Received: 14 July 2021 | Revised: 28 October 2022 | Accepted: 8 November 2022

DOI: 10.1111/psj.12492

ORIGINAL ARTICLE

PSJ POLICY STUDIES JOURNAL

Building blocks of polycentric governance

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Funding information

Australian Research Council, Grant/Award Number: DP220103921; US National Socio-Environmental Synthesis Center, Grant/Award Number: DBI-1639145; Swedish Research Council FORMAS, Grant/Award Number: 2020-01551

Abstract

Success or failure of a polycentric system is a function of complex political and social processes, such as coordination between actors and venues to solve specialized policy problems. Yet there is currently no accepted method for isolating distinct processes of coordination, nor to understand how their variance affects polycentric governance performance. We develop and test a building-blocks approach that uses different patterns or "motifs" for measuring and comparing coordination longitudinally on Australia's Great Barrier Reef. Our approach confirms that polycentric governance comprises an evolving substrate of interdependent venues and actors over time. However, while issue specialization and actor participation can be improved through the mobilization of venues, such a strategy can also fragment overall polycentric capacity to resolve conflict and adapt to new problems. A building-blocks approach advances understanding and practice of polycentric governance by enabling sharper diagnosis of internal dynamics in complex environmental governance systems.

KEYWORDS

coordination, environmental governance, network motifs, polycentric governance, self-organization

摘要

多中心系统的成败取决于复杂的政治过程与社会过程，例如行动者和场所之间 的协调（用于解决专门的政策问题）。不过，目前既没有公认的方法来分离不同 的协调过程，也没有公认的方法来理解协调过程的差异如何影响多中心治理绩。

效。我们提出并测试了一种构建块方法，该方法使用不同的模式或“图案”来 衡量和比较澳大利亚大堡礁的纵向协调。我们的方法证实，随着时间的推移，多中心治理包括一种不断发展的、由相互依存的决策安排和行动者组成的基础。不 过，尽管可以通过新的决策安排来改善问题专业化和行动者参与，但这种策略也能 分散用于解决冲突和适应新问题的多中心整体能力。构建块方法通过驱动复杂 环境治理系统中更清晰的内部动态诊断，进而促进对多中心治理的理解和实践。

关键词

环境治理，多中心治理，协调，自组织，网络图案

Resumen

El éxito o el fracaso de un sistema policéntrico es una función de procesos políticos y sociales complejos, como la coordinación entre actores y los acuerdos de toma de decisiones para resolver problemas de política especializados. Sin embargo, actualmente no existe un método aceptado para aislar distintos procesos de coordinación, ni para comprender cómo su variación afecta el desempeño de la gobernanza policéntrica. Desarrollamos y probamos un enfoque de bloques de construcción que utiliza diferentes patrones o “motifs” para medir y comparar la coordinación longitudinalmente en la Gran Barrera de Coral de Australia. Nuestro enfoque confirma que la gobernanza policéntrica comprende un sustrato en evolución de acuerdos de toma de decisiones y actores interdependientes a lo largo del tiempo. Sin embargo, si bien la especialización en temas y la participación de los actores se pueden mejorar a través de la movilización denuevos arreglos para la toma de decisiones, dicha estrategia también puede fragmentar la capacidad policéntrica general para resolver conflictos y adaptarse a nuevos problemas. Un enfoque de bloques de construcción avanza en la comprensión y la práctica de la gobernanza policéntrica al permitir un diagnóstico más preciso de la dinámica interna en sistemas complejos de gobernanza ambiental.

Palabras clave

coordinación, gobernanza ambiental, patrones de redes, gobernanza policéntrica, autoorganización

INTRODUCTION

Global sustainability depends on multiscale environmental governance (Clark & Harley, 2020). However, many governance actors struggle to coordinate and organize across the diverse and complex goals of sustainable development. A growing interest in collaborative governance, regime complexes, and polycentricity reflects this phenomenon (Jordan et al., 2015; Lemos & Agrawal, 2006; Morin et al., 2017). The concept of polycentricity, in particular, is often presented as key to resolving many complex social-ecological challenges (Biggs et al., 2012; Ostrom, 2012). Scholars of environmental politics, commons governance, and

policy studies describe polycentric governance as a self-organizing system of multiple actors coordinating across different decision-making venues and policy issues (Jordan et al., 2015; Kim, 2019; Ostrom, 2012). Yet, translating the concept of polycentricity into theory has mostly eluded scholarship, which remains characterized by abstract conceptual claims without concomitant empirical measurements, over-emphasis on snapshot case studies, and lack of counterfactuals (Heikkila & Weible, 2018; Jordan et al., 2018).

Participants in polycentric environmental governance also struggle with the practice of polycentricity. Australia's Great Barrier Reef (GBR) governance regime, which oversees the world's largest coral reef ecosystem (spanning 348,000 km^2, approximately the area of Germany or Malaysia), is a critical example. The GBR's highly regarded governance system is distinguished by a polycentric structure that has advanced since 1975 as a consequence of national (Australian) and state (Queensland) law, international oversight (UNESCO), public participation, and a diversity of other multi-actor, multilevel relationships involving joint rules, formal and informal partnerships, joint projects, and knowledge sharing (Day, 2017; Morrison, 2017; Olsson et al., 2008). In recent years, the health of the ecosystem has declined (Hughes et al., 2019), as actors have struggled to coordinate generally agreed goals and counteract deliberate political and industrial strategies designed to undermine coordination around rising stressors of land-based pollution and climate change (Lubell & Morrison, 2021; Morrison et al., 2020).

Deeper interrogation of patterns of coordination in polycentric systems like the Great Barrier Reef regime is needed because the success or failure of the governance of such systems is a function of these evolving patterns of social interaction and the social, economic, and political processes they represent. However, the current lack of a generally accepted method for empirically describing and analyzing evolving coordination dynamics makes it difficult to interrogate ongoing assumptions about polycentric systems. These include, for example, assumptions about the relationships between various forms of coordination and effectiveness (Bergsten et al., 2019; Bodin et al., 2022). Ideas about how coordination pertains to human agency in self-organized systems - such as collective action rooted in legitimacy and homophily (Jasny et al., 2019) - also require further development. To achieve these goals, researchers and decision makers need a better understanding of how coordination changes over time and place and the effects on legitimacy and performance.

In this paper, we suggest that the core constitutive elements of polycentric governance are patterns of coordination driven by actors. Following Urwin and Jordan (2008) and Metz et al. (2020), we define coordination broadly as the productive interdependent relationships among governance actors (within and outside of government) and between actors and decision-making venues (and among venues) that are formed to address policy issues (Box 1). Self-organization - the emergent and idealized quality of polycentric governance often assumed to lead to better outcomes - both shapes and is shaped by coordination (Boonstra & Boelens, 2011; Ostrom, 1994; Peters, 2015).

A central challenge for scholars interested in polycentricity involves developing systematic methods for measuring coordination and the various interactions among governance actors, decision-making venues, and policy issues. While no single project can thoroughly tackle that challenge, in this paper, we take strides in that direction by:

1. Using 3-mode network motifs to introduce a building-blocks approach for operationalizing polycentric governance systems, based on the logic that network motifs are fingerprints of social and political coordination;
2. Testing our building-blocks approach by exploring how broader social and political processes are reflected in evolving patterns of coordination in the Great Barrier Reef regime; and
3. Advancing the idea that we can improve how policymakers and civil society coordinate to solve policy problems by making micro- and meso-level changes to the building blocks of a polycentric governance system.

THE PROBLEMS WITH POLYCENTRICITY

At the beginning of the new millennium, environmental governance was still in the throes of the decentralization and collaboration wave (Lemos & Agrawal, 2006). Dozens of countries and transnational

BOX 1 Defining measurable elements of polycentricity

Polycentricity is defined here as a self-organizing governance system comprised of multiple governance actors, decision-making venues, and policy issues, and the relationships between them (Jordan et al., 2015; Kim, 2019; Ostrom, 2012). It can be broken down into the following measurable elements:

Governance actors: Actors are individuals or organizations that influence decision-making venues, have an interest or stake in a policy issue(s), or are affected by decisions in those venues and changes in the issues (Angst et al., 2022). Actors can include, for example, a government agency or government official, resource user groups, scientists and consultants, advocacy groups, journalists, and members of the public. Sometimes government-affiliated actors can be a venue - for example, a regulatory commission - but it is important to remember that not all venues are actors nor are all actors venues (Scharpf, 1997).

Decision-making venues: The necessary decision-making unit in any polycentric system is the decision-making venue, which is a collective action space with authority to design and adopt public policies and implement them. In that sense, a venue is similar to an action situation where actors engage with each other and through these interactions initiate actions (McGinnis, 2011). Venues also serve to address collective action concerns, such as addressing conflicts and disputes. Examples of decision-making venues include legislatures, regulatory commissions, city councils, and intergovernmental fora (Hedlund et al., 2020; Fischer & Leifeld, 2015).

Policy issues: Polycentric systems of governance draw together multiple policy issues, that is, topical policy areas or problems that they address, affect, or both. Issues can be both general and specific and vary in terms of salience and complexity. Governance actors typically organize around a general issue area that broadly draws all relevant venues and actors together (e.g., the sustainability of the Great Barrier Reef). Governance actors in polycentric systems also partition the general issue into multiple sub-issues that one or more venues might address (e.g., fisheries regulation, water quality management, climate adaptation) (Eshbaugh-Soha, 2006).

Relationship types: Polycentric systems feature multiple types of relationships via actors' political involvement in more than one venue, venues affecting other venues through their policy decisions, and policy issues affecting other issues. The nature of the relationships between venues, actors, and issues is wide-ranging. Venues can condition and affect each other via institutional rules and/or policy decisions. Issues can overlap by biophysical relationships. Additionally, venues, actors, and issues can also overlap. For example, as actors seek to influence or are affected by venues, venues implement policy decisions that affect issues, and issues change which, in turn, affects actors and venues (Pedercini et al., 2019). These relations can be emergent and/or formalized. They can also be productive (e.g., coordination, cooperation, knowledge-sharing, healthy conflict, competition) or unproductive (e.g., deliberate marginalization, social exclusion, political stalemate) or nonexistent (Ostrom et al., 1961). The emphasis in this paper is on one overarching relationship type (which we term 'coordination' to encompass all the productive ways that actors and venues work together on issues, as described above).

Building blocks: Building blocks are the various motifs of the specific combinations of actors, venues, issues, and relationships that comprise the minimal constellations of polycentricity (Bodin & Tengö, 2012; Dey et al., 2019; Leventon et al., 2017). They can be used to identify recurring patterns of coordination in polycentric governance systems (Falkner et al., 2010; Stewart et al., 2013).

organizations decentralized and democratized environmental governance to pursue gains in efficiency, justice, participation, and accountability (Andersson & Ostrom, 2008). However, by 2010, growing empirical evidence indicated that decentralization and collaboration were not a panacea for addressing environmental or social issues. Rapid and increasingly complex social and environmental change, including climate change, globalization, neoliberal modes of policymaking, and an increasingly diversified polity, called for a different kind of governance, focusing more on diverse responses and action at multiple scales. Analysts variously described this new kind of governance as multilevel, networked, fragmented, or polycentric (Andersson & Ostrom, 2008; Biermann et al., 2009). Out of all of these, the concept of polycentric governance and its defining features of purported self-organization and mutual adjustment best encapsulated the trend (Morrison, 2020).

Regarded as the logical alternative to both bottom-up and top-down systems, polycentric systems have been conceptualized as consisting of many centers of authority interacting within and across scales for a shared governance goal (Polanyi, 1951). Proponents claim that polycentric governance facilitates equal representation from different governance actors, encourages policy innovation and policy diffusion, and supports flexibility through rapid reconfiguration of policy networks to achieve specific goals (Jordan et al., 2015; Morrison, 2020). Polycentric governance also allows specialization, division of tasks between central, regional, and local levels, subsidiarity, and tailoring of interventions to local-regional circumstances and community preferences, thus improving the efficiency of environmental governance by matching interventions to the context and scale of the problem (Morrison et al., 2017). Many analysts also regard polycentric systems as more robust because their high degree of overlap and redundancy means that if one part of the system fails, others may take over their functions (Carlisle & Gruby, 2019). In addition, the multiple causal factors and symptoms of contemporary environmental problems, the high levels of uncertainty about the range of solutions, and the lack of conclusive answers as to who is responsible for the solution mean that alternative governance approaches are often impossible. For these reasons, polycentricity has risen as a concept of serious interest to researchers working across many environmental governance regimes, including the REDD+ regime, the global climate change regime, fisheries governance, and biodiversity regimes (Morrison et al., 2019).

Today, contemporary scholars understand environmental governance as a complex system with non-linear, self-organizing processes; this is an axiom across the current policy, sustainability, and complexity sciences (Cudworth & Hobden, 2011). Recent studies have also begun exploring the effectiveness of polycentricity (Huitema et al., 2018; Lubell & Morrison, 2021). Indeed, many polycentric governance systems are now struggling to deal with the rising risks of rapid environmental and social change, and more critical perspectives of polycentric governance are emerging (Morrison et al., 2019). Documented problems include fragmentation, low transparency, high transaction costs, policy incoherence, gridlock, unanticipated effects, inequities, freeloading, and ultimate compliance and implementation failure (Gallemore, 2017; Sovacool et al., 2017; Sunderlin et al., 2015). New archival and textual analyses, for example, have shown that polycentric systems are not necessarily better than other types of governance systems and that complex polycentric systems can mask problems, generate actor fatigue and policy stagnation, and decrease system capacity to address diverse governance challenges (Fisher & Leifeld, 2019; Hileman & Bodin, 2018). Recent analysts have also claimed that the concept of polycentricity is fraught with internal paradoxes and assumptions, and some large gaps in knowledge remain (Jordan et al., 2018; Morrison et al., 2019). Scholars are therefore working now to move polycentric governance from a nebulous concept to a more solid theory and practice for addressing global environmental change. Contemporary Institutional Analysis and Development (IAD) scholars, for example, caution that polycentric governance has more utility as a diagnostic and a description than a panacea for resolving the many challenges of global environmental change (Aligica & Tarko, 2011; Andersson & Ostrom, 2008). The realization of generalizable polycentric design principles has proven relevant mostly for discrete sets of static, homogenous, and tightly-bounded polycentric systems (Epstein et al., 2020; Ostrom, 2012).

In contrast, international relations scholars characterize polycentric governance less by its rules and boundaries and more as a 'regime complex' (Keohane & Victor, 2011) with costs and benefits of coordination manageable through nonhierarchical steering or 'orchestration' (Abbott et al., 2016). These

orchestration studies have begun to extend focus beyond inter-state regimes to include actors at the sub-national level, in bureaucracies, and outside the official realm of governmental decision-making (e.g., corporations, non-profits) (Green & Auld, 2017; Morin et al., 2017).

Policy scientists have also targeted wicked institutional settings, with insights into actor cooperation, learning, and bargaining (Berardo & Lubell, 2019; Lubell, 2013; Morrison et al., 2019). The Ecology of Games Framework (EGF), for example, targets the drivers, mechanisms, and outcomes of complex institutional settings using multi-level network approaches (Lubell, 2013). The EGF posits that learning, cooperation, and bargaining represent three core social processes in complex governance systems. These processes emerge from the combination of actors participating in policy forums, actors' interests in particular policy issues, and the assignment of policy issues to particular institutional jurisdictions. Empirical EGF results suggest that over time, polycentric systems cycle between top-down and bottom-up processes of cooperation (Lubell & Robbins, 2021).

However, despite these advances, research on polycentricity remains mostly comprised of normative concepts or descriptive single case studies at one point in time and assessing the functional quality of a polycentric system is still a black box. In particular, we have yet to establish a method for understanding how key processes such as coordination vary over time, and how this variance shapes governance legitimacy and performance. Governance analysts have, therefore, yet to deal with the tension between bottom-up and top-down coordination in polycentric systems, and the extent to which actors rather than venues or policy issues themselves are responsible for such dynamics (Biermann et al., 2009; Kim, 2019; Leventon et al., 2017). Indeed, theoretical progress on polycentricity remains constrained by a failure to account for how the gamut of relationships in any governing system will vary in type, purpose, and intensity across time (Galaz et al., 2012; Morrison et al., 2017). Longitudinal variance in polycentric coordination matters, because the success or failure of a polycentric system is a function of these evolving patterns and the social and political processes they represent. Addressing these ongoing gaps is also critical to interrogating assumptions about coordination, such as assumptions that self-organization is a function of actor homophily (Jasny et al., 2019), or that patterns of coordination are dependent on the type of policy issue (Hedlund et al., 2020), or that more policy coordination eventually leads to more efficient and legitimate governance (e.g., Bergsten et al., 2019).

LONGITUDINAL AND NETWORK INNOVATIONS IN ANALYZING COMPLEX GOVERNANCE SYSTEMS

Multiple strands of polycentricity studies indicate no single path to understanding complex governance relations (Jordan et al., 2015; Kim, 2019; Ostrom, 2012). Many different approaches to understanding governance need to be tested, and their value will depend on the research goals, availability of the data, the nature of the problem, and the system under consideration. Some analysts have begun to adopt longitudinal approaches, drawing on archival and textual analyses (Epstein et al., 2020), whereas others have embraced approaches that combine quantitative information about individual system components into a multi-dimensional and relational space with matrices of quantitative data (Anderies et al., 2022; Cumming et al., 2020). New approaches have also combined, for example, developments in event-sequence analysis (Spekkink, 2015), with developments in organizational ecology (Abbott et al., 2016), statistical network modeling (Morin et al., 2017), and evolutionary psychology (Marks et al., 2019). Social and discursive network analysts, in particular, have begun to use network approaches to map polycentric governance topologies (e.g., Fisher & Leifeld, 2019; Hollway & Koskinen, 2016; Kim, 2019; Pattberg et al., 2018) for a variety of environmental problems at a range of scales.

Network approaches have demonstrated many benefits over a descriptive or normative approach for understanding polycentric governance. These benefits include a general way to represent structure and interdependence; capacity to develop new theories about the relationship between structure and process and how networks change over space and time (including in response to shock) (Datta et al., 2022); and new ways to think about intervening in problems, for example by adding or removing links in a network

(Valente, 2012). Additional and more ambitious benefits of a network approach potentially include: (1) a more subtle, nuanced way to understand how structure and agency influence environmental efforts (for example, if a new 'polycentric' governance system is only partially successful, are its failures due to structural inadequacies?); (2) more precise detection of threshold effects and feedbacks (allowing researchers to address the question of whether a system must be strongly polycentric in order for a particular social process to occur); (3) reduced arbitrariness of decisions (and hence, forestalling of arguments) about the characteristics of a system's polycentric structures and processes; and (4) more direct comparison between different case studies, facilitating qualitative and quantitative synthesis and comparison (e.g., meta-analysis) and the establishment of broad general principles (Bodin et al., 2019; Cumming et al., 2020; Lubell et al., 2020; Spekkink, 2015).

3-MODE NETWORK MOTIFS AS BUILDING BLOCKS OF POLYCENTRIC COORDINATION

Network analyses generally use either a node-by-node matrix or a list form of the same data in which pairs of interacting nodes are listed, sometimes with an interaction strength. However, such analyses typically only capture a slice of polycentric systems—one-mode networks of collaboration among policy actors (Berardo & Lubell, 2019), or two-mode networks of actor connections to issues or actor participation in venues (Lubell et al., 2016). Very few studies use a three-mode network analysis that treats venues, actors, and issues as nodes, and the relationships among them as links (Fried et al., 2022; Kim, 2019). Furthermore, key processes such as coordination that lead to self-organization are rarely separated or studied longitudinally. Applications of longitudinal and automated methods to the Ostrom's core theoretical constructs, for example, have recently illuminated important variations across polycentric systems (Heikkila & Weible, 2018). These longitudinal methods and the network innovations described above highlight the potential for identifying recurring patterns and segments in polycentric governance, in other words, "building blocks" of polycentricity (Falkner et al., 2010; Stewart et al., 2013).

A building-blocks perspective highlights the potential for 3-mode networks to map interdependent patterns of agency (i.e., coordination) in polycentric governance systems. In polycentric governance, 3-mode network analysis could help us to understand the results of policy actors' social network relations and participation in policy venues, their focus on different issues, and the links between those issues. It could also help account for different jurisdictions of policy venues and their associations with other biophysical, ecological, social, and institutional processes. Structural patterns in three-mode networks can represent how connections *between* different types of system components associate with linkages *within* different types of system components. Theoretical arguments can then be developed to identify the processes that might produce different configurations, and how they might be desirable or undesirable from a set of normative evaluation criteria. Hence, an understanding of the most prevalent processes can inform analysis of structural patterns, and vice versa.

Drawing on the theoretical and empirical innovations described above, we suggest that the core constitutive elements of coordination (venues, actors, issues, and their relationships [Box 1]) can be drawn together into three major categories. The first category (actor-to-venue) narrows the focus on just actors and venues, putting aside issues, which have already been analyzed in many polycentric studies (e.g., Berardo & Lubell, 2019; Mancilla García & Bodin, 2019). The second category (venue-to-issue) focuses on the ways different venues address different (or the same) policy issues in networked action situations (with action situations understood as venues) (McGinnis, 2011).[1] The third category (actor-to-venue-to-issue) combines all types of nodes and links (and thus the first two categories), and has only very recently been utilized in empirical studies relying on an explicit network approach (Fried et al., 2022). We begin to tackle this challenge in this paper.

Proposed typology of building blocks of polycentricity

Figure 1 illustrates how different building blocks might be associated with hypothetical types of coordination. Coordination occurs for various reasons, including when governance actors take into account interdependence between issues and sectors within polycentric systems (Metz et al., 2020). Coordination may emerge from bottom-up processes through self-organized activities and from top-down processes where the institutional rules allocate and dictate the distribution of political resources. The existence and interdependencies of decision-making venues can also shape actor behaviors and outcomes.

In Figure 1, the circles represent a hypothetical set of governance actors, the boxes represent decision-making venues, the diamonds represent policy issues, and the lines indicate relationships. Horizontally, the motifs are aligned from loosely coordinated to tightly coordinated and vertically from partially to deeply polycentric.

Example interpretations of selected types of motif are shown in panels 1–3 in Figure 1, along with examples from references to the relevant literature. Motifs '*a*' - '*e*' (top horizontal panel) potentially represent different levels of actor coordination in one or more venues. An interpretation of '*c*', for example, would be two actors coordinating in and outside the same venue (Morrison, 2007). By contrast, Motif '*e*' shows a situation where two actors communicate and coordinate in the same venue but with one of the actors participating in a distinct venue. Institutional analysts refer to such a phenomenon as 'layering', whereby new venues are added, gradually changing the structure and power dynamics of a polycentric system (Heikkila et al., 2018; Van der Heijden, 2011).

Motifs '*f*' – '*i*' (middle horizontal panel) then potentially represent how such venues link to issues, where '*f*', for example, represents a venue addressing one of two interdependent issues. A generic exam-

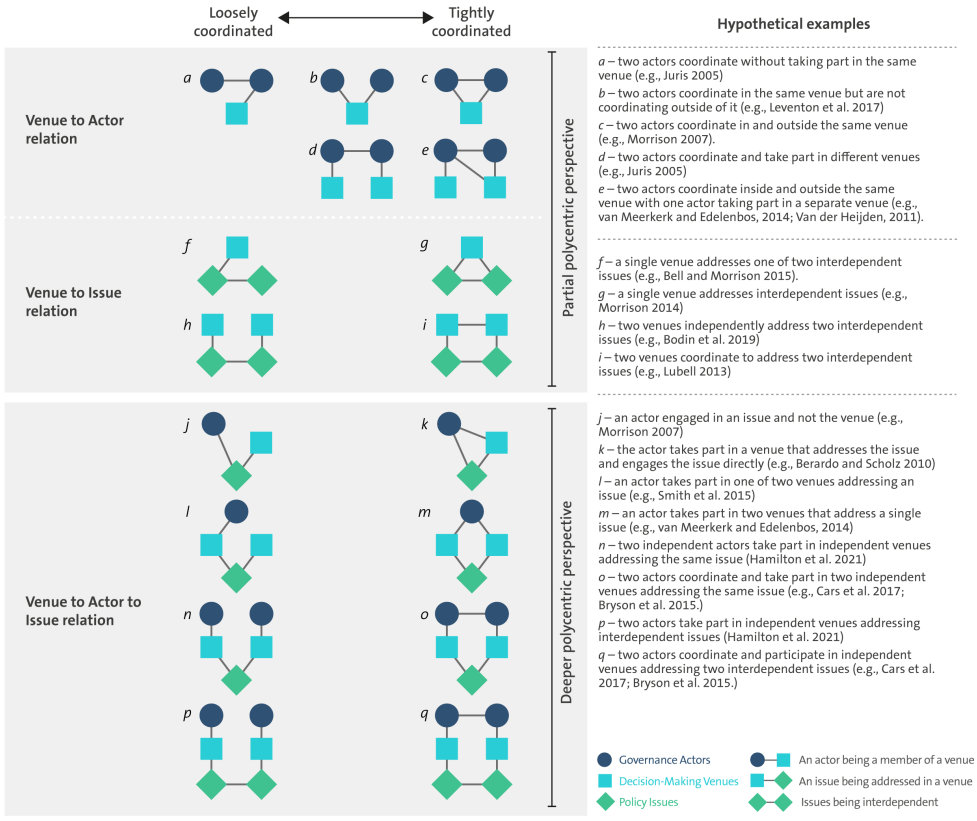

FIGURE 1 Proposed typology of building blocks of polycentricity

ple of '*f*' could therefore be a disaster response forum that only peripherally includes consideration of climate projections (Bell & Morrison, 2015).

Finally, Motifs '*j*' – '*p*' (bottom horizontal panel) represent additional patterns of independencies and interdependencies among actors, issues, and venues. '*J*', for example, represents an actor engaged with an issue but not the venue. One empirical illustration of '*j*' can be found in Morrison's (2007) study of an actor with a high-stake interest in an issue but not involved in the representative venue. '*K*', by contrast, forms a closed actor-venue-issue triangle because that actor is participating in the relevant venue. In '*o*' and '*q*', two actors coordinate outside the venues but engage in distinct, interdependent venues that address one issue or two interdependent issues. Consistent with network science, motifs '*o*' and '*q*' are associated with high-risk/closed bonding ties, characterized by a single body or integrated legal framework that oversees or compels frequent interaction or substantial resource commitment from multiple actors (Hedlund et al., 2020; Metz et al., 2020). In '*p*', by contrast, two independent actors participate in two independent venues that deal with two interdependent issues. An empirical illustration of '*p*' can be found in Hamilton et al. (2021) who document actors and venues independently making decisions about interdependent issues. Whether these building block motifs are "good" or "bad" for governance depends entirely on the context. It is possible, for example, that the loosely coordinated motif '*a*' in the upper left corner is the preferred motif over the tightly coordinated motif '*i*' in the upper right corner, depending on the situation.

MATERIALS AND METHODS: ANALYZING POLYCENTRIC GOVERNANCE OF THE GREAT BARRIER REEF

Overall approach

While there is a generally accepted network literature on 2-mode motifs (i.e., actors and venues, or actors and issues), and we know that numerous different 3-mode motifs (actors-venues-issues) potentially exist, we still do not know which of these motifs are prevalent or absent, nor what they mean. Our approach was therefore deliberately exploratory. To overcome this lack of empirical knowledge, we first undertook a series of workshops to identify the most obvious motifs possible in polycentric environmental governance systems. Three workshops, including the 7 authors plus 11 other participants, were hosted at the facilities of the National Socio-Environmental Synthesis Center in Annapolis, Maryland between 2018 and 2019. All workshop participants had expertise in either environmental governance or social-ecological modeling, and 7 had specific expertise in analyzing polycentric environmental governance systems from the different perspectives of political science, political geography, environmental policy, and social network analysis.

Over the course of the workshops, we began to identify key motifs compatible with polycentric environmental governance systems, distilling both from our understanding of previous theories of environmental policy integration (e.g. Peters, 2015; Tosun & Lang, 2017; Urwin & Jordan, 2008), collaborative environmental governance (e.g. Hamilton & Lubell, 2018) and social-ecological networks (Bodin et al., 2016; Westerink et al., 2017), as well as from recently published research on polycentricity in Australia, the USA and Europe (e.g. Hedlund et al., 2020; Heikkila & Weible, 2018; Morrison et al., 2019). We focused on motifs representing the core social and political processes we believed vary across polycentric systems. We based our selection on the distinction between closed and open networks, a hallmark of all network science research. We assumed, therefore, that actor linkages represent productive relations (e.g. coordination, collaboration, cooperation, healthy competition and conflict) and that a lack of actor-to-actor linkages signals unhealthy conflict, avoidance, high transaction costs, or simply a reflection of actors' limitations in that they cannot necessarily connect with every other actor (assuming the number of actors is not very small). We also excluded motifs that did not provide the opportunity to analyze joint interdependencies between and within nodes, for example, single actors linked to single issues. Polycentric

systems potentially contain hundreds of building blocks, so to avoid continuing ad nauseam, we stopped eliciting motifs upon reaching saturation (that is, when the same motifs began to be repeated). This process elicited seventeen motifs.

Justification and delineation of the case

We then sought to advance our understanding of polycentricity by applying the building blocks to the polycentric governance of the Great Barrier Reef. The data-rich Great Barrier Reef (GBR) governance regime was chosen as it is an ideal case for studying polycentricity. It offers multiple qualitative and quantitative data sources, including longitudinal actor and venue data (Morrison, 2017), issue data (Bellwood et al., 2019; GBRMPA, 1976–2015), expert knowledge, and previous analyses (Craik, 2017; Olsson et al., 2008) dating back to 1975. The GBR is also of interest because the emergence of its polycentric governance system (Figure 2) is regarded as a major governance innovation. The original innovation occurred through the creation of the national *GBR Marine Park Act*, the delegated GBR Marine Park Authority (GBRMPA), and a national-state *Intergovernmental Agreement* in the 1970s. These innovations were followed by UNESCO World Heritage listing and a phase of policy layering in the 1980s and early 1990s as further international and state-based water, coastal and terrestrial arrangements were introduced (Morrison, 2017). By the 2000s, the system began to represent an idealized polycentric structure. Self-organization stood at its zenith in 2005 (Day, 2017), in the wake of the successful rezoning of the marine park, a process that involved an award-winning public participation exercise undertaken over several years. However, by 2015, multiscale drivers had led those original coordinating networks to progressively re-form; the drivers included central agency burnout, industry backlash, capacity constraints, and the emergence of new issues outside the original interest groups (GBRMPA, 2019; Hughes et al., 2019; Morrison, 2017).

Over the 4 decades of the case study period (1975–2015), many different actors have interacted according to multiple overarching sets of rules and norms. Key actors included Traditional Owners, the Great Barrier Reef Marine Park Authority, UNESCO, intergovernmental organizations, national government, state government, local government, government-owned corporations, industry associations, private industries, environmental NGOs, and science and media organizations (Morrison, 2017). Key decision-making venues included the Great Barrier Reef Ministerial Forum and the UNESCO World Heritage Committee. The Great Barrier Reef Ministerial Forum compelled the Queensland government

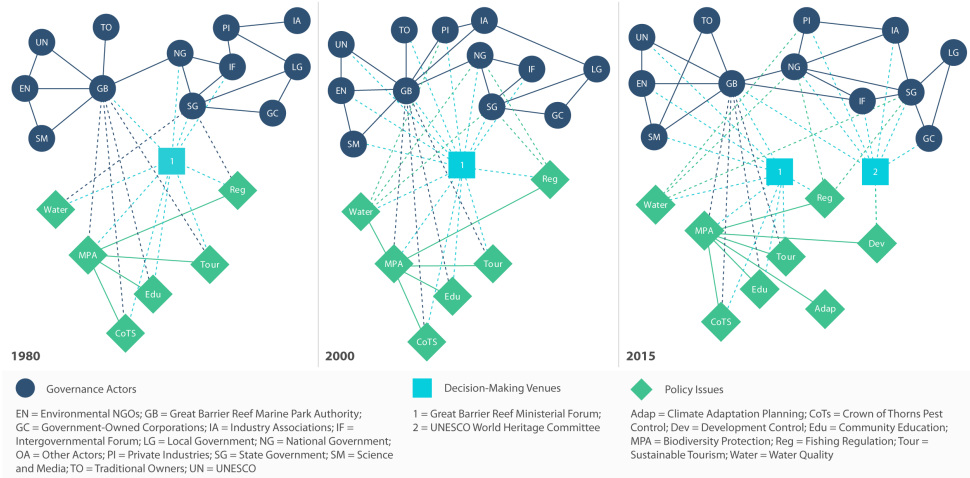

FIGURE 2 3-Mode network models of the polycentric Great Barrier Reef regime

and the Australian government (through the Great Barrier Reef Marine Park Authority) to work together as set out under the Intergovernmental Agreement between the Australian and Queensland governments (Australian Government, 2015). The World Heritage Committee continues to implement the World Heritage Convention and consists of representatives from 21 national governments signatory to the Convention (UNESCO, 2022a).

Over 4 decades, the boundary of the system has evolved to reflect the changing issues of the day. In the early days, key issues included biodiversity protection, fishing regulation, and sustainable tourism. By 2015, issues of climate adaptation planning, Crown of Thorns pest control, coastal development control, community education, and water quality had gained in prominence. Multiple datasets show how different members and non-members have come and gone with changing rules and norms. Such datasets include records on public participation, cooperative state (Queensland) and national (Australian) law, international (UNESCO) oversight, and a variety of other multi-actor, multi-level relationships involving joint rules, formal and informal partnerships, joint projects, and knowledge sharing (Morrison, 2017). The value of the GBR case is therefore twofold: (1) the rich data availability enables the combination of quantitative techniques with deeper ethnographic and interpretive techniques, and (2) the longitudinal data availability enables in-depth insight into how a polycentric system varies over time.

Data

We selected and combined two different longitudinal datasets on the GBR, combining data on actors, venues, issues, and their relationships with expert assessment in order to develop 3-mode network models of this real-world regime at three points in time (1980, 2005, 2015) (Figure 2). The first dataset, assembled by Morrison et al. (2017), contains 231 documents (audits, assessments, reports, reviews, and inquiries) of different features of the GBR regime authorized 1975–2016 by regional, state, national, and global agencies, records of 32 stratified and key-informant interviews with key actors from research institutes, industry bodies, the GBRMPA, environmental law firms, local and international ENGOs, and the Australian and Queensland governments, and participant observation records from 7 government and scientific meetings held between 2015 and 2016. The second dataset contains 41 Great Barrier Reef Marine Park Authority Annual Reports, from 1976 to 2016, and is publicly available at elibrary.gbrmpa.gov.au.

There were multiple reasons for using these datasets. First, the documentary components of both datasets (inquiries, reviews, annual reports, assessments, audits, and meeting minutes) are publicly available, enabling the research to be replicable. Second, the datasets provide detailed insight into the history of the regime, which would not necessarily be available from data collected through a snapshot study focusing on contemporary actors, venues and issues. These longitudinal governance datasets reveal that some actors and venues persist while others rise and fall, and why they do so – such datasets enable a longer perspective and deeper insight into the institutional backbone of a regime (Cao et al., 2019). Subsequent analyses of the two datasets (Bellwood et al., 2019; Morrison, 2017) also recognize similar phases of the regime, enabling us to easily connect the issues data with the data on actors, venues, and their relationships. The first phase (1980s) is recognized across both datasets as one of regime growth, characterized by intergovernmental legislative protection, a World Heritage listing, and complementary policy layering at multiple levels (Olsson et al., 2008). The second phase (2005) is recognized as one of regime consolidation and mismatch between threats, goals and interventions, characterized by the successful rezoning of the reef followed by dramatic changes to the regional context for managing the reef as a consequence of an adjacent mining boom, generating regime drift (Day, 2017). The third phase (2015) is recognized as one of regime conversion and realignment, characterized by the ongoing threat of World Heritage In-Danger listing and rising realization of the impacts of climate change (Bellwood et al., 2019; Morrison, 2017).

To develop the 3-mode networks, we extracted a qualitative model of the changing structure (actors, venues and relationships) of the polycentric governance regime from the first data set (for a detailed description of the original data and method, see Morrison, 2017 methods and Figure 2), and connected it with a quantitative analysis of issues extracted from the second data set using NVivo (for a detailed

description of the original data and method, see Great Barrier Reef Marine Park Authority 1976–2015 and Bellwood et al., 2019 methods and Figure 3). We sorted the actors into 13 different actor types (Traditional Owners, the Great Barrier Reef Marine Park Authority, UNESCO, intergovernmental organizations, national government, state government, local government, government-owned corporations, industry associations, private industries, environmental NGOs, science and media organizations, and miscellaneous actors). We then sorted the issues into 8 high stakes issues: climate adaptation planning, Crown of Thorns pest control, coastal development control, community education, biodiversity protection, fishing regulation, sustainable tourism, and water quality issues. The two venues chosen were the Great Barrier Reef Ministerial Forum and the UNESCO World Heritage Committee.

The Great Barrier Reef Ministerial Forum and the UNESCO World Heritage Committee were chosen as venues, and the Great Barrier Reef Marine Park Authority was chosen as an actor (rather than a venue) for two reasons. First, the Great Barrier Reef Ministerial Forum and the UNESCO World Heritage Committee both held high-level and longstanding decision-making powers over the 40-year study period. The World Heritage Committee made decisions according to the 1972 World Heritage Convention – decisions reached through a rotating set of representatives from 21 national governments signatory to the Convention. The Great Barrier Reef Ministerial Forum also held high-level and longstanding decision-making powers – this forum compelled both the Queensland government and the Australian government (through the Great Barrier Reef Marine Park Authority) to work together as set out under the 1979 Intergovernmental Agreement. The Ministerial Forum comprised a changing set of two ministers from the Australian and Queensland governments each with responsibility for decisions relating to the environment and marine parks, tourism, natural resource management and/or science (Australian Government, 2015). Second, while actors such as the GBRMPA were critically important to shaping and implementing legislation and strategies to manage issues such as fisheries, tourism, biodiversity conservation, the authority remained an actor rather than a venue because its decision-making powers were constrained by the minister, for example through the aforementioned Ministerial Forum (Australian

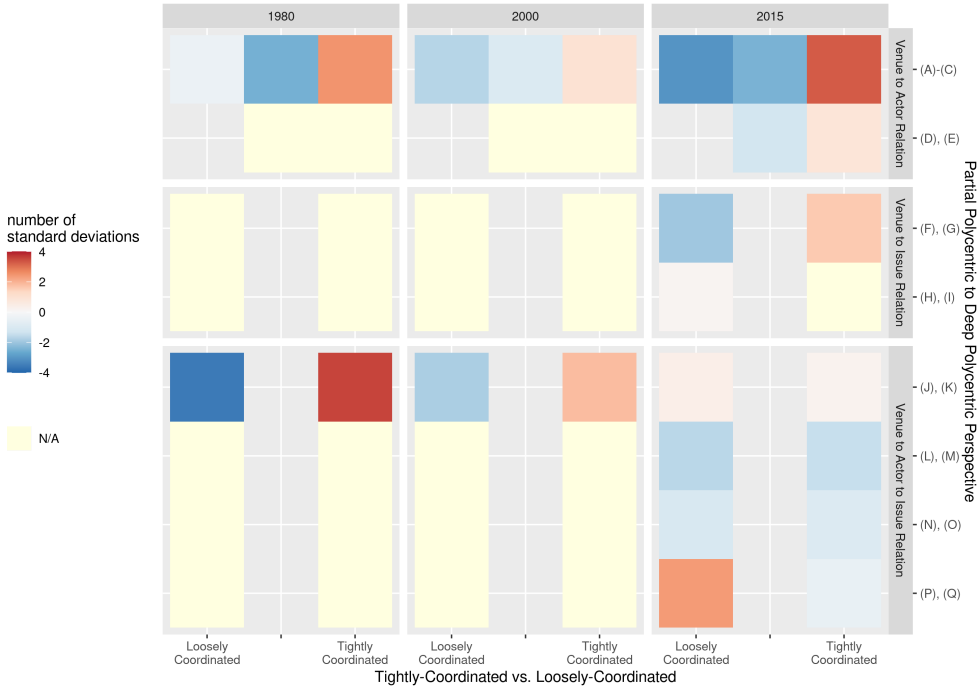

FIGURE 3 Polycentric coordination in the Great Barrier Reef

Government, 2021; Craik, 2017; Wettenhall, 2005). Indeed, the national environment minister's control and oversight of GBRMPA increased during the mid-2000s as a consequence of broader restructuring (the *Uhrig Review*) as well as the increasing politicization of the reef – this constrained power has most recently been evident in the authority's failure to use Section 662E of the *Great Barrier Reef Marine Park Act* to manage activities on the edge of the marine park as well as the Authority's constrained use of the latest reef bleaching report during the lead-up to the 2022 federal election (Foley, 2022; Morrison, 2017; Uhrig, 2003).

In considering the relationships between actors, venues and issues, limitations with the original data sources (Bellwood et al., 2019; Morrison, 2017) and lack of a general conceptual understanding of different types of relationships (Tang et al., 2016) compelled us to include all types of productive relationships, including not just coordination but also cooperation and knowledge-sharing, as well as healthy conflict and competition. The absence of a link therefore signifies either no relationship or an unproductive relationship (e.g., political stalemate or deliberate marginalization).

Random graph modeling and validation

We then conducted a series of conditional uniform to random graph tests to compare the observed frequency of the 17 building blocks (Figure 3) in the three different GBR networks (1980, 2000, and 2015) with the frequency distribution of building blocks in 10,000 simulated random networks (the baseline or null model; Figure S1). Conditional uniform random graph tests compare the observed empirical network with a set of simulated (random) networks where the potential edges between each pair of nodes are assigned with a uniform probability that would preserve the number of observed edges but would randomly rewire them among the nodes. The null model assumes that actors and institutions are randomly forming relationships, and significant deviations from the random expectations provide evidence of the non-random social and political processes driving network structure. In other words, the observed deviations of the occurrences of the building blocks vis-à-vis their occurrences in the random networks are evidence of actors' deliberate attempts to seek partners, venues and issues to address particular problems in different ways. While there are lots of deviations from such a simplistic null model to expect in any real-world network, the ones that deviate most from random are the most meaningful to analyze as their presence (or absence) indicates the strength or weakness of particular social and political processes operating in the system.

We considered a value (i.e., the frequency of a specific motif) as significantly deviated from the null model if 5% or less of the simulated networks displayed a higher or lower value (lower value for significantly underrepresented motifs, and a higher value for significantly overrepresented motifs). This Conditional Uniform Graph (CUG) test serves as an initial hypothesis test to refute the basic null model described above. The approach is limited in the sense that it cannot fully account for motif entanglements (interdependencies) as the edges are assumed to form independently at random. It also assumes that the numbers of venues, actors, and issues is fixed. Hence, the resulting distributions of motif frequencies cannot be compared in absolute terms across networks which differ in these numbers. We mitigated this problem by comparing relative indicators such as number of standard deviations instead. It is important to note here that there are other statistical techniques such as multilevel Exponential Random Graph Models (ERGM, see Lusher et al., 2013), which can account for more complex null models, but are beyond the scope of this article. We propose such techniques to be used in the future. Nonetheless, CUGs serve as a feasible demonstration of the three-level multilevel network approach we introduce here.

To create the heat map, we then took the frequencies for all 17 building blocks and determined by how many standard deviations these values differed from the mean in the set of random networks. Observed frequencies that were in either tail ("extreme" relative to average) of the frequency distribution generated by the simulated random networks enabled us to determine which features of the observed networks deviated the most from an expectation of links being created entirely at random.

Finally, we used previously published and expert knowledge (Craik, 2017; Day, 2017; Olsson et al., 2008) alongside event sequence analysis (Morrison, 2017; Spekkink, 2015) to validate the building blocks and how they changed over time.

RESULTS

In Figure 2, we show how the hypothetical building blocks appear (or not) in our re-constructed polycentric governance regime of the Great Barrier Reef at three points in time. In Figure 3 (and Figure S1), we show which building blocks are predominant or suppressed at different times based on the conditional uniform random network modeling method comparing the observed real-world frequencies to 10,000 simulated networks. The results suggest the Great Barrier Reef exhibits a relatively stable, path-dependent governance system that has recently experienced incremental change in some patterns of coordination, with both positive and negative implications. Below, we explore these results by comparing them against expert knowledge and previous qualitative and quantitative research to provide additional interpretation of the building blocks and their utility.

Polycentric substrates of actor-venue relations

Our results (Figures 2 and 3) confirm that coordination between Great Barrier Reef governance actors within the same decision-making venue has always been higher than might be expected under a random process of association - and increasing. In 1980, coordination among actors who were also members of the same venue (‘*c*’) was significantly overrepresented relative to random networks, while at the same time any two actors of the same venue who were not coordinating (‘*b*’) were significantly underrepresented (Figure 3). This result concurs with previously published analyses of the high levels of social capital in the broader catchment (Marshall et al., 2011; Morrison, 2014). By the 2000s, coordination between governance actors was very present but not noticeably obvious (i.e., statistically significant) because the network was nearly fully connected, a finding that can be attributed to the prolonged public participation exercise undertaken as part of the 2004 rezoning of the marine park (Day, 2017). The 1980 pattern was further strengthened in 2015 (*b* and *c* significantly under- and over-represented, respectively), which suggests an overall increase in coordination among actors jointly participating in the same venue.

Differentiated polycentric venues

Concurrently, there was an increasing coordination of issues around venues, where venues had jurisdiction over independent issues. The Great Barrier Reef governance system also gradually moved from a state-of-play in the early years where the building blocks linking venues to issues resembled a random graph, to a situation in the 2000s where the venue strengthened its coordination of issues (*g*). This result can be attributed to increased oversight by the national environment minister in the wake of the successful rezoning (Morrison, 2017; Olsson et al., 2008). By 2015, “participation by proxy” (*f*) where interdependent issues were only indirectly linked to venues, was rare, confirming published reports and expert knowledge of underlying self-organization combined with increased within-venue coordination over time (Day, 2017). By 2015, tight venue-issue coordination was prevailing (with *g* rather common, and *f* significantly underrepresented). Furthermore, while the results for *f* confirm that tight coordination was prevalent, it should be noted that the only issue being addressed by the new 2015 venue (development control) was dependent on another issue (biodiversity protection), which was solely addressed by the original venue. In other words, the addition of the new venue contributed to looser venue-issue coordination than would otherwise have occurred – this can also be understood as polycentric fragmentation (Pahl-Wostl & Knieper, 2014).

Differentiated polycentric power and capacity to adapt to new issues

From a polycentric perspective, the results become even more interesting when taking a deeper view that considers all three types of nodes. By 2015, no motifs associated with tight coordination across all three types of nodes were significantly overrepresented. Motifs like *'o'* and *'q'* were significantly rare, where these network structures involved coordination across multiple venues that jointly considered issues. In other words, the emergence of new issues heralded new actors and forums, but these operated independently and did not align with other parts of the system. The strongest increase in coordination was seen for motifs that did not fully incorporate all types of nodes. This pattern of "delinked" coordination was corroborated by the significant overrepresentation of motif *'p'*, where actors were failing to coordinate across venues with jurisdiction over interdependent issues.

In summary, while the regime appears to have become more polycentric over time, its overall complexity has masked important internal changes – changes which are highlighted by this building blocks analysis. In essence, the GBR has experienced over time the emergence of coordination around new issues and venues, with the new venues coordinating policy decisions but not fully considering independencies with other parts of the system. This result concurs with previously published and expert knowledge of the real-world system. The GBR Ministerial Forum (in both its previous iteration as a ministerial forum and its current iteration as a working relationship between two environment ministers) has continued as the formal host of the key venue since 1979, coordinating key stakeholders including the national and state governments, the delegated marine park authority, and nongovernment interests representing science, conservation, tourism, agriculture, and fishing groups at multiple levels (Craik, 2017; Day, 2017). By 2015, however, a shadow venue had re-emerged (the World Heritage Committee) in response to a new issue (development control), and actor competition (or lack of coordination across venues) became common, despite the interdependent nature of the issues being addressed by the two venues (Morrison, 2017). Some actors participated in the new venue but did not bring along other actors with whom they were previously coordinating.

This underlying pattern is further illuminated when considering how actors with high stakes in issues began to rely less on venue representatives after 1980. Actors did not let high stakes in issues steer their venue engagement as strongly as they did in 1980. In 1980 and 2000, any actor with a high-stake interest in an issue never relied on representative venue participation (*j*) and they often engaged in a closed actor-venue-issue triangle (*k*) – this was a pattern that deviated significantly from the baseline assumption in 1980 for both *'k'* and *'j'*. By 2000, venue membership had become so common that zero instances of *'j'* and multiple instances of *'k'* did not significantly deviate from the baseline. Conversely, actors of 1980 (and to some extent 2000) who did not have a strong interest in a particular issue relied more on venue representation – a feature that was less prominent in later years when being part of a venue became more important in and of itself. The importance of venues in and of itself (as opposed to high stakes in issues guiding venue participation) is reflected in 2015 when actors with strong interests in issues failed to participate in the relevant venues (noting that the several occurrences of *'j'* were not significantly different from the baseline).

The building blocks analysis also highlights the risks of venue-centered governance for overall polycentric capacity, and the importance of a substrate of interdependent venues and actors over time. For example, the period of functional navel-gazing that characterized the 2000s saw venues become more important than issues in steering behaviors over time. As the venue became more important, coordination suffered. As documented elsewhere (Morrison, 2017), tensions between actors and capacity constraints also caused an alternative venue to emerge out of the shadows. After the shadow venue emerged, venue membership itself became even more important than before, a tendency that is revealed by the lack of coordination between actors, venues, and high-stake issues (*'k'* is precisely as common as would be expected by pure chance in 2015, whereas it was well on the upper [right] side of the random distribution in 1980 and 2000, albeit not statistically significant in the latter period). The increased importance of venue membership also reflects the significant overrepresentation of loosely coordinated cross-venue relations (*'p'*), as discussed above. While this development might appear destructive, the fact that coordi-

nation across venues did occur during this period ('e' > 0; GB coordinates across venues with NG, IF, UN, EN, and SM) meant that there was still potential to bring actors back closer together (and/or bring some issues more clearly back in) in the future.

Again, these results concur with previously published and expert knowledge of the broader real-world system, which is characterized by a history of high social capital and influential actors (Marshall et al., 2011; Morrison, 2014). Indeed, while outside the time period of this analysis, ongoing relations between members of the Reef 2050 Advisory Committee and the Independent Expert Panel, which convened in late 2015 in response to the issues raised in the 2014 GBR Outlook Report, are evidence of this ongoing substrate of interdependent and influential actors, and the critical role they continue to play (DAWE, 2022). While these actors cannot be technically considered to have formal decision-making power as per our definition in Box 1, they are clear evidence of emerging venues with more informal powers (as per Morrison et al., 2019).

DISCUSSION

The success of polycentric governance is dependent upon how well actors can overcome numerous and interlinked collective action challenges (Berardo & Scholz, 2010; Ostrom, 2010). The escalating challenges of the Anthropocene require both horizontal coordination of resources and information across ecologically and socially diverse landscapes, and cross-level, vertical coordination from local to global levels of policymaking (Hamilton & Lubell, 2019; Howlett & Rayner, 2007; Peters, 2015; Schaffrin et al., 2015; Tosun & Lang, 2017). The complex, inequitable, and often contentious settings in which such coordination must occur in turn require organization and cooperation among heterogenous stakeholder groups (Hamilton et al., 2021; Hedlund et al., 2020; McGinnis, 2011). Our approach advances understanding and practice of polycentric governance by (1) isolating the effects of venues on coordination in a polycentric system, and (2) furthering the development of explicit, quantitative measures of how coordinative structures evolve over time.

First, we have shown how venue mobilization can be seen as a reaction to conflict as coalitions of actors mobilize different institutions to pursue their preferred policies (Baumgartner & Jones, 1991). However, while mobilization of shadow venues has improved issue specialization and actor participation over time, the system's overall capacity to resolve conflict and adapt to new problems has weakened. Indeed, the results show that venue coordination of issues is rarer than venue coordination of actors, implying that actor coordination may feature lower transaction costs than the institutional change required to respond to new issues by creating new or changing existing venues (Metz et al., 2020). The evolution of polycentric governance thus exhibits a tension between venue formation to pursue the interests of advocacy coalitions, versus increased institutional fit through alignment of venue participation and jurisdiction with social-ecological interdependencies. Failure to anticipate and attend to these tensions can affect system performance.

Second, our analysis bridges policy process scholarship and the environmental governance literature to provide a first-cut methodology to assess and measure coordination comparatively and longitudinally. The building blocks visualize how actors confronting social-ecological problems must navigate a multitude of decisions, including whether to engage with other actors, venues, and issues. These decisions are influenced by various social and political processes, ranging from motivations to fulfill basic individual social-psychological values and desires through to efforts to minimize social tensions or maximize problem-solving capacity for a collective action problem (Nohrstedt & Bodin, 2019). While the observed motifs do not capture everything, they offer measurable structural fingerprints and practical ideas for shaping the key social and political processes of coordination. They also potentially offer new insight into remaining key questions of complexity, self-interest, and conflict and power in polycentric systems.

Our study system is relatively small by comparison to other polycentric networks (e.g., see McLaughlin et al., 2022), with only a few venues, and its rate of change over four decades has been relatively slow (Datta et al., 2022). Its characteristics make it suitable as a first case study and proof of concept of the value of the methods developed in this manuscript. However, it is also important to note that larger, more rapidly changing systems may incorporate additional complexities. Indeed, there are additional "forces" in larger and more dynamic polycentric systems that we have not been able to work into this two-dimensional space. One is the expansion or contraction of the system over time and the role of redundancy (an essential element of polycentric theory) and its effect on functional quality. Another is the tendency for specialization versus generalization—do actors and venues tend to focus on one issue at a time, or try to deal with many linked issues? Empirically, we have shown how over time the GBR governance system has become more complex. Figure 3 demonstrates that as the number of actors, venues, and issues increases over time, the theoretically possible number of interconnections increases exponentially, making it more challenging for actors to "stay connected" across a broadening set of actors, venues, and issues. There are clearly increasing tradeoffs between complexity and coordination over time, as a consequence of the emergence of a broader set of issues and more informal venues. Indeed, as actors are compelled to consider a broader range of interdependencies, transaction costs are increased and coordination becomes more challenging. Some analysts have termed this phenomenon the "Institutional Complexity Trap", warning of actor fatigue, policy stagnation, and decreased system capacity to address diverse governance challenges (Bolognesi et al., 2021).

While not within the scope of this paper, we encourage future researchers to explore more complex systems and strategies for managing these inherent trade-offs. An interesting line of inquiry is the combination of actor-centric political theory with ecological approaches for understanding a way out of the complexity trap. Recent organizational ecology scholarship on organizational niches, legitimation, and competition (Abbott et al., 2016), for example, could explain why some combinations of actors and venues are able to build legitimacy and effect system change in complex settings. Isolating those building blocks that build and enable the system-wide capacity required to solve the complex problem of climate change could be a game-changer for the long-term sustainability of polycentric systems like the Great Barrier Reef. Additional challenges include understanding diverse motivations, relationships and power dynamics in polycentric systems, as set out below:

Polycentric actor motivations

Polycentric systems adjust over time in response to new issues, the discovery of new connections between issues, or actor dissatisfaction with the status quo (Lubell & Robbins, 2021; Morrison, 2017). But as new actors and new venues emerge, the question becomes about how coordination continues—do actors continue to work together across separate venues, or do institutional rules achieve new coordination by expanding jurisdictions or creating administrative rules that link venues? It may be that top-down coordination is harder (with higher transaction costs) and therefore rarer; thus, it is far easier to have actors engaging in bottom-up coordination (Metz et al., 2020). It may also be that the rush to develop and join new formal venues can undermine the momentum and reason for developing those venues in the first place. However, coordination among heterogeneous actors is also rare and difficult – previous studies confirm that actors tend to collaborate mostly within their respective policy silos and homophily prevails (Lubell et al., 2016). More work is needed to understand whether this tendency is due to higher transaction costs or merely that actors privilege the priorities of their social network rather than the priorities of the venue (Morrison, 2007; Nohrstedt & Bodin, 2019). Indeed, some may want to problem-solve, others may follow obstructionist goals (participation in venues and creation of new venues to block or delay decision-making) (Bolognesi & Nahrath, 2020). Capturing the motivations and interests of actors participating in venues is critical to interrogating the assumption behind the core tenet that institutions reduce transaction costs.

Relationships of conflict and power across polycentric venues

Further work is also needed to understand power and conflict dynamics, for example through translating our building blocks into "signed graphs" that explicate positive or negative values on ties corresponding to collaborative and antagonistic types of relationships (Tang et al., 2016). A link in a building block, for example, could not only reflect two actors coordinating outside a venue and collectively engaged in policy-making in that venue; it could also reflect two actors in conflict outside of a venue seeking to negotiate an agreement in a venue (Bodin et al., 2020). Indeed, polycentric governing arrangements combine distributed power with coordination across various decision-making venues, these power arrangements are neither static nor conflict-free (Jenkins-Smith et al., 2018; Lubell et al., 2020; Pahl-Wostl & Knieper, 2014; Weible & Heikkila, 2017). In general, further detail on different types of linkages is desperately needed to capture different types of interactions (not just coordination, conflict, information, and resource exchange but also negotiation, appropriation, rhetoric, and resistance) and the way they are infused with different usages of power (e.g., designed, pragmatic, and framing power; Morrison et al., 2019, 2020; Vantaggiato & Lubell, 2022). For example, while the Great Barrier Reef Marine Park Authority is constrained in terms of decision-making power, it still plays a major role in not only implementing public policy (e.g., through administering the Marine Park Act), but also in influencing policies for governing the GBR as a whole through the release of Outlook Reports, which are a major driver of legislative action and longer-term strategies. Similar observations can be made for the Reef 2050 Advisory Committee and the Independent Expert Panel, which formed in late 2015 at the end of our period of analysis. More work needs to be done to capture these different types of relationships and diverse ways of wielding power in polycentric systems. We encourage future researchers to explore more nuanced analysis of polycentric relationships and venues (including more inclusive sets of emerging venues with more informal relationships and powers) as fruitful lines of inquiry, with reference to Morrison et al. (2019) on different types of power.

Finally, it is important to reflect on the several challenges and limitations of a building blocks approach. The approach is demanding in terms of data, time, and modeling expertise. We also acknowledge limitations with our statistical analysis (CUG) in that motif interdependencies are not fully accounted for, and the applied baseline (null) model is hardly ever observed in real world settings. We encourage future studies to address these limitations, for example by utilizing and building on recent advances in multilevel ERGM. New techniques in complexity science, organizational ecology, science and technology studies, and evolutionary psychology (such as agent-based modeling and dynamic statistical network modeling) also have the potential to provide further insight and provide a way to empirically assess processes (and associated functions) that themselves are often hard (or maybe even impossible) to measure directly (Abbott et al., 2016; Bernstein & Hoffmann, 2019; Gerrits & Marks, 2017; Morin et al., 2017; Orach et al., 2020; Schlüter et al., 2019; Spaargaren, 2011). Scholars interested in these approaches should be careful to specify the boundaries of their case, and it may be necessary to "essentialize" the number of nodes and ties in a network, as we have done to focus on high-level actors and venues.

By focusing on governance actors, venues, issues, and coordination we were able to limit the numbers of nodes and links in the networks to a manageable number. While it could be argued that this simplification reduces the power of the analysis to find significant deviations from an assumed null model, we found that it eased the contextual interpretability of the analytical results and thus served as a better test of the building-blocks approach. Such delineation and abstraction should be justified and clearly communicated. We acknowledge that bounding the research in this way constrains what can be learned from the data, and we wholeheartedly encourage future researchers to undertake a more comprehensive network analysis of this regime for alternative future purposes, especially focusing on the changing relationships and powers of the different actors to make decisions as well as to shape and implement them.

Indeed, identifying building blocks in this way involves a necessary reductionism that potentially misses more holistic insights into other fundamental properties of complex governance systems, such as context and embeddedness. Such reductionism is not intended as a substitute to in-depth and discursive knowledge of single case studies or constructivist approaches, but rather as a parallel and complementary

approach. We recommend that deep case knowledge is necessary to make sense of the quantitative results and interpret the building blocks in a meaningful way. Qualitative approaches are often better at explaining the underlying individual social and political processes that drive network structures. For example, our deep case study knowledge of the GBR allowed us to interpret the changing building blocks in the context of changing issues and interest groups, their institutional choices and their conflictual, competitive and power-laden interrelations. In other words, we were able to reveal not just that institutional change was delinked from the system, but why (e.g., because new powerful interest groups were pursuing different goals). Combining quantitative measurement of coordination with more qualitative and discursive techniques (such as expert assessment and ethnographic and interpretive techniques) will thus remain critical to understanding polycentric governance and improving its capacity to resolve conflict and adapt to new problems.

CONCLUSIONS

Polycentric governance of the Great Barrier Reef is an ongoing project. By March 2022, corals had bleached again for the fourth time in 7 years, reinforcing ongoing anxiety about the ecosystem's future capacity to recover before yet another bleaching event (GBRMPA et al., 2022). By January 2023, the World Heritage Committee was still undecided about whether to list the ecosystem as 'In Danger' on the basis of severe coral bleaching, poor water quality and broader delays on climate action (UNESCO, 2022b). Improving the sustainability of such complex and critical ecosystems continues to require a high level of coordination. But many polycentric regimes remain paralyzed by specialized policy issues and interest groups.

In this paper, we have deconstructed polycentricity into a set of core building blocks that capture typical interactions among governance actors, decision-making venues, and policy issues (while acknowledging this initial set could and should be further scrutinized and expanded). We have used these building blocks to measure critical dynamics of polycentric governance, such as coordination among actors, venues, and issues, in a relatively small and slowly-changing governance network. We have shown how the mobilization of new venues can improve issue specialization and actor participation, but also weaken overall capacity to resolve conflict and adapt to new problems. In doing so, we have shown how micro- and meso-level changes can shape system functioning in ways that correspond with, rather than contradict, previous qualitative analyses. Our approach suggests a way to move polycentric governance understanding and practice beyond particularized or abstract notions of governance complexity, toward more rigorous theoretical development, and meaningful policy practice. Future mixed methods and comparative research, extending our building-blocks approach, will be critical to deeper understandings of polycentric governance and ultimately smarter efforts at sustainability and climate policy reform.

AUTHOR CONTRIBUTIONS

Tiffany H. Morrison, Örjan Bodin, Graeme S. Cumming, Mark Lubell, Ralf Seppelt, and Christopher M. Weible conceived the idea, lead the study design, and contributed analytic concepts and ideas. Tiffany H. Morrison, Örjan Bodin, and Tim Seppelt collected, collated, and analyzed the qualitative and quantitative data. All authors drafted, reviewed, and edited the paper.

ACKNOWLEDGMENTS

This work was supported by the US National Socio-Environmental Synthesis Center (SESYNC) under funding received from the National Science Foundation DBI-1639145, the Australian Research Council under funding received from the Australian Research Council (ARC) Discovery Program DP220103921 and the Swedish Research Council FORMAS through grant 2020-01551.

CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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ENDNOTE

[1] One of the confusing things about studying polycentric governing systems that we try to clarify in Box 1 and reiterate here is that decision-making venues can be (but are not always) both the setting that governance actors participate in to influence the system and – yet – those same venues can also act as governance actors. For example, a government bureaucracy serves as a decision-making venue in rulemaking and acts as a governance actor in a different decision-making venue, perhaps hosted by another government bureaucracy. Part of the confusion is the tendency for the field of policy studies to combine individual and organizational entities into one category. More to the point, both decision –making venues and actors can have "agency" and, thus, can coordinate, which is important when interpreting the patterns in Figure 1.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Morrison, Tiffany H., Örjan Bodin, Graeme S. Cumming, Mark Lubell, Ralf Seppelt, Tim Seppelt, and Christopher M. Weible. 2023. Building blocks of polycentric governance. *Policy Studies Journal*, 00, 1–25. https://doi.org/10.1111/psj.12492