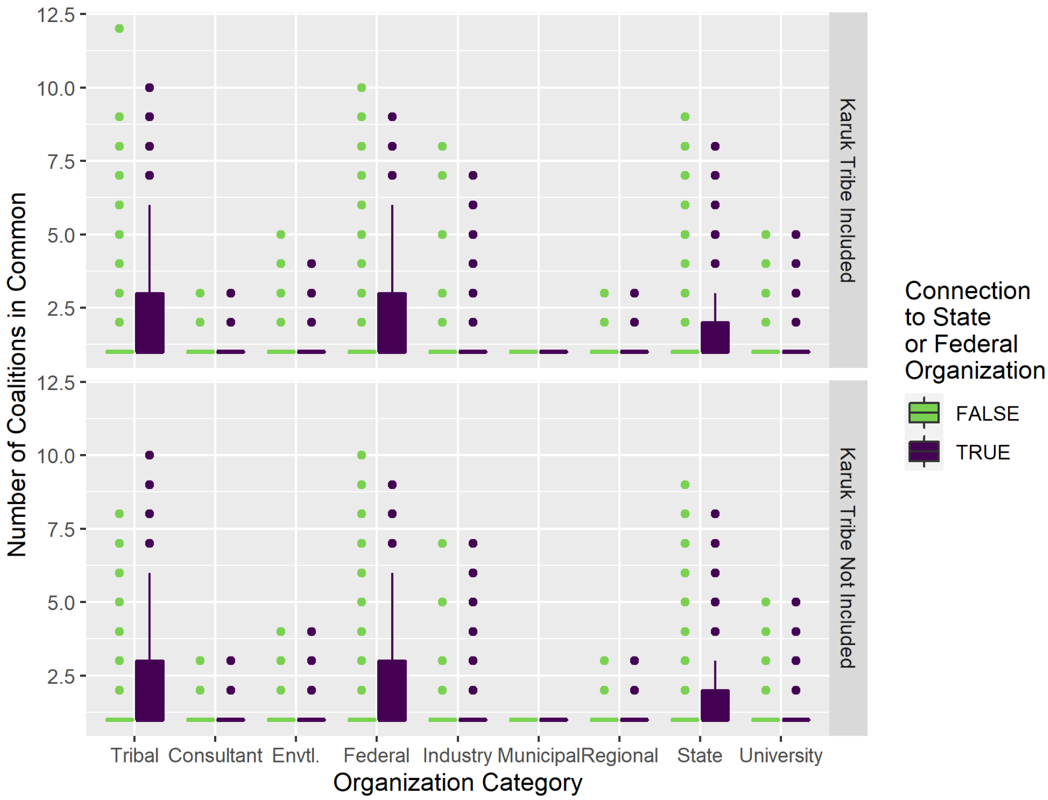
Indigenous engagement in Klamath water quality governance

Klamath water quality coalitions are characterized by a wide diversity of organizations and actors. We found that Karuk tribal managers are engaging in a wide range of intersecting water quality issues, ranging from dam removal to cannabis cultivation to toxic algae, in part, by participating in 21 distinct coalition groups. As shown in our community detection analysis, these coalitions have created new linkages between different kinds of governments, organizations, and water quality issues at multiple levels. This has resulted in a heterogeneous group with a high level of mixing across different types of organizations, particularly within the central technical working group. Community detection further demonstrated that the emergent structures in our network were not simply recapitulating existing coalitions but represent a reconfiguring of organizational connections. Reflecting differences across water quality issues, the more oppositional issue of dam removal presented a less dense and more modular network structure, when compared to other more tightly connected networks for issues that are more conducive to mutual benefits arising from collective action, such as toxic algae.

Although noting ongoing barriers to Indigenous participation, our network analysis does not suggest that tribes like the Karuk were being relegated to stakeholder status. For example, our analysis demonstrated that tribal governments, including the Karuk and others, were more centrally positioned within our water quality network and more strongly connected to influential organizations than environmental NGOs. Further, the Karuk and other Klamath Basin tribes were clearly represented in the central technical working group that emerged through coalition connections. Through this central group, Klamath Basin tribes were also highly connected to state and federal agencies as key decision makers and funders.

Our findings suggest that the emergent structure of the all-issues network is supporting tribal engagement, in part through the creation of weak ties across multiple policy forums. This contributes to our understanding of how tribes are growing their adaptive management capacity in Klamath water governance through creating cross-scale links in multi-jurisdictional networks. At the same time, we acknowledge that current tribal representation does not translate to the full team of Karuk experts, technical and cultural, which would be needed to ensure equitable participation in cross-basin water management decisions, and we consider this limitation in light of system transformation goals.

Fig. 5. Boxplots showing the number of coalitions in common (link weights) between each node category and state/federal nodes. Tribal and state/federal nodes were as strongly connected to one another as federal and state/federal nodes in the network. All other categories of nodes had significantly fewer coalitions in common with state/federal nodes. These results held whether the Karuk Tribe's statistics were excluded from the analysis or not.



A trajectory toward system transformation

As Klamath water governance systems evolve and change, we view social network analysis as a promising tool for detecting and understanding trajectories of system transformation toward Indigenous-led water governance. Our work builds on criteria for the meaningful inclusion of Indigenous peoples in water governance set forth by Indigenous peoples themselves, as described in our literature review. We also build on Meadows (2008) and her analysis of the most effective ways for intervening in a system to effect change, e.g., by changing information flows, system structures, goals, and paradigms.

Following Meadows (2008), our social network analysis conveys that tribes are activating key mechanisms for system transformation in water quality governance. For example, we see that Klamath Basin tribal engagement is increasing "information flows" between tribes and a wide range of external groups. This occurs through tribes creating a number of new water quality coalitions and connecting existing water quality coalitions in new ways to potentially foster greater knowledge exchange and policy innovation. Tribal engagement is also changing "system structures" for Klamath water governance, as demonstrated by the central technical working group that emerged in our all-issues network. Further, tribes are creating "new goals" for water quality management and policy by inserting Indigenous knowledge and self-determination into collaborative management, as with establishing cultural beneficial uses for water in state policy (State Water Resources Control Board 2017, Diver et al. 2022). Finally, through building network connections, which expose a larger number of non-tribal communities to tribal perspectives, tribes increase their capacity for "shifting paradigms" for water management, which includes contributing new ways of thinking in dominant science and policy forums about human relationships with rivers. In the Klamath context, such paradigm shifts are exemplified by the recent Yurok Tribe decision to recognize the legal personhood of the Klamath River under tribal law (Smith 2019), as well as the Karuk Tribe's advocacy on eco-cultural restoration and revitalization that refuses the artificial separation between nature and culture in water resource management (Karuk Tribe DNR 2009, Weir 2009).

Restoring tribal watersheds: tensions at the confluence

Social network analysis can identify structural patterns of interaction among water governance actors that contribute to system transformation toward tribally led water governance. However, in closing, we return to the ongoing tension between tribal engagement in technical management processes and deeper needs for Indigenous self-determination, restoration, and repair that are carefully articulated in the Indigenous water governance literature. In response to the decline in water quality and salmon populations, tribes like the Karuk are increasingly entering science and policy realms to effect change. When the Karuk Tribe engages in collaborative, technical water quality coalitions, it gains access to additional information and resources for protecting the health of the salmon, the river, and the people. However, for tribes striving to restore cultural keystone species like salmon in the Klamath (Garibaldi and Turner 2004), participating in polycentric, collaborative water governance is not really a choice, but is rather a necessity, because of the basin-wide nature of water quality problems and colonial legacies of land dispossession.

For the Karuk, the most important confluence on the Klamath is its junction point with the Salmon River at Katimiîn. This is the location in which, each year, the final series of ceremonies occurs at the close of *Pikyávish*. *Pikyávish* is often referred to as "World Renewal Ceremonies" and the word *pikyávish* translates literally as "to fix it." These ceremonies are performed to keep the earth in balance and pray for all living things. For Karuk people, this place is the center of the universe and a spiritual balance point for all of existence. It is also the only dip-net fishing site currently available to Karuk subsistence fishers. This illustrates the place-based nature of Karuk knowledge systems that are rooted in ceremonies and subsistence practices coming together at particular locations along the river.

We use the metaphor of confluence, a physical junction point of two rivers, to envision a meeting place for multiple knowledge streams and the importance of place-based management. It arises from conversations with co-author and traditional dip-net fisherman, Ron Reed, that emphasize the importance of this confluence for himself, his family, and other Karuk people. This is consistent with research on Indigenous geographies that recognize the importance of particular places in shaping and holding Indigenous knowledge systems as living and changing entities. Re-centering collaborative water governance analysis around this particular confluence point helps to privilege Reed's experience engaging in technocratic governance, as well as Karuk worldviews rooted in particular places on the Klamath.

To envision a meeting place for knowledge streams shaping Karuk water governance, we start by recognizing the limitations of collaborative water management processes in realizing Indigenous restoration of particular place-based relationships. Although complex and multi-jurisdictional institutions are needed to understand and respond to basin-wide problems, technical meetings and negotiations have not yet achieved desired improvements to Klamath fish returns. In recent years, Karuk dip-net subsistence harvests have been minimal due to declining salmon runs. While tribal communities are waiting to see results, the time and effort required to participate in technical management processes have taken Karuk leaders away from the river, their families, and their cultural centers.

However, research emphasizes how Indigenous place-based management in the Klamath requires maintaining community connections to the river, restoring Indigenous knowledge systems, and nurturing self-governance at home, along with healthy fish populations. Given limited time and capacity, there is a strong tension between the need to participate in external technical working groups at the basin scale versus the need to participate in place-based cultural practices, ceremony, and tribal stewardship at home. For Indigenous peoples, effective salmon restoration requires both.

We began with the premise of linking knowledge systems based on a two-eyed seeing philosophy, which draws from both western science and traditional knowledge systems, yet we recognize that this is not a simple endeavor. Collaborative water governance asks tribal community members to allocate limited time and resources between very different kinds of responsibilities and mindsets. Tribal members are joining basin-wide technical working groups to improve water quality in an effort to bring back salmon, a vital part of Karuk culture and identity. However, such bureaucratic spaces typically center western scientific knowledge over Indigenous knowledge systems. In this way, technical working groups can re-inscribe the dominance of western values and ways of knowing in tribal communities, thereby leading to epistemic violence. Exacerbating this problem, time consuming technical frameworks inherent to the culture and norms of western science rather than engaging in Karuk knowledge systems and cultural practices as priorities in their own right. (See Smith et al. in press.)

With these concepts in mind, we might reconsider what a productive meeting point for collaborative governance could look like for the Karuk Tribe and talk with tribal managers about what is needed to more authentically center Indigenous communities in water governance systems. For example, what are particular interventions that might alleviate some of the tensions that arise at the confluence of knowledge systems and cultures to privilege place-based management? How can collaborative water governance efforts leverage cross-scale links to prioritize and support tribal leadership for restoring particular, culturally important places? In addition to participating in technocratic governance, what is required to enable tribal leaders to take protective actions at home, lead a traditional lifestyle (if desired), connect to culturally important places, engage tribal youth, and improve social well-being in their community?

Meaningful interventions can be guided by Indigenous water governance scholarship. In the Klamath context, such interventions include structural changes around resource distribution that enhance tribal capacity and self-determination, e.g., increased resources for tribal programs, housing, and child care, especially in rural areas. This could lead to tribes hiring more cultural practitioners and technical support, thereby preventing burn-out for overstretched tribal leaders. Additional resources for tribal youth programs could support cultural training and higher education opportunities. Another important intervention involves increasing the tribe's jurisdictional authority over cultural resources and their ancestral territory. This could enable the tribe to focus more of its energies on stewarding culturally important places like Katimiîn, as opposed to focusing tribal capacity on negotiating with state agencies over management priorities and authority.

CONCLUSION

This article leverages social network analysis to consider the collaborative turn in water governance. We ask whether and how structural changes in water quality institutions are occurring to support greater resources and jurisdictional authority for Native

American tribes like the Karuk. In the Klamath system, we find that tribes are a key part of central technical working groups on water quality, as opposed to being excluded from decision making. These changes suggest important developments on a trajectory of system transformation of historial exclusion toward Indigenous-led water governance institutions. Building on Indigenous water governance scholarship, system transformation includes working with Indigenous knowledge systems to shift paradigms in how people think about and act on their understandings of human relationships to rivers. Findings suggest the need to enable increased tribal participation in current collaborative management processes, as well as to envision beyond technical management processes toward place-based Indigenous management. As Indigenous and allied scholars have argued, system transformation toward Indigenous water governance is bold and challenging work that includes societal transformation, intergenerational healing, and reconciliation, both for the benefit of affected landscapes and for Indigenous peoples that maintain deep connections to their traditional territories and waters (McGregor 2018, Middleton-Manning et al. 2018).

Responses to this article can be read online at:
https://www.ecologyandsociety.org/issues/responses.php/12942

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Data Availability:

Because of tribal research policy requirements, the data/code that support the findings of this study are not publicly available beyond current appendices. Data requests can be made through the Karuk Tribe's research coordinator and should follow Karuk Practicing Pikyav tribal research requirements, [online]: URL https://sipnuuk.karuk.us/system/files/atoms/file/ATALM17_PracticingPikyav.pdf

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Appendix 1. Detailed log-linear results.

Log-linear models follow a Poisson distribution and are appropriate for count data that can be represented in matrix form (Morris 1991). In our case, we used the matrices to evaluate how often each category of organization (e.g., environmental NGOs) was connected to all other organization categories (including its own category) via coalition membership and coalitions held in common. Counts of self-assortment by like categories fell along the matrix diagonal, indicating cases of indirect homophily.

Because we are exploring assortment patterns in projected bipartite networks, we cannot measure direct or intentional homophily; i.e., we do not know if organizations are joining coalitions specifically to self-assort or if that is a by-product of coalition connections.

With the log-linear model, we can compare a main-effect model (Which category is most represented in coalitions?) to a uniform model (Are organizations on average more likely to be in coalitions with like-category organizations?) and to a differential model (Which categories of organizations, if any, are more likely to be tied to like-organizations through coalition connections. We fit sets of log-linear models for 1) aggregated water-quality issues and 2) each issue from Table 2 in the main text separately: we compared a log-linear model of differential mixing to main effects and uniform homophily models for the four issues with the largest coalition networks—toxic algae, dam removal, fish diseases, and water nutrients—which yielded nearly identical results to the all-issues network.

Homogeneous tie formation was significantly greater than heterogeneous tie formation for a limited set of organization categories: consultant (1.6 times more likely than if connections were distributed proportionally across organization type; i.e., no preference for any organizational category), environmental (3.7), industry (3.2), municipal (14.6), and regional governments (2.7).

For issue-specific log-linear models, we noted that like-tie formation was not a significant factor for any individual water quality issue, except dam removal. In this isolated case, homogeneity by organization category was 3.96 times more likely than expected with the null condition of “no homogeneity” (i.e. heterogeneous assortment where connections are distributed proportionally across organization type). This was primarily due to very strong homogeneous ties among environmental organizations (33.72 times more likely than expected with the null condition).

Tables A1.1 -A1.6 give the results of the different statistical models. Figures A1.1 and A1.2 show heatmaps (as in Figure 3 from the main text) for the individual water quality issues.

Table A1.1: Log-linear results for coalition-based relationships according to organization type for all[§] issues				
Parameter		Main effects only	Uniform mixing	Differential mixing
Reference category main effects		3.399***	3.320***	3.345***
Ego organization types				
	Consultant (1)	0.222***	0.184**	0.258***
	Environmental (2)	1.437***	1.288***	1.078***
	Federal (3)	0.633***	0.677***	0.770***
	Industry (4)	-0.334***	-0.316***	-0.394***
	Municipal (5)	-3.957***	-3.855***	-3.891***
	Regional (6)	0.884***	0.879***	0.833***
	State (7)	0.398***	0.344***	0.519***
	Tribe (8)	0.372***	0.424***	0.476***
	University (9)	ref	ref	ref
Alter organization types				
	Consultant (1)	0.526***	0.561***	0.585***
	Environmental (2)	1.297***	1.165***	0.949***
	Federal (3)	-0.236***	-0.264***	-0.102
	Industry (4)	0.005	0.065	0.002
	Municipal (5)	-2.127***	-2.015***	-2.047***
	Regional (6)	0.352***	0.295***	0.202***
	State (7)	0.656***	0.667***	0.755***
	Tribe (8)	-0.393***	-0.391***	-0.323***
	University (9)	ref	ref	ref
Interactions				

Uniform			**0.745 (2.1)*** **	
Differential	**Consultant**			**0.438 (1.6)*** **
	Environmental			**1.313 (3.7)*** **
	Federal			**-0.275 (0.8)**
	Industry			**1.175 (3.2)*** **
	Municipal			**2.684 (14.6)* **
	Regional			**1.005 (2.7)*** **
	State			**-0.014 (1.0)**
	Tribe			**0.217 (1.2)**
	University			**0.224 (1.3)**
G^2		**5168.93**	**5621.94**	**5823.79**
AIC		**1611.3**	**1160.3**	**974.42**
df		**64**	**63**	**55**

[§]All issues include bacteria, cannabis, dam removal, fish diseases, nutrients, sediment, and toxic algae. *p<0.05, **p<0.01, ***p<0.001; Note that main effects values (gray cells) are all significant because they function as intercepts in the log-linear models. The interaction results (white cells) indicate where mixing is evaluated as an overall trend (uniform model) or a trend specific to different organization types (differential model).

Table A1.2: Log-linear results for coalition-based relationships according to organization type for four largest[§] issues				
Parameter		**Main effects only**	**Uniform mixing**	**Differential mixing**
Reference category main effects		**3.332*****	**3.261*****	**3.283*****
Ego organization types				
	Consultant (1)	**0.354*****	**0.319*****	**0.400*****
	Environmental (2)	**1.422*****	**1.297*****	**1.071*****
	Federal (3)	**0.499*****	**0.523*****	**0.636*****
	Industry (4)	**-0.548*****	**-0.527*****	**-0.625*****
	Municipal (5)	**-3.880*****	**-3.789*****	**-3.912*****
	Regional (6)	**0.794*****	**0.782*****	**0.728*****
	State (7)	**0.527*****	**0.477*****	**0.657*****
	Tribe (8)	**0.369*****	**0.426*****	**0.492*****
	University (9)	**ref**	**Ref**	**ref**
Alter organization types				
	Consultant (1)	**0.547*****	**0.559*****	**0.589*****
	Environmental (2)	**1.232*****	**1.109*****	**0.861*****
	Federal (3)	**-0.025**	**-0.033**	**0.099**
	Industry (4)	**-0.050**	**0.012**	**-0.053**
	Municipal (5)	**-2.054*****	**-1.955*****	**-1.985*****
	Regional (6)	**0.406*****	**0.368*****	**0.274*****
	State (7)	**0.674*****	**0.671*****	**0.774*****
	Tribe (8)	**-0.612*****	**-0.610*****	**-0.498*****
	University (9)	**ref**	**Ref**	**ref**
Interactions				
Uniform			**0.688 (2.0)*****	
Differential	**Consultant**			**0.353 (1.4)*****

	Environmental			**1.342 (3.8)*** **
	Federal			**-0.329 (0.7)**
	Industry			**1.245 (3.5)*** **
	Municipal			**2.614 (13.7)***
	Regional			**0.983 (2.7)*** **
	State			**-0.109 (0.9)**
	Tribe			**0.281 (0.8)**
	University			**0.215 (1.2)**
G^2		**4603.56**	**4958.63**	**5190.21**
AIC		**1496.5**	**1143.5**	**927.89**
df		**64**	**63**	**55**

[§]Four largest issues include dam removal, fish diseases, nutrients, and toxic algae.
**p*<0.05, **p<0.01, ***p<0.001; Note that main effects values (gray cells) are all significant because they function as intercepts in the log-linear models. The interaction results (white cells) indicate where mixing is evaluated as an overall trend (uniform model) or a trend specific to different organization types (differential model).

Table A1.3: Log-linear results for coalition-based relationships for the toxic algae issue only				
Parameter		**Main effects only**	**Uniform mixing**	**Differential mixing**
Reference category main effects		2.933***	2.932***	2.917***
Ego organization types				
	Consultant (1)	0.854***	0.852***	0.862***
	Environmental (2)	1.061***	1.058***	1.064***
	Federal (3)	0.552***	0.552***	0.591***
	Industry (4)	-1.164***	-1.161***	-1.148***
	Municipal (5)	-2.889***	-2.887***	-2.943***
	Regional (6)	0.166**	0.167**	0.091
	State (7)	0.410***	0.408***	0.427***
	Tribe (8)	0.156*	0.156*	0.186**
	University (9)	ref	ref	ref
Alter organization types				
	Consultant (1)	0.802***	0.801***	0.807***
	Environmental (2)	1.021***	1.019***	1.022***
	Federal (3)	0.313***	0.312***	0.353***
	Industry (4)	-1.497***	-1.495***	-1.483***
	Municipal (5)	-1.690***	-1.687***	-1.699***
	Regional (6)	-0.183**	-0.183**	-0.289***
	State (7)	0.895***	0.895***	0.906***
	Tribe (8)	0.109	0.110	0.137*
	University (9)	ref	ref	ref
Interactions				
Uniform			**0.024 (1.02)**	
Differential	Consultant			**0.019 (1.02)**
	Environmental			**0.033 (1.03)**

	Federal			**-0.278 (0.76)**
	Industry			**-0.286 (0.75)**
	Municipal			**1.725 (5.61)**
	Regional			**0.918 (2.5)*** **
	State			**-0.03 (0.97)**
	Tribe			**-0.245 (0.78)**
	University			**-0.041 (0.95)**
G^2		**2828.78**	**2828.99**	**2853.79**
AIC		**576.12**	**577.91**	**569.1**
df		**64**	**63**	**55**

**p*<0.05, **p<0.01, ***p<0.001; Note that main effects values (gray cells) are all significant because they function as intercepts in the log-linear models. The interaction results (white cells) indicate where mixing is evaluated as an overall trend (uniform model) or a trend specific to different organization types (differential model).

Table A1.4: Log-linear results for coalition-based relationships for dam removal issue only				
Parameter		**Main effects only**	**Uniform mixing**	**Differential mixing**
Reference category main effects		2.082***	1.879***	1.971***
Ego organization types				
	Environmental (1)	1.921***	1.678***	0.906***
	Federal (2)	-0.472***	-0.409***	-0.260*
	Industry (3)	0.206*	-0.018	0.378**
	Regional (4)	1.562***	1.570***	1.682***
	State (5)	-0.144	-0.212	-0.019
	Tribe (6)	-0.188	-0.051	-0.031
	University (7)	ref	ref	ref
Alter organization types				
	Environmental (1)	1.592***	1.132***	-0.108
	Federal (2)	0.041	0.218	0.373**
	Industry (3)	0.971***	1.089***	1.289***
	Regional (4)	0.831***	0.428***	0.968***
	State (5)	0.529***	0.679***	0.825***
	Tribe (6)	-0.260*	-0.136	0.014
	University (7)	ref	ref	ref
Interactions				
Uniform			**1.377 (3.96)*** **	
Differential	Environmental			**3.518 (33.72)*** **
	Federal			**0.114 (1.12)**
	Industry			**0.170 (1.19)**
	Regional			**0.410 (1.51)** **
	State			**0.442 (1.56)**
	Tribe			**0.611 (1.84)**

	University			**-11.258 (1.29e^{-05})**
G^2		**2821.83**	**3358.95**	**3683.22**
AIC		**1156.1**	**620.93**	**308.66**
df		**36**	**35**	**29**

**p*<0.05, **p<0.01, ***p<0.001; Note that main effects values (gray cells) are all significant because they function as intercepts in the log-linear models. The interaction results (white cells) indicate where mixing is evaluated as an overall trend (uniform model) or a trend specific to different organization types (differential model).

Table A1.5: Log-linear results for coalition-based relationships for fish diseases issue only				
Parameter		Main effects only	Uniform mixing	Differential mixing
Reference category main effects		3.093***	3.094***	3.090***
Ego organization types				
	Consultant (1)	0.557***	0.559***	0.564***
	Environmental (2)	0.784***	0.787***	0.794***
	Federal (3)	0.477***	0.476***	0.485***
	Industry (4)	-1.890***	-1.891***	-1.898***
	Regional (5)	-0.883***	-0.884***	-0.871***
	State (6)	0.010	0.011	-0.004
	Tribe (7)	0.328***	0.326***	0.317***
	University (8)	ref	ref	ref
Alter organization types				
	Consultant (1)	0.889***	0.889***	0.895***
	Environmental (2)	1.183***	1.184***	1.191***
	Federal (3)	0.099	0.099	0.115
	Industry (4)	-1.499***	-1.501***	-1.504***
	Regional (5)	-0.739***	-0.741***	-0.725***
	State (6)	0.885***	0.884***	0.879***
	Tribe (7)	-0.898***	-0.898***	-0.931***
	University (8)	ref	ref	ref
Interactions				
Uniform			**-0.016 (0.98)**	
Differential	Consultant			**-0.039 (0.96)**
	Environmental			**-0.039 (0.96)**
	Federal			**-0.107 (0.90)**
	Industry			**0.311 (1.36)**

	Regional			**-0.396 (0.67)**
	State			**0.060 (1.06)**
	Tribe			**0.232 (1.26)**
	University			**0.024 (1.02)**
G^2		**2356.03**	**2356.10**	**2357.93**
AIC		**382.62**	**384.54**	**396.72**
df		**49**	**48**	**41**

**p*<0.05, **p<0.01, ***p<0.001; Note that main effects values (gray cells) are all significant because they function as intercepts in the log-linear models. The interaction results (white cells) indicate where mixing is evaluated as an overall trend (uniform model) or a trend specific to different organization types (differential model).

Table A1.6: Log-linear results for coalition-based relationships for nutrients issue only				
Parameter		**Main effects only**	**Uniform mixing**	**Differential mixing**
Reference category main effects		3.178***	3.186***	3.186***
Ego organization types				
	Consultant (1)	0.493***	0.499***	0.491***
	Environmental (2)	0.840***	0.852***	0.847***
	Federal (3)	0.317***	0.315***	0.323***
	Industry (4)	-1.345***	-1.355***	-1.363***
	Regional (5)	-1.044***	-1.050***	-1.034***
	State (6)	0.419***	0.422***	0.424***
	Tribe (7)	0.087	0.082	0.086
	University (8)	ref	ref	ref
Alter organization types				
	Consultant (1)	0.902***	0.905***	0.900***
	Environmental (2)	1.169***	1.178***	1.176***
	Federal (3)	0.254***	0.255***	0.267***
	Industry (4)	-2.519***	-2.527***	-2.555***
	Regional (5)	-0.514***	-0.522***	-0.508***
	State (6)	0.672***	0.675***	0.678***
	Tribe (7)	-0.394***	-0.396***	-0.385***
	University (8)	ref	ref	ref
Interactions				
Uniform			**-0.083 (0.92)**	
Differential	Consultant			**-0.048 (0.96)**
	Environmental			**-0.067 (0.96)**
	Federal			**-0.165 (0.90)**
	Industry			**0.732 (1.36)**

	Regional			**-0.546 (0.67)**
	State			**-0.099 (1.06)**
	Tribe			**-0.179 (1.26)**
	University			**-0.034 (1.02)**
G^2		**2214.89**	**2217.29**	**2219.00**
AIC		**382.98**	**384.58**	**394.85**
df		**49**	**48**	**41**

**p*<0.05, **p<0.01, ***p<0.001; Note that main effects values (gray cells) are all significant because they function as intercepts in the log-linear models. The interaction results (white cells) indicate where mixing is evaluated as an overall trend (uniform model) or a trend specific to different organization types (differential model).

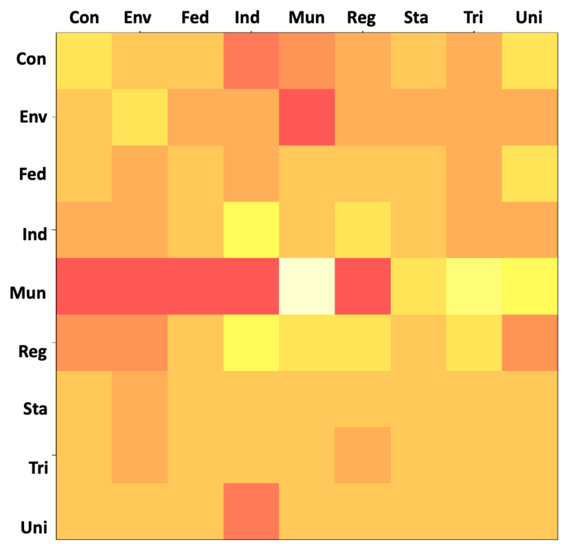

Figure A1.1: Heat map for big four issues (toxic algae, dam removal, nutrients, fish diseases). Con=consultant; Env=environmental; Fed=federal;Ind=industry; Mun=municipal; Reg=regional; Sta=state; Tri=tribe; uni=university.

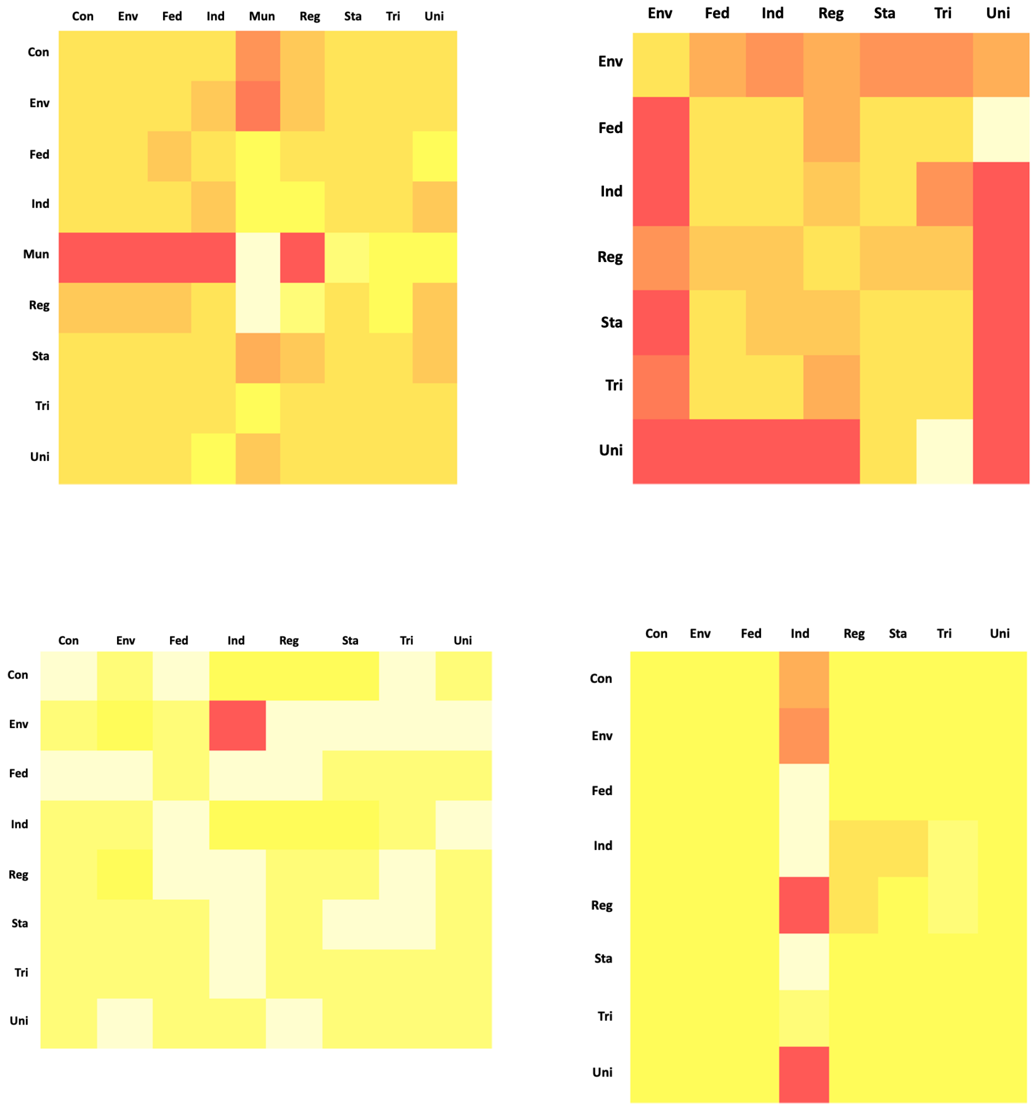

Figure A1.2: Heat maps for (clockwise from top left) toxic algae, dam removal, nutrients, fish diseases. Con=consultant; Env=environmental; Fed=federal;Ind=industry; Mun=municipal; Reg=regional; Sta=state; Tri=tribe; uni=university.

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Appendix 2. Details on community detection algorithm selection.

We tried the following community detection algorithms: walktrap, fastgreedy, spinglass, edge betweenness, Louvain, and leading eigenvalue. We confirmed that no algorithm created detected-communities that contain only the members of one coalition; the algorithms either split coalition members between detected-communities or includes members of other coalitions in addition (Tables A2.1-A2.6). We also checked how these algorithms performed on water quality issue-specific subsets of our network. For each of the issues identified in Table 2 of the main text, we created ‘subnetworks’ that included only nodes that were involved in a given issue, and then ran the community detection algorithms on these. At this smaller scale, all but walktrap and fastgreedy did create communities that were identical with original coalitions. This suggests that walktrap and fastgreedy were more effective than the others at generating emergent structure because they were not reproducing any of the original coalitions in their detected-communities (at the sub-network scale).

We also ruled out community detection algorithms that created single-organization communities. Edge Betweenness creates many communities, many of them single organizations, and may not be appropriate for a weighted network (according to warnings given by igraph). Spinglass also created single-organization communities. Of the remaining four algorithms, fast greedy, leading eigenvalue, and Louvain all created five communities, one of which grouped together three separate satellite groups but not other satellite groups (at the right, in Figures A2.1 parts C, D, and E).

Table A2.1: Coalitions split between detected-communities for walktrap algorithm.

Detected-community	**1**	**2**	**3**	**4**	**5**	**6**	**7**
CCHAB	0	0	31	0	0	0	0
CalHydroReform	0	3	1	0	0	29	0
CROPProject	18	0	3	0	0	0	0
FishDiseaseWG	0	0	9	2	0	0	0
FASTA	0	0	8	0	0	0	0
IM15	0	0	7	0	0	0	0
IMIC/IM11	0	2	16	0	0	0	0
KBMP	0	0	74	0	0	0	0
BGAlgae	0	0	38	0	0	0	0
KlamENGO	0	4	2	0	0	0	0
KFHAT	0	0	17	0	0	0	0
KlamFishReintroPlan	0	0	10	0	0	0	0
KHSA	0	31	14	0	0	0	0
IFRMP	0	1	28	0	0	0	0
KRRC	0	0	2	4	0	0	0
Consortium	0	0	5	0	0	0	0
KlamWaterUseAssn	0	13	0	0	0	0	0
NCResPartner	1	0	3	0	10	0	0
TempTMDLAdv	0	0	10	0	0	0	0
UpKlamWatAction	0	1	8	0	0	0	0
WKRP	1	0	6	0	0	0	11

Table A2.2: Coalitions split between detected-communities for spinglass algorithm (single-organization communities are highlighted)

Detected-community	1	2	3	4	5	6	7
CCHAB	0	0	30	0	0	0	1
CalHydroReform	0	4	0	0	0	29	0
CROPProject	0	0	1	20	0	0	0
FishDiseaseWG	0	0	10	0	0	0	1
FASTA	0	0	8	0	0	0	0
IM15	0	0	7	0	0	0	0
IMIC/IM11	0	6	11	1	0	0	0
KBMP	0	4	24	2	0	0	44
BGAlgae	0	1	32	2	0	0	3
KlamENGO	0	6	0	0	0	0	0
KFHAT	0	1	14	1	0	0	1
KlamFishReintroPlan	0	1	9	0	0	0	0
KHSA	0	38	7	0	0	0	0
IFRMP	0	4	19	1	0	0	5
KRRC	0	1	5	0	0	0	0
Consortium	0	0	4	0	0	0	1
KlamWaterUseAssn	0	13	0	0	0	0	0
NCResPartner	0	1	2	11	0	0	0
TempTMDLAdv	0	1	8	0	0	0	1
UpKlamWatAction	1	1	4	0	1	0	2
WKRP	0	1	2	13	0	0	2

Table A2.3: Coalitions split between detected-communities for fast greedy algorithm

Detected-community	**1**	**2**	**3**	**4**	**5**
CCHAB	31	0	0	0	0
CalHydroReform	0	0	29	0	4
CROPProject	3	0	0	18	0
FishDiseaseWG	11	0	0	0	0
FASTA	8	0	0	0	0
IM15	7	0	0	0	0
IMIC/IM11	13	0	0	0	5
KBMP	39	30	0	2	3
BGAlgae	38	0	0	0	0
KlamENGO	1	0	0	0	5
KFHAT	17	0	0	0	0
KlamFishReintroPlan	10	0	0	0	0
KHSA	10	0	0	0	35
IFRMP	27	0	0	0	2
KRRC	5	0	0	0	1
Consortium	5	0	0	0	0
KlamWaterUseAssn	0	0	0	0	13
NCResPartner	2	0	0	11	1
TempTMDLAdv	10	0	0	0	0
UpKlamWatAction	4	0	0	4	1
WKRP	5	0	0	13	0

Table A2.4: Coalitions split between detected-communities for Louvain algorithm

Detected-community	**1**	**2**	**3**	**4**	**5**
CCHAB	0	0	1	0	30
CalHydroReform	0	33	0	0	0
CROPProject	18	0	0	0	3
FishDiseaseWG	0	0	1	0	10
FASTA	0	0	0	0	8
IM15	0	0	0	0	7
IMIC/IM11	0	3	0	3	12
KBMP	0	1	41	3	29
BGAlgae	0	0	0	1	37
KlamENGO	0	4	0	2	0
KFHAT	0	0	1	1	15
KlamFishReintroPlan	0	0	0	1	9
KHSA	0	4	0	34	7
IFRMP	0	2	5	2	20
KRRC	0	0	0	1	5
Consortium	0	0	1	0	4
KlamWaterUseAssn	0	0	0	13	0
NCResPartner	11	0	0	1	2
TempTMDLAdv	0	0	1	1	8
UpKlamWatAction	0	1	2	0	6
WKRP	12	0	2	1	3

Table A2.5: Coalitions split between detected-communities for leading eigenvalue algorithm

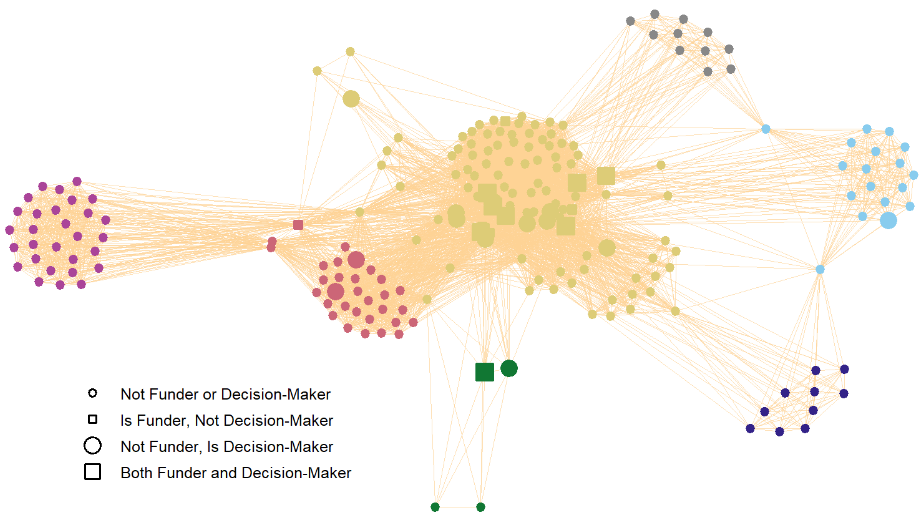
Detected-community	**1**	**2**	**3**	**4**	**5**
CCHAB	0	1	0	0	30
CalHydroReform	4	0	29	0	0
CROPProject	0	1	0	18	2
FishDiseaseWG	0	1	0	0	10
FASTA	0	0	0	0	8
IM15	0	0	0	0	7
IMIC/IM11	6	1	0	0	11
KBMP	4	46	0	0	24
BGAlgae	1	5	0	0	32
KlamENGO	6	0	0	0	0
KFHAT	1	1	0	0	15
KlamFishReintroPlan	1	0	0	0	9
KHSA	38	0	0	0	7
IFRMP	4	6	0	0	19
KRRC	3	0	0	0	3
Consortium	0	1	0	0	4
KlamWaterUseAssn	13	0	0	0	0
NCResPartner	1	0	0	11	2
TempTMDLAdv	1	1	0	0	8
UpKlamWatAction	1	4	0	0	4
WKRP	1	2	0	12	3

Table A2.6: Coalitions split between detected-communities for edge betweenness algorithm (single-organization communities are highlighted)

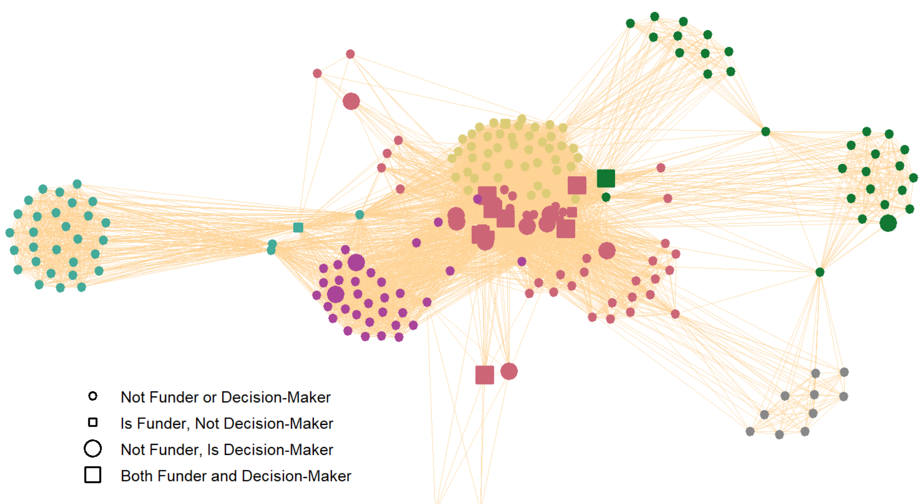
Detected-community	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
CCHAB	0	0	0	31	0	0	0	0	0	0	0	0	0	0	0
CalHydroReform	0	0	32	1	0	0	0	0	0	0	0	0	0	0	0
CROPProject	0	0	0	3	0	0	0	18	0	0	0	0	0	0	0
FishDiseaseWG	0	0	0	9	0	0	0	0	0	0	0	0	0	1	1
FASTA	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0
IM15	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0
IMIC/IM11	2	0	2	14	0	0	0	0	0	0	0	0	0	0	0
KBMP	0	0	0	74	0	0	0	0	0	0	0	0	0	0	0
BGAlgae	1	0	0	37	0	0	0	0	0	0	0	0	0	0	0
KlamENGO	1	0	3	2	0	0	0	0	0	0	0	0	0	0	0
KFHAT	0	0	0	15	0	0	0	0	0	0	1	1	0	0	0
KlamFishReintroPlan	1	0	0	9	0	0	0	0	0	0	0	0	0	0	0
KHSA	31	0	3	11	0	0	0	0	0	0	0	0	0	0	0
IFRMP	1	0	1	27	0	0	0	0	0	0	0	0	0	0	0
KRRC	1	0	0	1	0	0	1	0	0	0	0	0	1	1	1
Consortium	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0
KlamWaterUseAssn	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NCResPartner	0	0	0	3	10	0	0	1	0	0	0	0	0	0	0
TempTMDLAdv	1	0	0	8	0	0	0	0	1	0	0	0	0	0	0
UpKlamWatAction	0	1	1	6	0	0	0	0	0	1	0	0	0	0	0
WKRP	0	0	0	6	0	11	0	1	0	0	0	0	0	0	0

Figure A2.1 Projected network with nodes colored by community for the six algorithms we tested.

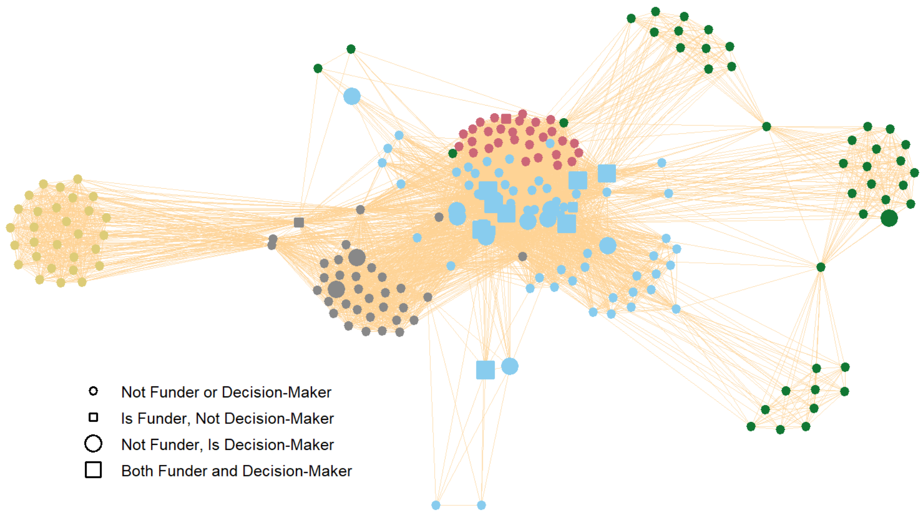
A) Walktrap



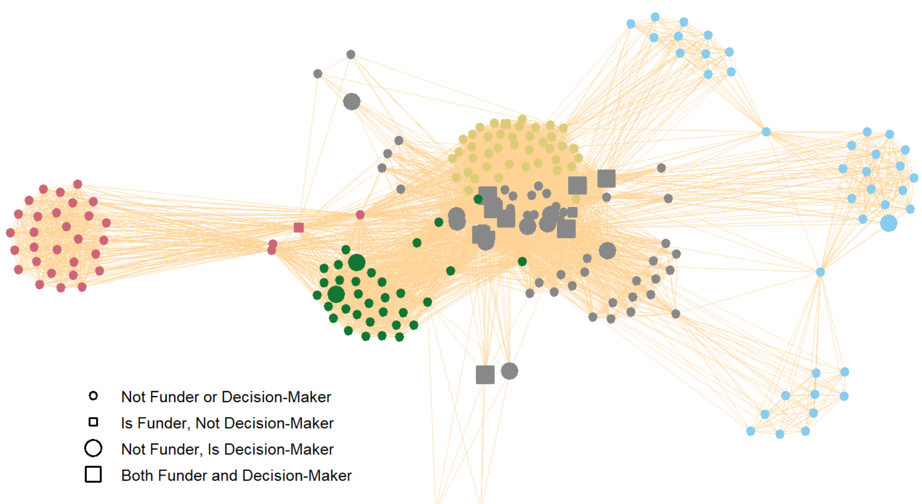
B) Spinglass (note two single-organization communities, at bottom)



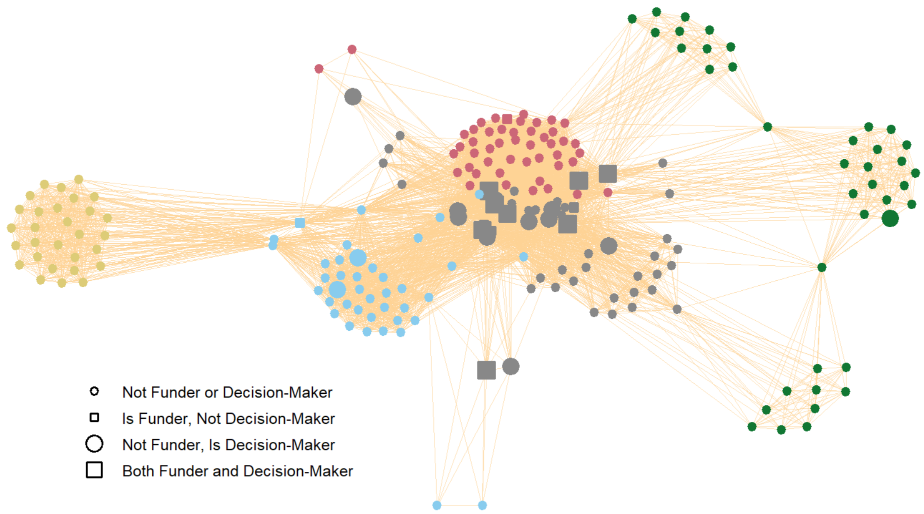
C) Fast Greedy



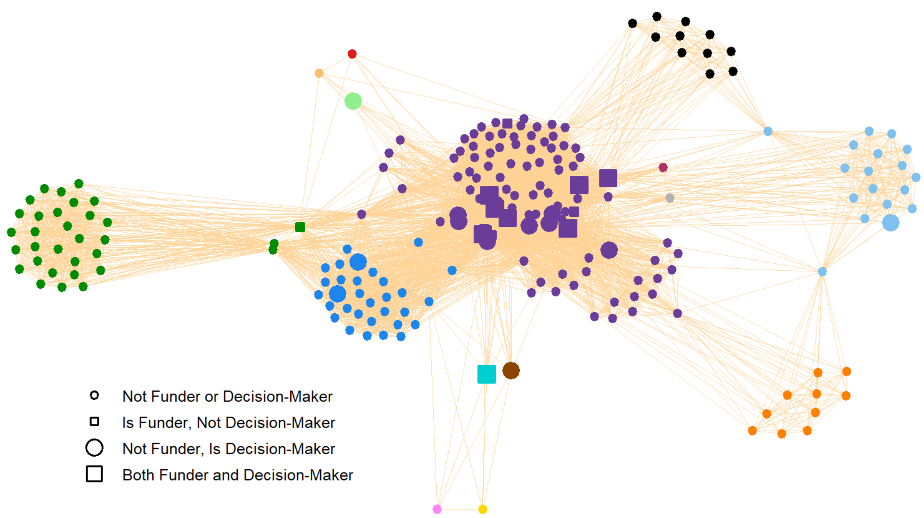
D) Louvain



E) Leading Eigenvalue



F) Edge Betweenness (note many single-organization communities)



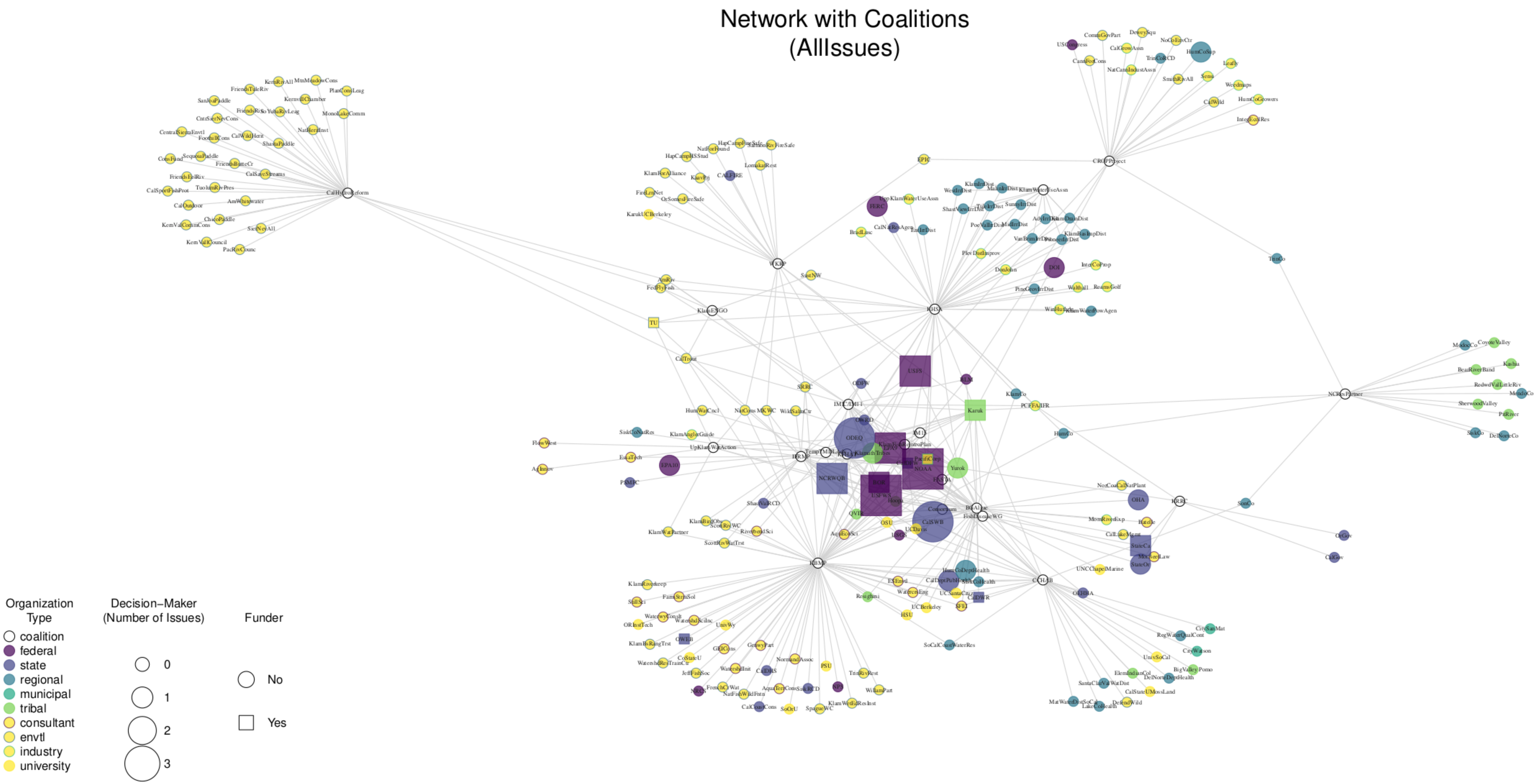
Ultimately, we chose walktrap both via triangulation with the Fruchterman-Reingold algorithm used for laying out the figures (the communities look more consistent with clusters that are visually apparent using the F-R algorithm), and also via triangulation with our system knowledge: the satellite groups that are lumped together work on very different water quality issues and are only linked by one node in common. Fast greedy, leading eigenvalue, and Louvain all grouped these satellite groups together in one large peripheral group in a way that did not make sense (nor did they lump together the other satellite communities). Walktrap, by contrast, highlighted both the central group as well as the individual satellite groups; this better echoed our understanding of how the system functions, and represents the best balance between 'lumping' and 'splitting.' As a methodological note, the walktrap algorithm detects the underlying structure of the network by identifying communities based on random walks through the network (Pons and Latapy 2005), while the Fruchterman–Reingold algorithm for laying out network diagrams relies on a mathematical analogy of the physics of the links behaving as springs, where link weights affect how strong the springs are and how many springs are shared among nodes pulls them close together (Fruchterman and Reingold 1991).

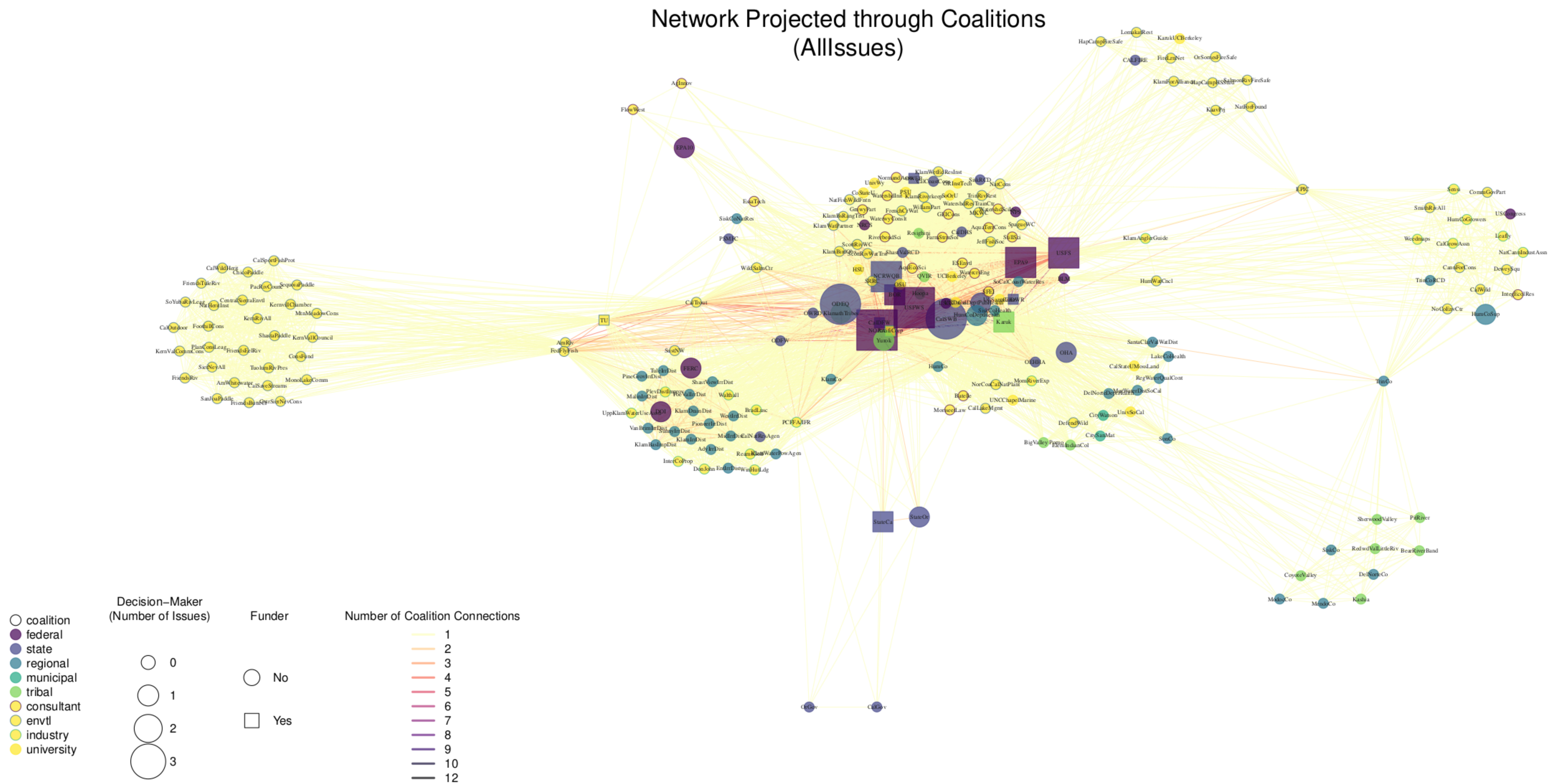
References:

Fruchterman, Thomas M. J.; Reingold, Edward M. (1991), "Graph Drawing by Force-Directed Placement", Software – Practice & Experience, Wiley, 21 (11): 1129–1164, doi:10.1002/spe.4380211102

Pons, P. and M. Latapy. 2005. Computing communities in large networks using random walks. In *International symposium on computer and information sciences*, pp. 284-293. Springer, Berlin, Heidelberg. [online] URL: arXiv:physics/0512106

Appendix 3. Larger version of network figure including labels and more detailed legends.


Network with Coalitions
(AllIssues)
Organization Type
coalition
federal
state
regional
municipal
tribal
consultant
envtl
industry
university
Decision–Maker (Number of Issues)
0
1
2
3
Funder
No
Yes


Network Projected through Coalitions
(AllIssues)
coalition
federal
state
regional
municipal
tribal
consultant
envtl
industry
university
Decision–Maker
(Number of Issues)
0
1
2
3
Funder
No
Yes
Number of Coalition Connections
1
2
3
4
5
6
7
8
9
10
12

Appendix 4. List of coalitions and the categories of their members.

Coalitions were defined as groups that bring together multiple science and policy organizations to work on Klamath Basin water quality problems. Selected coalitions were groups that the Karuk Tribe worked with on water quality during the study period (2018-2019), although the tribe was not a formal member of all the coalitions.

Table A4.1: Coalitions and the categories of their members

Coalition Name	consultant	envtl	federal	industry	municipal	regional	state	tribal	university	Total
California Cyanobacteria and Harmful Algal Bloom Network	1	1	4	1	2	9	5	4	4	31
California Hydropower Reform Coalition	0	33	0	0	0	0	0	0	0	33
Cannabis Removal on Public Lands Project	1	7	3	6	0	3	0	1	0	21
Fish Disease Working Group	0	0	3	0	0	0	2	4	2	11
Flow Account Scheduling Technical Advisory Team	0	0	3	0	0	0	0	4	1	8
KHSA Interim Measure 15 (Baseline WQ Monitoring)	0	0	2	1	0	0	2	2	0	7
KHSA Interim Measures Implementation Committee (IMIC or IM11 Workgroup)	0	3	4	2	0	0	6	3	0	18
Klamath Basin Monitoring Program	14	18	9	1	0	4	12	6	10	74
Klamath Blue-Green Algae Workgroup	6	2	7	2	0	3	8	5	5	38

Klamath Environmental NGOs	0	6	0	0	0	0	0	0	0	6
Klamath Fish Health Assessment Team	0	2	6	2	0	0	3	4	0	17
Klamath Fisheries Reintroduction Plan	0	1	2	0	0	0	2	4	1	10
Klamath Hydroelectric Settlement Agreement	0	6	3	10	0	18	5	3	0	45
Klamath Integrated Fisheries Restoration and Monitoring Plan (ESSA)	2	8	5	0	0	1	6	5	2	29
Klamath River Renewal Corporation	0	0	0	1	0	0	4	1	0	6
Klamath Tribal Water Quality Consortium	0	0	0	0	0	0	0	5	0	5
Klamath Water Users Association	0	0	0	0	0	13	0	0	0	13
North Coast Resource Partnership	0	0	0	0	0	7	0	7	0	14
Temperature TMDL Advisory Team	1	0	2	1	0	0	4	2	0	10
Upper Klamath Watershed Action Plan	2	3	1	0	0	0	2	1	0	9
Western Klamath Regional Partnership	0	13	2	0	0	0	1	1	1	18

Appendix 5. Nodal characteristics for each organization in the network.

In centrality statistics averages in figure 4 in the main text, we note that the Karuk Tribe centrality statistics are higher than all other nodes because it forms our network boundary. Therefore, we calculate the centrality statistics of tribal organizations both with and without the Karuk Tribe's centrality statistics, in order to evaluate the positioning of tribal nodes in the network without the outlier of the Karuk Tribe. Note that the Tribe's links to other tribal nodes are still included in the centrality statistics of those organizations; we just do not include the Tribe's own centrality statistics in the average.

Table A5.1 centrality statistics of each organization in the network

Name	Category	Degree	Strength	Betweenness	DM	Fund
Karuk	tribal	176	340	2582.392845	1	1
CalTrout	envtl	140	199	2273.801132	0	0
TU	envtl	96	117	1743.427409	0	1
HumCo	regional	119	130	1370.466436	0	0
USFS	federal	119	191	1004.36482	2	1
BLM	federal	104	147	988.3508052	0	0
AmRiv	envtl	78	98	750.9039564	0	0
FedFlyFish	envtl	78	98	750.9039564	0	0
SRRC	envtl	125	183	573.4926119	0	0
NatCons	envtl	88	98	528.1569617	0	0
Yurok	tribal	138	286	472.6976064	1	0
EPA9	federal	109	179	411.4525385	2	3
PacifiCorp	industry	131	232	348.6928622	0	4
NOAA	federal	136	271	306.2157799	3	2
CalDFW	state	135	263	286.0552317	0	1
USFWS	federal	110	235	269.9508504	3	3
MKWC	envtl	91	118	255.2008374	0	0
OWRD	state	107	134	243.238555	0	0
KlamCo	regional	74	81	242.7078058	0	0
KlamathTribes	tribal	124	242	222.3210873	1	0
ODEQ	state	122	222	209.7641913	3	0
SonCo	regional	42	43	209.1108841	0	0
PCFFA/IFR	industry	53	66	191.4684596	0	0
CalSWB	state	99	157	176.4881844	3	0
SoCalCoastWaterRes	regional	87	103	161.6264589	0	0

BOR	federal	96	203	158.2181716	1	1
USGS	federal	103	184	141.3230358	0	0
TrinCo	regional	32	33	126.8217783	0	0
NCRWQB	state	96	194	125.2880064	2	1
EPIC	envtl	35	37	119.131389	0	0
UCDavis	university	101	177	97.24260704	0	0
ODFW	state	67	107	96.3053685	0	0
OEHHA	state	51	67	94.03377495	0	0
SFEI	consultant	95	140	93.54045393	0	0
HumCoDeptHealth	regional	95	140	93.54045393	1	0
SiskCoHealth	regional	95	140	93.54045393	0	0
CalDWR	state	95	140	93.54045393	0	2
CalDeptPubHealth	state	95	140	93.54045393	1	0
UCSantaCruz	university	95	140	93.54045393	0	0
KlamWatPartner	envtl	76	81	89.94360485	0	0
HSU	university	75	83	83.48298514	0	0
Hoopa	tribal	92	184	65.08342599	0	0
OSU	university	90	155	64.14441338	0	0
QVIR	tribal	90	158	52.97402983	0	0
RiverbendSci	consultant	75	82	51.39335822	0	0
ShastValRCD	state	81	117	47.27204392	0	0
AquEcoSci	consultant	88	138	40.09316205	0	0
StateCa	state	13	15	34.16391677	1	1
StateOr	state	13	15	34.16391677	1	0
ESEnvtl	consultant	82	110	28.39195333	0	0
WatercrsEng	consultant	82	110	28.39195333	0	0
UCBerkeley	university	82	110	28.39195333	0	0
KlamBirdObs	envtl	79	101	26.98816483	0	0
ScottRivWatTrst	envtl	79	101	26.98816483	0	0
ScottRivWC	envtl	79	101	26.98816483	0	0
AquaTerrCons	consultant	73	73	25.61156502	0	0
FarmStrmSol	consultant	73	73	25.61156502	0	0
GEICons	consultant	73	73	25.61156502	0	0
GrnwyPart	consultant	73	73	25.61156502	0	0
NormandAssoc	consultant	73	73	25.61156502	0	0

StillSci	consultant	73	73	25.61156502	0	0
WatershdInit	consultant	73	73	25.61156502	0	0
WatershdSciInc	consultant	73	73	25.61156502	0	0
WaterwyConslt	consultant	73	73	25.61156502	0	0
FrenchCrWat	envtl	73	73	25.61156502	0	0
JeffFishSoc	envtl	73	73	25.61156502	0	0
KlamBsRangTrst	envtl	73	73	25.61156502	0	0
KlamRiverkeep	envtl	73	73	25.61156502	0	0
KlamWetEdResInst	envtl	73	73	25.61156502	0	0
NatFishWildFntn	envtl	73	73	25.61156502	0	0
SpagueWC	envtl	73	73	25.61156502	0	0
TrinRivRest	envtl	73	73	25.61156502	0	0
WatershdResTrainCtr	envtl	73	73	25.61156502	0	0
WillamPart	envtl	73	73	25.61156502	0	0
NPS	federal	73	73	25.61156502	0	0
NRCS	federal	73	73	25.61156502	0	0
OWEB	state	73	73	25.61156502	0	2
CalCoastCons	state	73	73	25.61156502	0	0
CalDHS	state	73	73	25.61156502	0	0
SiskRCD	state	73	73	25.61156502	0	0
CoStateU	university	73	73	25.61156502	0	0
ORInstTech	university	73	73	25.61156502	0	0
PSU	university	73	73	25.61156502	0	0
SoOrU	university	73	73	25.61156502	0	0
UnivWy	university	73	73	25.61156502	0	0
Batelle	consultant	37	37	18.64657816	0	0
MoriseetLaw	consultant	37	37	18.64657816	0	0
CalLakeMgmt	envtl	37	37	18.64657816	0	0
NorCoaCalNatPlant	envtl	37	37	18.64657816	0	0
MomRiverExp	industry	37	37	18.64657816	0	0
OHA	state	37	37	18.64657816	1	0
UNCChapelMarine	university	37	37	18.64657816	0	0
EssaTech	consultant	28	28	17.58284121	0	0
SiskCoNatRes	regional	28	28	17.58284121	0	0

PSMFC	state	28	28	17.58284121	0	0
Resighini	tribal	73	77	17.11844624	0	0
DOI	federal	44	44	14.92925449	1	0
FERC	federal	44	44	14.92925449	1	0
BradLusc	industry	44	44	14.92925449	0	0
DonJohn	industry	44	44	14.92925449	0	0
InterCoProp	industry	44	44	14.92925449	0	0
PlevDistImprov	industry	44	44	14.92925449	0	0
ReamsGolf	industry	44	44	14.92925449	0	0
UppKlamWaterUseAssn	industry	44	44	14.92925449	0	0
Walthall	industry	44	44	14.92925449	0	0
WinHutLdg	industry	44	44	14.92925449	0	0
EntIrrDist	regional	44	44	14.92925449	0	0
KlamWaterPowAgen	regional	44	44	14.92925449	0	0
PineGrovIrrDist	regional	44	44	14.92925449	0	0
CalNatResAgen	state	44	44	14.92925449	0	0
AdyIrrDist	regional	44	56	12.56561812	0	0
KlamBasImpDist	regional	44	56	12.56561812	0	0
KlamDrainDist	regional	44	56	12.56561812	0	0
KlamIrrDist	regional	44	56	12.56561812	0	0
MalinIrrDist	regional	44	56	12.56561812	0	0
MidIrrDist	regional	44	56	12.56561812	0	0
PioneerIrrDist	regional	44	56	12.56561812	0	0
PoeValIrrDist	regional	44	56	12.56561812	0	0
ShastViewIrrDist	regional	44	56	12.56561812	0	0
SunnyIrrDist	regional	44	56	12.56561812	0	0
TuleIrrDist	regional	44	56	12.56561812	0	0
VanBrimIrrDist	regional	44	56	12.56561812	0	0
WestIrrDist	regional	44	56	12.56561812	0	0
DefendWild	envtl	30	30	5.100627734	0	0
CitySanMat	municipal	30	30	5.100627734	0	0
CityWatson	municipal	30	30	5.100627734	0	0
DelNorteDeptHealth	regional	30	30	5.100627734	0	0
LakeCoHealth	regional	30	30	5.100627734	0	0

MatWaterDistSoCal	regional	30	30	5.100627734	0	0
RegWaterQualCont	regional	30	30	5.100627734	0	0
SantaClarValWatDist	regional	30	30	5.100627734	0	0
BigValley Pomo	tribal	30	30	5.100627734	0	0
ElemIndianCol	tribal	30	30	5.100627734	0	0
CalStateUMossLand	university	30	30	5.100627734	0	0
UnivSoCal	university	30	30	5.100627734	0	0
SustNW	envtl	44	49	4.962421707	0	0
HumWatCncl	envtl	16	16	4.824285994	0	0
KlamAnglerGuide	industry	16	16	4.824285994	0	0
WildSalmCtr	envtl	28	37	4.37642419	0	0
EPA10	federal	9	9	2.016803615	1	0
AgInnov	consultant	8	8	1.203881095	0	0
FlowWest	consultant	8	8	1.203881095	0	0
CalGov	state	5	5	0.7833333333	0	0
OrGov	state	5	5	0.7833333333	0	0
FireLrnNet	envtl	17	17	0.4973670112	0	0
HapCampFireSafe	envtl	17	17	0.4973670112	0	0
HapCampHSStud	envtl	17	17	0.4973670112	0	0
KaavPrj	envtl	17	17	0.4973670112	0	0
KlamForAlliance	envtl	17	17	0.4973670112	0	0
LomakatRest	envtl	17	17	0.4973670112	0	0
NatForFound	envtl	17	17	0.4973670112	0	0
OrSomesFireSafe	envtl	17	17	0.4973670112	0	0
SalmonRivFireSafe	envtl	17	17	0.4973670112	0	0
CALFIRE	state	17	17	0.4973670112	0	0
KarukUCBerkeley	university	17	17	0.4973670112	0	0
IntegEcolRes	consultant	20	20	0.3256509077	0	0
CalWild	envtl	20	20	0.3256509077	0	0
CannForCons	envtl	20	20	0.3256509077	0	0

CommGovPart	envtl	20	20	0.3256509077	0	0
DeweySqu	envtl	20	20	0.3256509077	0	0
NoCoEnvCtr	envtl	20	20	0.3256509077	0	0
SmithRivAll	envtl	20	20	0.3256509077	0	0
USCongress	federal	20	20	0.3256509077	0	0
CalGrowAssn	industry	20	20	0.3256509077	0	0
HumCoGrowers	industry	20	20	0.3256509077	0	0
Leafly	industry	20	20	0.3256509077	0	0
NatCannIndustAssn	industry	20	20	0.3256509077	0	0
Sensi	industry	20	20	0.3256509077	0	0
Weedmaps	industry	20	20	0.3256509077	0	0
HumCoSup	regional	20	20	0.3256509077	1	0
TrinCoRCD	regional	20	20	0.3256509077	0	0
DelNorteCo	regional	13	13	0.1746666575	0	0
MendoCo	regional	13	13	0.1746666575	0	0
ModocCo	regional	13	13	0.1746666575	0	0
SiskCo	regional	13	13	0.1746666575	0	0
BearRiverBand	tribal	13	13	0.1746666575	0	0
CoyoteValley	tribal	13	13	0.1746666575	0	0
Kashia	tribal	13	13	0.1746666575	0	0
PitRiver	tribal	13	13	0.1746666575	0	0
RedwdValLittleRiv	tribal	13	13	0.1746666575	0	0
SherwoodValley	tribal	13	13	0.1746666575	0	0
AmWhitewater	envtl	32	32	0.1007320561	0	0
CalOutdoor	envtl	32	32	0.1007320561	0	0
CalSaveStreams	envtl	32	32	0.1007320561	0	0
CalSportFishProt	envtl	32	32	0.1007320561	0	0
CalWildHerit	envtl	32	32	0.1007320561	0	0
CentralSierraEnvtl	envtl	32	32	0.1007320561	0	0
ChicoPaddle	envtl	32	32	0.1007320561	0	0
CntrSierNevCons	envtl	32	32	0.1007320561	0	0
ConsFund	envtl	32	32	0.1007320561	0	0
FoothillCons	envtl	32	32	0.1007320561	0	0
FriendsButteCr	envtl	32	32	0.1007320561	0	0
FriendsEelRiv	envtl	32	32	0.1007320561	0	0

FriendsRiv	envtl	32	32	0.1007320561	0	0
FriendsTuleRiv	envtl	32	32	0.1007320561	0	0
KernRivAll	envtl	32	32	0.1007320561	0	0
KernValCommCons	envtl	32	32	0.1007320561	0	0
KernVallCouncil	envtl	32	32	0.1007320561	0	0
KernvillChamber	envtl	32	32	0.1007320561	0	0
MonoLakeComm	envtl	32	32	0.1007320561	0	0
MtnMeadowCons	envtl	32	32	0.1007320561	0	0
NatHeritInst	envtl	32	32	0.1007320561	0	0
PacRivCounc	envtl	32	32	0.1007320561	0	0
PlanConsLeag	envtl	32	32	0.1007320561	0	0
SanJoaPaddle	envtl	32	32	0.1007320561	0	0
SequoiaPaddle	envtl	32	32	0.1007320561	0	0
ShastaPaddle	envtl	32	32	0.1007320561	0	0
SierNevAll	envtl	32	32	0.1007320561	0	0
SoYubaRivLeag	envtl	32	32	0.1007320561	0	0
TuolumRivPres	envtl	32	32	0.1007320561	0	0

Appendix 6. Details of multimembership models.

We used MCMCglmm in R to estimate the parameters of the multimembership model. This kind of model controls for structure in the network, i.e. all links to one particular node may have something in common and therefore not be independent, so for each link, we control for the identity of each of the nodes on either side of the link. In this Appendix we give the raw model output and a table of parameters interpreted on the count scale, as well as plots of the MCMC posteriors and their chains. To generate these results, we obtained 1e7 MCMC samples and then thinned them by 1e3 (the long runs were necessary due to slow mixing). See Hadfield (2010) for details on MCMCglmm's calculations of pMCMC and posterior mean calculations. These results are for a model that does not include the Karuk Tribe's links (because they are the network boundary).

Table A6.1: Parameter estimates directly from R output; Tribal is the reference level (Intercept), SF is whether the other node is a state or federal organization, and ":" indicates an interaction.

	post.mean	l-95% CI	u-95% CI	eff.samp	pMCMC
(Intercept)	0.0594	-0.02874	0.1564	145.49	0.2
SFTRUE	0.42872	0.30747	0.54846	126.15	<0.001 ***
Catconsultant	-0.07119	-0.17169	0.01966	104.17	0.116
Catenvtl	-0.03315	-0.11776	0.05765	52.56	0.438
Catfederal	0.07871	-0.02882	0.19045	75.82	0.182
Catindustry	-0.04429	-0.16227	0.07224	44.8	0.442
Catmunicipal	-0.04317	-0.38115	0.39989	36.83	0.726
Catregional	0.03201	-0.05172	0.13692	67.04	0.464
Catstate	0.03899	-0.05684	0.12837	93.97	0.418
Catuniversity	-0.02097	-0.14326	0.10266	58.81	0.692
SFTRUE:Catconsultant	-0.37393	-0.55209	-0.23464	107.1	<0.001 ***
SFTRUE:Catenvtl	-0.39933	-0.53479	-0.25798	70.29	<0.001 ***
SFTRUE:Catfederal	-0.07286	-0.26142	0.11328	47.91	0.376
SFTRUE:Catindustry	-0.27044	-0.46902	-0.08634	76.98	0.022 *

SFTRUE:Catmunicipal	-0.74422	-1.409	-0.24612	51.12	<0.001 ***
SFTRUE:Catregional	-0.53469	-0.69302	-0.38581	98.63	<0.001 ***
SFTRUE:Catstate	-0.18369	-0.32316	-0.04816	84.73	0.022 *
SFTRUE:Catuniversity	-0.34645	-0.51627	-0.20821	80.56	<0.001 ***

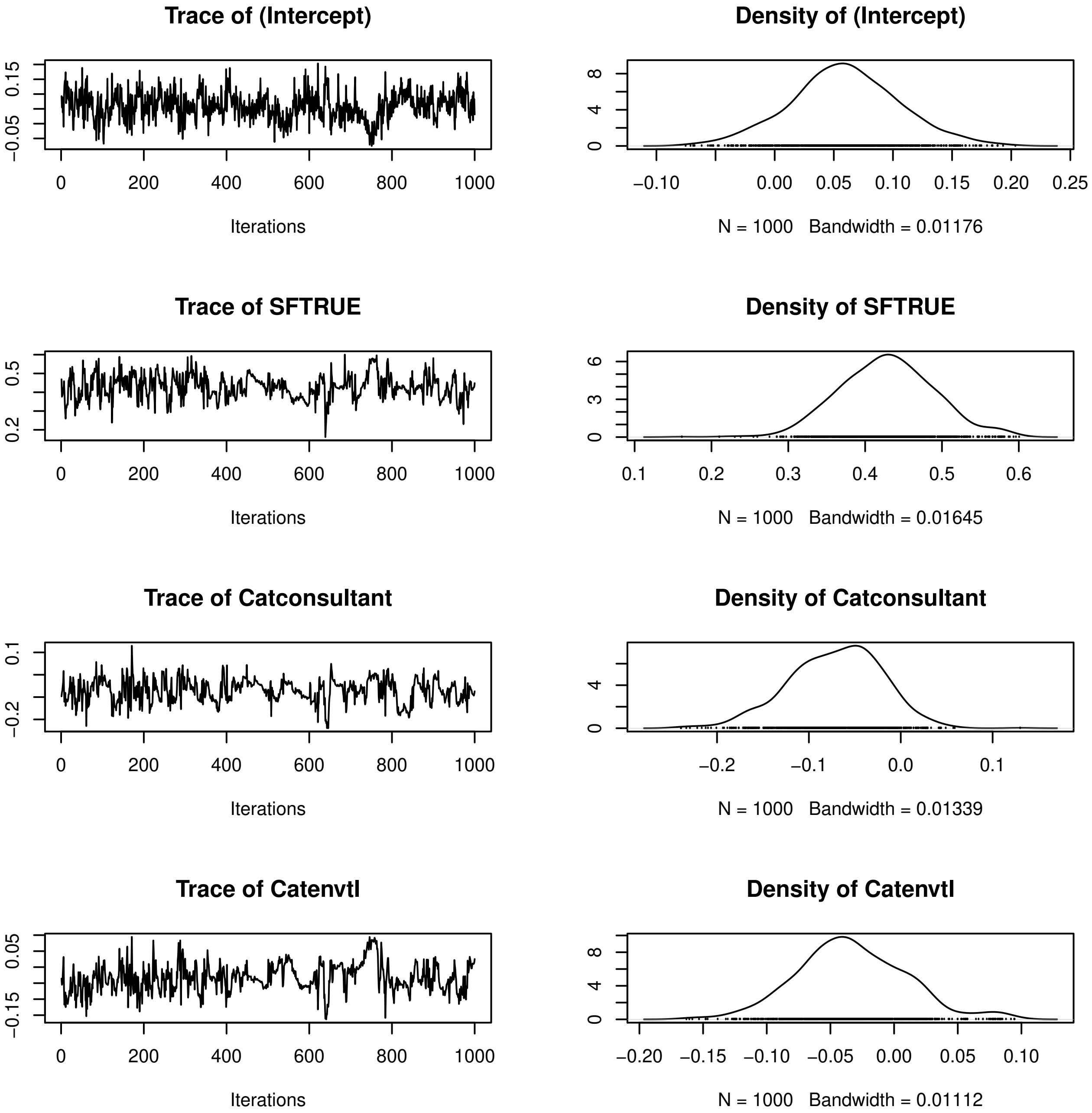
Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

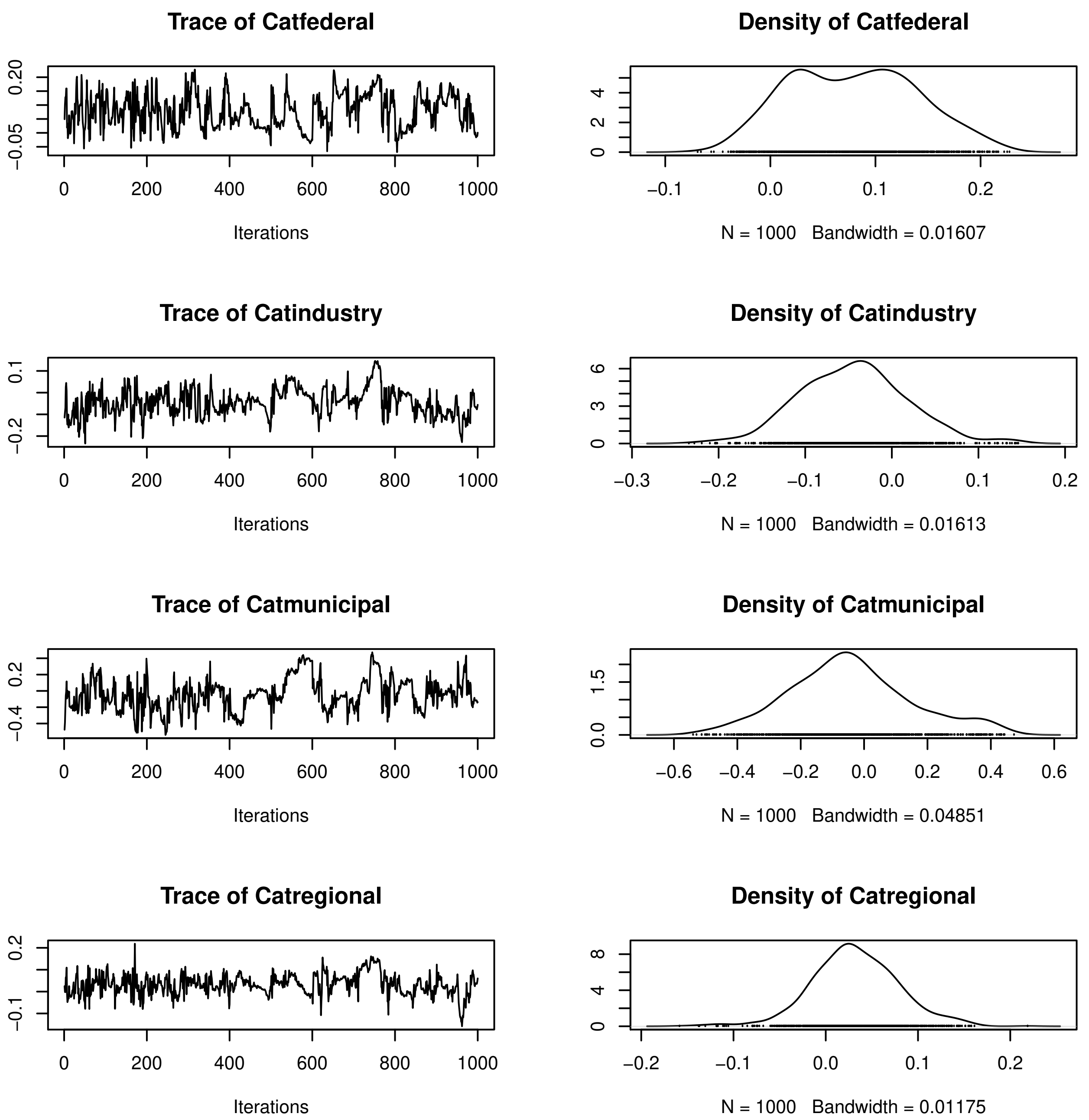
Table A6.2: Parameter estimates transformed to the count scale:

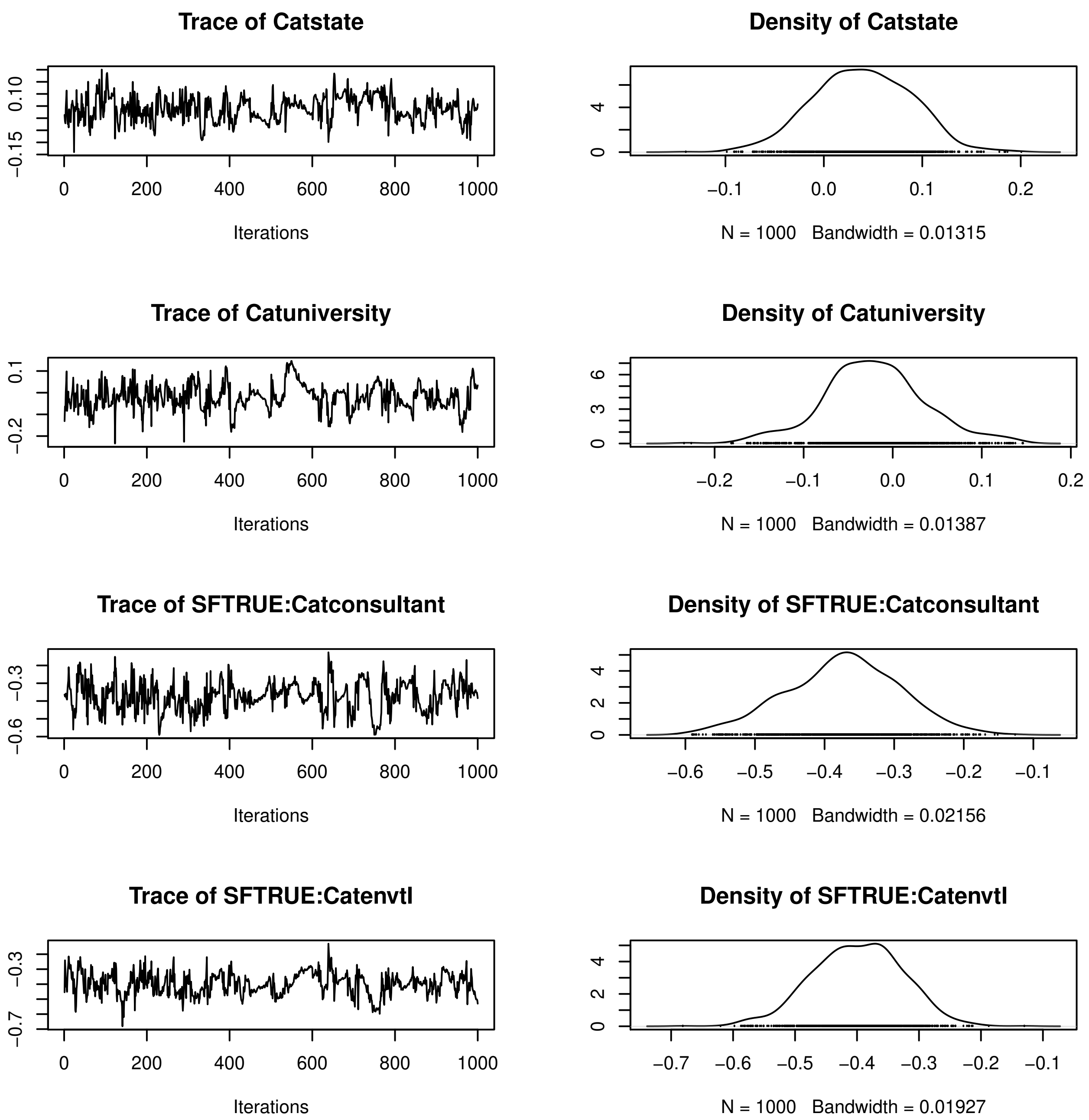
Category	Connection to non-State/Fed	Connection to State/Fed
Tribal	1.06	1.63
Federal	1.15	1.64
State	1.1	1.41
Environmental NGO	1.03	1.06
Industry	1.02	1.19
Regional	1.1	0.99
University	1.04	1.13
Municipal	1.02	0.74
Consultant	0.99	1.04

Jarrod D Hadfield. Mcmc methods for multi-response generalized linear mixed models: The MCMCglmm R package. Journal of Statistical Software, 33(2):1–22, 2010.

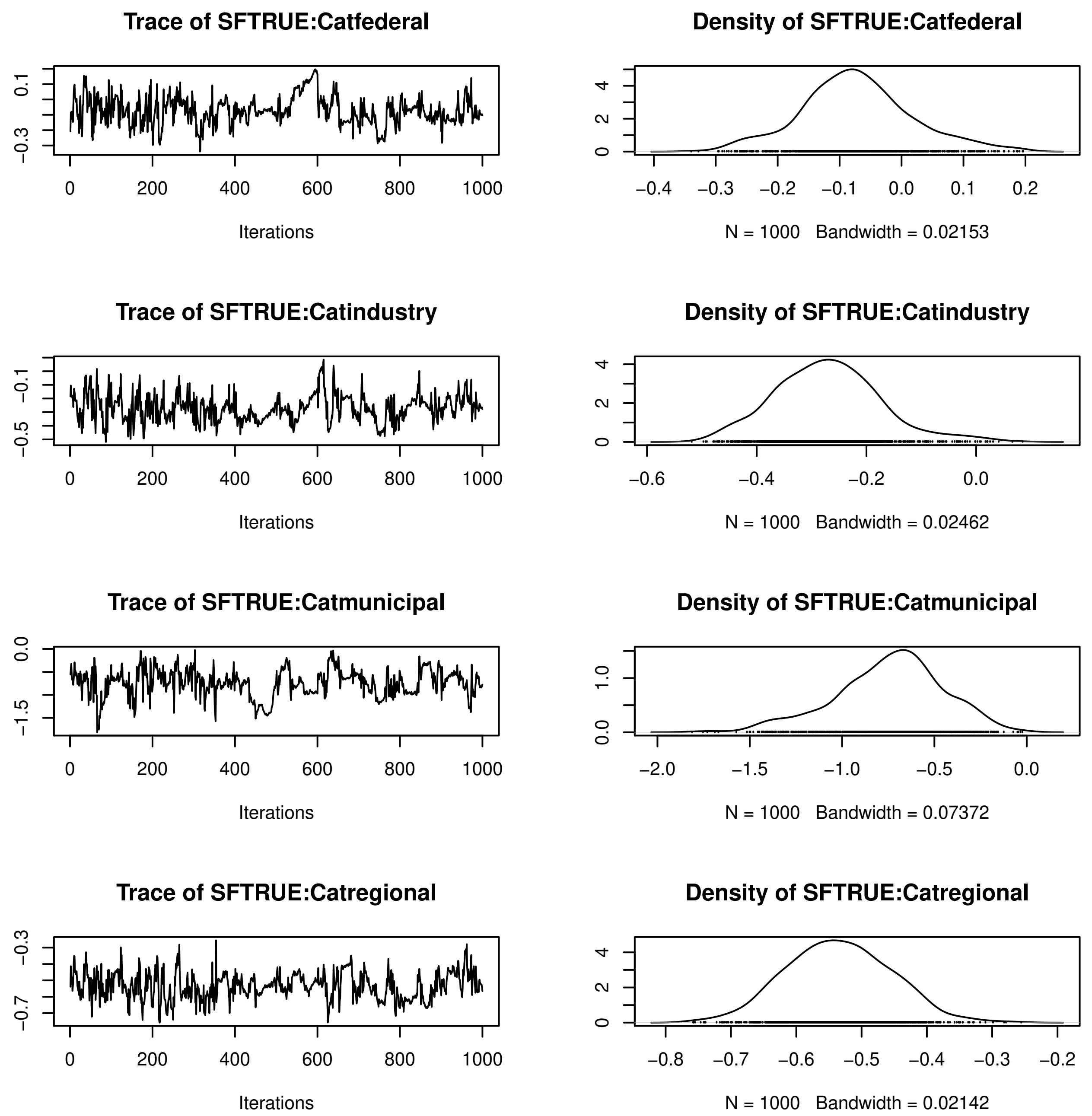
The figures below are the traces and posteriors for all parameters in the model.

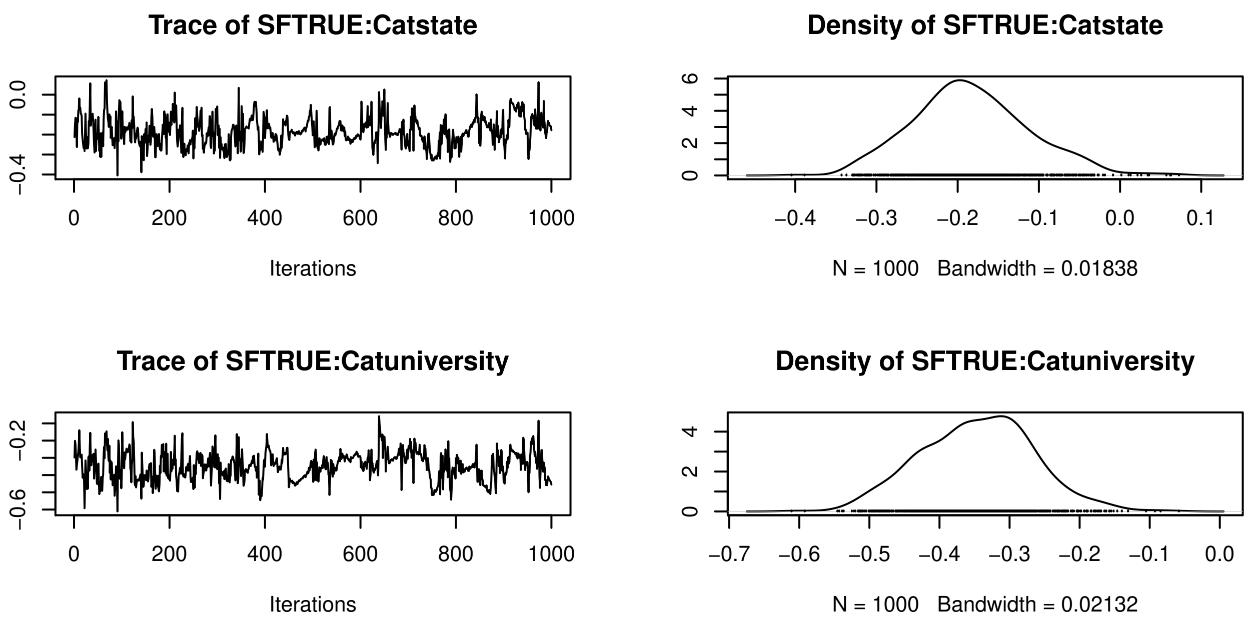

Trace of (Intercept)
Iterations
Density of (Intercept)
N = 1000 Bandwidth = 0.01176
Trace of SFTRUE
Iterations
Density of SFTRUE
N = 1000 Bandwidth = 0.01645
Trace of Catconsultant
Iterations
Density of Catconsultant
N = 1000 Bandwidth = 0.01339
Trace of Catenvtl
Iterations
Density of Catenvtl
N = 1000 Bandwidth = 0.01112

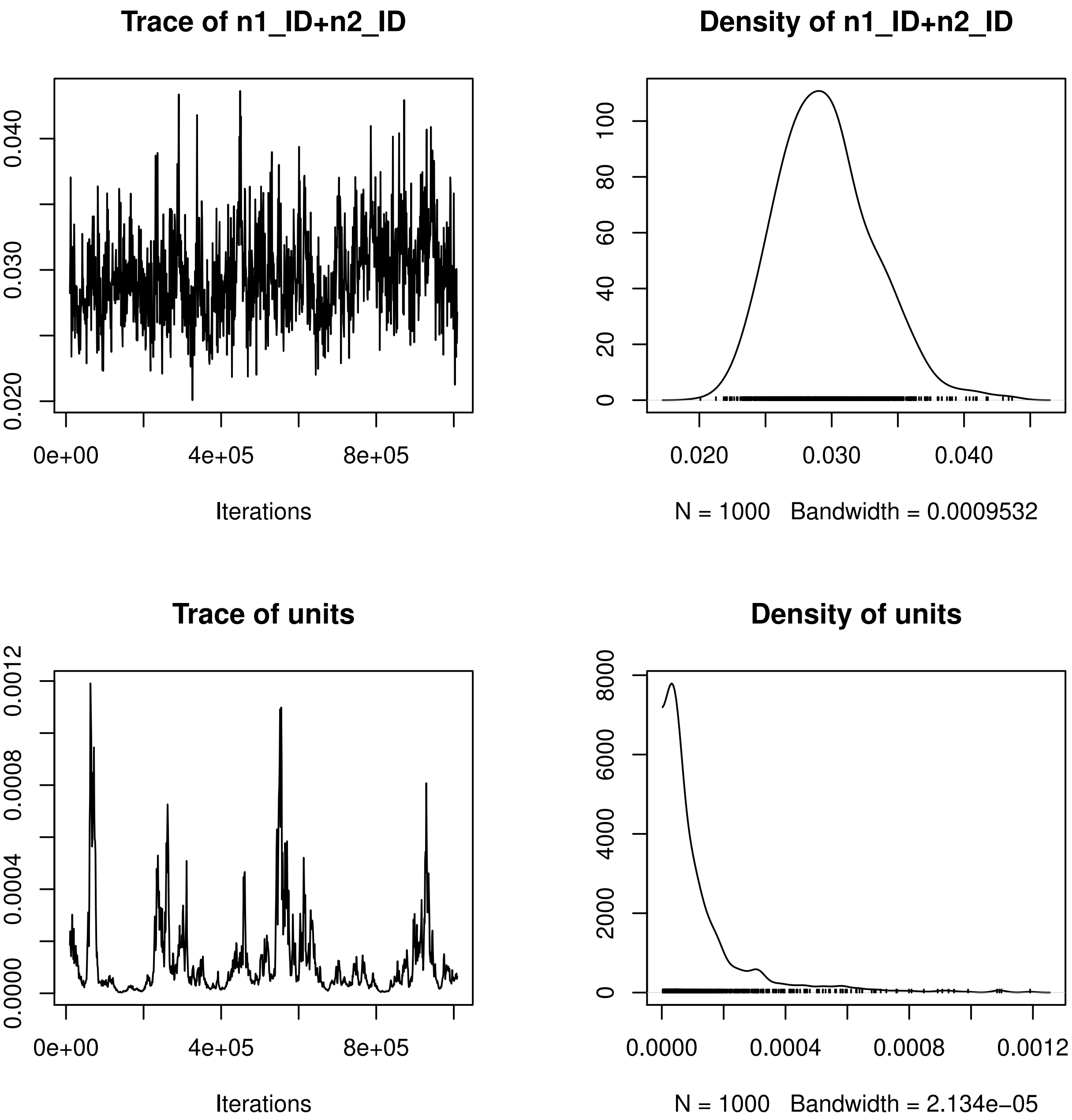

Trace of Catfederal
Iterations
Density of Catfederal
N = 1000 Bandwidth = 0.01607
Trace of Catindustry
Iterations
Density of Catindustry
N = 1000 Bandwidth = 0.01613
Trace of Catmunicipal
Iterations
Density of Catmunicipal
N = 1000 Bandwidth = 0.04851
Trace of Catregional
Iterations
Density of Catregional
N = 1000 Bandwidth = 0.01175



Trace of Catstate
−0.15
0.10
0
200
400
600
800
1000
Iterations
Density of Catstate
0
4
−0.1
0.0
0.1
0.2
N = 1000   Bandwidth = 0.01315
Trace of Catuniversity
−0.2
0.1
0
200
400
600
800
1000
Iterations
Density of Catuniversity
0
3
6
−0.2
−0.1
0.0
0.1
0.2
N = 1000   Bandwidth = 0.01387
Trace of SFTRUE:Catconsultant
−0.6
−0.3
0
200
400
600
800
1000
Iterations
Density of SFTRUE:Catconsultant
0
2
4
−0.6
−0.5
−0.4
−0.3
−0.2
−0.1
N = 1000   Bandwidth = 0.02156
Trace of SFTRUE:Catenvtl
−0.7
−0.3
0
200
400
600
800
1000
Iterations
Density of SFTRUE:Catenvtl
0
2
4
−0.7
−0.6
−0.5
−0.4
−0.3
−0.2
−0.1
N = 1000   Bandwidth = 0.01927


Trace of SFTRUE:Catfederal
Iterations
Density of SFTRUE:Catfederal
N = 1000 Bandwidth = 0.02153
Trace of SFTRUE:Catindustry
Iterations
Density of SFTRUE:Catindustry
N = 1000 Bandwidth = 0.02462
Trace of SFTRUE:Catmunicipal
Iterations
Density of SFTRUE:Catmunicipal
N = 1000 Bandwidth = 0.07372
Trace of SFTRUE:Catregional
Iterations
Density of SFTRUE:Catregional
N = 1000 Bandwidth = 0.02142


Trace of SFTRUE:Catstate
0.0
−0.4
0
200
400
600
800
1000
Iterations
Density of SFTRUE:Catstate
0
2
4
6
−0.4
−0.3
−0.2
−0.1
0.0
0.1
N = 1000 Bandwidth = 0.01838
Trace of SFTRUE:Catuniversity
−0.2
−0.6
0
200
400
600
800
1000
Iterations
Density of SFTRUE:Catuniversity
0
2
4
−0.7
−0.6
−0.5
−0.4
−0.3
−0.2
−0.1
0.0
N = 1000 Bandwidth = 0.02132


Trace of n1_ID+n2_ID
0.020
0.030
0.040
0e+00
4e+05
8e+05
Iterations
Density of n1_ID+n2_ID
0
20
40
60
80
100
0.020
0.030
0.040
N = 1000   Bandwidth = 0.0009532
Trace of units
0.0000
0.0004
0.0008
0.0012
0e+00
4e+05
8e+05
Iterations
Density of units
0
2000
4000
6000
8000
0.0000
0.0004
0.0008
0.0012
N = 1000   Bandwidth = 2.134e−05