



Evolving polycentric governance of the Great Barrier Reef

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A growing field of sustainability science examines how environments are transformed through polycentric governance. However, many studies are only snapshot analyses of the initial design or the emergent structure of polycentric regimes. There is less systematic analysis of the longitudinal robustness of polycentric regimes. The problem of robustness is approached by focusing not only on the structure of a regime but also on its context and effectiveness. These dimensions are examined through a longitudinal analysis of the Great Barrier Reef (GBR) governance regime, drawing on in-depth interviews and demographic, economic, and employment data, as well as organizational records and participant observation. Between 1975 and 2011, the GBR regime evolved into a robust polycentric structure as evident in an established set of multiactor, multilevel arrangements addressing marine, terrestrial, and global threats. However, from 2005 onward, multiscale drivers precipitated at least 10 types of regime change, ranging from contextual change that encouraged regime drift to deliberate changes that threatened regime conversion. More recently, regime realignment also has occurred in response to steering by international organizations and shocks such as the 2016 mass coral-bleaching event. The results show that structural density and stability in a governance regime can coexist with major changes in that regime's context and effectiveness. Clear analysis of the vulnerability of polycentric governance to both diminishing effectiveness and the masking effects of increasing complexity provides sustainability science and governance actors with a stronger basis to understand and respond to regime change.

environmental governance | polycentric governance | robustness | networks | climate change

Public good problems, such as refugee settlement, megalopolis growth management, and global climate mitigation, are typically complex, uncertain, and multiscale. Economies of scale and singular institutional solutions (whether public, collective, private, or decentralized) do not solve such problems successfully, indicating the need for a multiscale or polycentric governance approach (1, 2). A polycentric governance regime is characterized by multiple governing authorities not necessarily related to each other and functioning as a set of independent, interacting actors (1, 3, 4). These complex networks of state, substate, and nonstate actors organize their relationships with one another through both bottom-up and top-down processes of social learning and mutual adjustment to generate and achieve shared goals unique to that particular situation (4–6). This study investigates the assumption that a polycentric regime will remain robust over time; that is, that a regime will be capable of adapting longitudinally while still maintaining alignment with shared regime goals (7). It approaches the problem of long-term robustness by focusing not only on the structural density and stability of a given regime (determined by the complexity of key actors and instruments) but also on the broader context and underpinning effectiveness of a regime (8). “Regime context” in this paper is broadly understood as comprising the geographic, environmental, economic, and political drivers that shape the relative priorities and influence of key institutions and actors over time (9–11). “Regime effectiveness” is defined as the

authority and ability of actors and instruments to achieve regime goals and respond to emergent problems (Fig. 1) (12, 13).

The long-term robustness of large-scale polycentric governance systems is of central importance to key themes of sustainability science and is especially applicable to our understanding of the adaptability, vulnerability, and resilience of human–environment systems and of society's role in guiding these toward sustainability (14). However, in its treatment of socioecological systems (SESs), sustainability science literature has said little about the role of polycentric governance in regulating SES behavior. A review of the 662 sustainability science articles published in PNAS, for example, finds only 11 referring to polycentric or polycentrism in their texts. Nevertheless, the popularity of polycentric governance—as an analytical lens and as a key principle for promoting regime robustness—has risen sharply in the past decade (3, 15–18).

The theory behind polycentrism is now well-established. Because of the suitability of polycentric governance for dealing with complex environmental problems at multiple scales, the polycentric model has gained traction in environmental resilience and adaptation studies (17). These studies have bridged the separate and sophisticated literature on the commons (4), global governance (5), resilience (19), policy networks (20), and advocacy coalitions (21). We now understand, for instance, that the gamut of polycentricism runs from weak coordination to strong polycentric structures (19). Further, true polycentric regimes combine the distribution of power with effective coordination among various centers of authority and across levels (22). Although polycentric systems have documented disadvantages, including leakages, redundancy, free-riding, high transaction costs, and complex accountability (23), they also have many advantages. In particular, polycentric structures are advantageous in creating institutional density in a system, which is believed to create a high level of resilience to external stresses and shocks (17, 19).

Significance

Global sustainability depends on robust environmental governance regimes. An investigation of the Great Barrier Reef regime between 1975 and 2016 reveals how complex environmental regimes become increasingly structurally dense and eventually reach a point of stabilization. However, structural complexity and stability alone do not necessarily mean the system is robust. Instead, a complex but stable structure can mask exogenous change, which then can generate more endogenous change; this phenomenon has implications for the environmental outcomes of complex regimes. Therefore, it is vital to anticipate and account for change in designing, implementing, and evaluating sustainable environmental governance.

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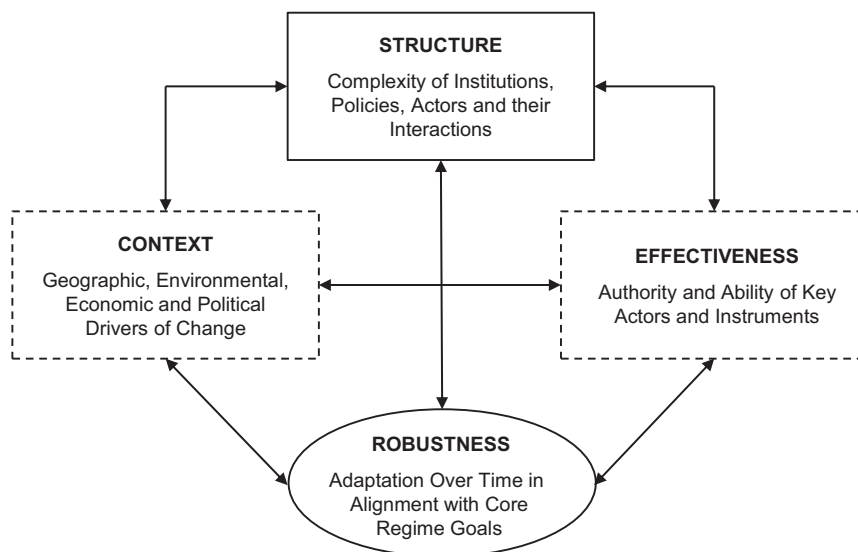


Fig. 1. Robust polycentric governance of SESs is a function of structure, context, and effectiveness. Most studies of polycentric governance concentrate on governance structure. A critical challenge in empirical approaches is to internalize context and effectiveness in understanding SESs.

However, although huge strides are being made in understanding polycentric environmental governance, the field is still considered new, with many unanswered questions and unexplained assumptions (24, 25). Specifically, very little work has interrogated the actual long-term robustness of polycentric environmental governance regimes. Even the best examples of polycentric governance are struggling with how best to monitor and improve ecosystem health. Take the example of Australia's Great Barrier Reef (GBR), which suffered extensive coral bleaching in 2016 (26). The GBR regime is widely regarded as one of the most successful environmental governance systems in the world (27). The regime is characterized by a polycentric arrangement that has evolved since 1975 through public participation, cooperative state (Queensland) and national (Australian) law, international oversight, and a variety of other multilevel relationships. These arrangements involve knowledge sharing, formal and informal partnerships, joint projects, and joint rules (28, 29). The regime is regarded as a pioneer in the governance of iconic ecosystems (30). Today, however, its state-of-the-art polycentric governance system is struggling to improve outcomes for this important ecosystem.

This article addresses one of the most significant assumptions of polycentric environmental governance—that a polycentric regime will remain robust over time—and implicitly tests the assumed relationship between structure and robustness to highlight the importance of paying far more attention to the context and effectiveness of governance regimes in SES studies. Polycentric governance is assumed to be more robust because of the advantages of greater popular support, reduced risk of regulatory capture, local experimentation, multiscale fit, and multiple checks and balances (4, 19). Many of these advantages are the product of structural density in a system, and thus many studies have focused on how structural considerations (e.g., networks, scale-bridging, and coordination) can be enhanced to improve robustness and thereby improve environmental outcomes (20, 23). However, the additional influence of context and effectiveness on robustness over time is less understood. Therefore the focus here is to extend understandings of robustness longitudinally by accounting not only for structure but also for context and effectiveness in polycentric environmental governance regimes. Although the case of the GBR regime is used as an example, emerging research in sustainability science suggests the same

need to attend to context and effectiveness in governance of the commons and climate change (10, 31, 32). In addressing this theme, the primary purpose of this paper is to build sustainability science in ways that treat context and effectiveness as endogenous to SES systems and thereby to improve environmental outcomes.

A typology of regime robustness and change was initially developed from the existing policy and sustainability sciences literature (6, 7, 12, 21, 33, 34). Polycentric regime development and change then was investigated through a longitudinal case study of the GBR. Its globally iconic governance regime was delineated according to the extensive set of arrangements encompassing not only management within the GBR Marine Park but also regional land-based water-quality and global climate-change governance. The goals, structure, context, and effectiveness of the regime were studied by initially cataloguing the regime and then undertaking stakeholder interviews, key informant interviews, participant observation, and documentary review. Documentary material ($n = 231$) included all inquiries, reviews, reports, assessments, and audits of different aspects of the regime commissioned in 1975 and up until 2016 by global, national, state, and regional agencies. To supplement qualitative analysis of the broader context, demographic, economic, and employment data also were extracted from these documents, enabling process-tracing of the changing Australian coal price [expressed in Australian dollars (AUD\$)] in 1975–2015 (35), the changing Australian budget cash balance as percent of gross domestic product (GDP) from 1975–2015 (36), and the changing Great Barrier Reef Marine Park Authority (GBRMPA) budget and number of employees from 1976–2015 (37). In-depth confidential interviews ($n = 32$) were held with key informants and a stratified set of individuals from the national and state governments, the GBRMPA, industry bodies, local and international environmental nongovernment organizations (ENGOs), environmental law firms, and research institutes. Interviews addressed changes to reef governance over time and how these changes related to context, structure, and effectiveness. Developments throughout this time were assessed to reveal differential impacts for structure and effectiveness. Then further analysis was undertaken to explain how the different types of change resulted in different polycentric regime outcomes. Participant observation also was undertaken at government and scientific meetings ($n = 7$) to confirm and supplement the analysis (Fig. S1).

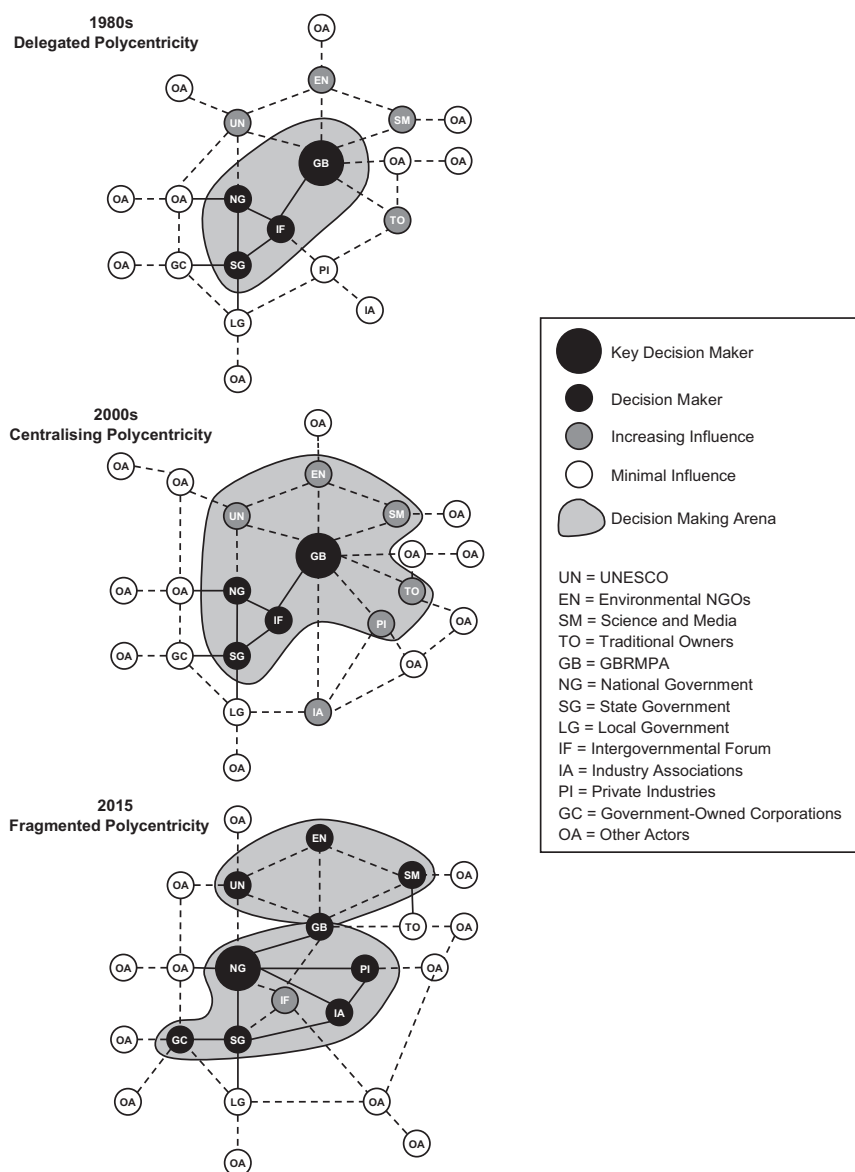


Fig. 2. Conceptual representation of changing regime structures. In the early years, the statutory agency model effectively delegated responsibility for GBR policy and governance to the GBRMPA. Over time, the regime evolved into a more dense polycentric structure, evident in a variety of multiactor multilevel arrangements. (The abbreviations used in the figure are defined in the legend in the figure.) Key national government agencies and departments include the Australian Department of Environment, Australian Maritime Safety Authority (Commonwealth Department of Transport), Australian Fisheries Management Authority, and Quarantine. At the state level, Queensland government agencies include the Queensland Department of Environment, Parks and Wildlife Service, Premiers Department, Department of State Development, Queensland Fisheries Management Authority, Queensland Boating and Fisheries Patrol, and Department of Primary Industries. Important nongovernment actors include Indigenous Peoples groups, local marine advisory committees, scientists, natural resource management groups, NGOs, the media, and industry associations at international, national, and local levels. By 2015, the polycentric governance of the GBR had fragmented into two layers, as evidenced by light steering at the international scale and recentralization at the national scale. Although informative, these models are only indicative and do not account for the changing conditions in which actors interact, such as new venues of interaction such as the courts and the United Nations Framework Convention on Climate Change Conferences of the Parties, which also can substantially influence regime structure.

Results

The Production of a Polycentric Governance Regime. The GBR is the largest coral reef ecosystem in the world, covering around 348,000 km² (approximately the size of Italy or Japan). The GBR generates more than AUD\$5.2 billion in reef tourism and AUD\$500 million in recreation and commercial fishing annually (38). The land area that drains into the GBR is ~468,000 km² and is dominated by mining, agricultural, and, increasingly, urban uses. More than 1.1 million people live in the wider GBR catchment, and 40% growth is expected by 2031. The traditional owners,

the Aboriginal and Torres Strait Islander people, also maintain strong connections with the environment. The GBR is a highly informative case study for understanding generational regime change as it has evolved over the last 40 y, now assuming a relatively polycentric and outwardly stable state (Fig. 2).

A documentary review was undertaken of all inquiries, reviews, reports, assessments, and audits of different aspects of the regime commissioned 1975–2016 by global, national, state, and regional agencies ($n = 231$). The review revealed that the GBR demonstrated a typical pattern of regime development, beginning with de

agencies and departments and nongovernment groups at international, national, and local levels. The management of the GBR received international acclaim, with the rezoning process receiving 19 international, national, and local awards.

Between 1975 and 2004, the regime expanded as new policies, laws, and practices were created and implemented. From the mid-2000s onward, however, the structural stability in the governance regime began to mask major changes in the regime's context and effectiveness (Fig. 3 and Table S1). These changes occurred in two distinct phases.

Multiscale Drivers Precipitate Regime Drift. An unprecedented boom in industrialization and urbanization in the wider GBR catchment characterized the first phase, with a near doubling of shipping exports combined with high population growth (Fig. 4). At the height of this boom, the state government approved four new gas refineries in one section of the GBR. In addition, a significant portion of Australia's coal and gas outputs were either extracted from the GBR catchment and/or transported through it. These developments brought about major new stressors for the GBR and radically increased the enforcement, assessment, and stakeholder management costs for the GBRMPA and other associated agencies. At the same time, political and industry backlash against the 2004 Reef rezoning generated a national election commitment to review the GBRMP Act 1975 and the GBRMPA itself against a broader review of all statutory authorities in Australia (Fig. 3 and Table S1). The recommendations were substantial; they included the introduction of new 5-year Outlook Reports and the transfer of powers to manage finances and develop policy (including rezoning and structural adjustment policy) for the GBR from the GBRMPA Board to the national environment minister. A further recommendation to separate the positions of Chair and CEO was never applied, thereby maintaining the responsibility of a single individual for the GBRMPA's overall strategic direction, governance, and organizational management. As a result, control and oversight by the national environment minister increased, and the ability of the Board (appointed by joint agreement between both state and national governments)

to act or be an objective critic of the Chair and CEO (appointed by the national environment minister) became constrained.

Interviewees identified that after the 2004 rezoning there was very little additional resourcing, updating, or strengthening of institutional arrangements. Planning, management, and assessment (e.g., as evidenced by the environmental assessment process) remained focused on the impacts of individual developments (e.g., ports, acute shipping, or urban pollution incidents) rather than on the cumulative effects of a chronic increase in shipping, climate change, and urban development. There was reluctance, shared by the GBRMPA and the national environment department, to use relevant tools (e.g., Special Management Areas, Section 662e of the GBRMP Act 1975) to manage activities that fell outside the bounds of the marine park. Government revenue from the expanding mining and ports industries was not directed toward the GBR, and the GBRMPA remained reliant on a diminishing tourism tax to compensate for industry impacts (Fig. 5). Interviewees also stated that industry permit applications did not reflect contemporary knowledge of threats and that there were more frequent incidents of illegal fishing.

In the latter part of the first phase, the AAA credit rating of the state and national governments was downgraded as a result of the 2007–2008 global financial crisis. This downgrading was accompanied by public spending cuts (Fig. 3 and Table S1). The events stimulated internal restructuring within the GBRMPA, doubling the number of managers. Interviewees stated that this restructuring further reduced staff interaction with the Board. The GBRMPA's collaborative networks with interest groups (e.g., science, tourism, and fishing through the GBR Consultative Committee) were also progressively wound back from the zenith of public participation that had been reached at the time of the rezoning. In 2011, as part of a new Ministerial Council system, the Great Barrier Reef Ministerial Council was discontinued as a formal Australian Governments Council (CoAG). Although the Council reemerged as an informal ministerial forum (with representation comprising the national and state environment ministers), this change further accentuated the role of the national environment

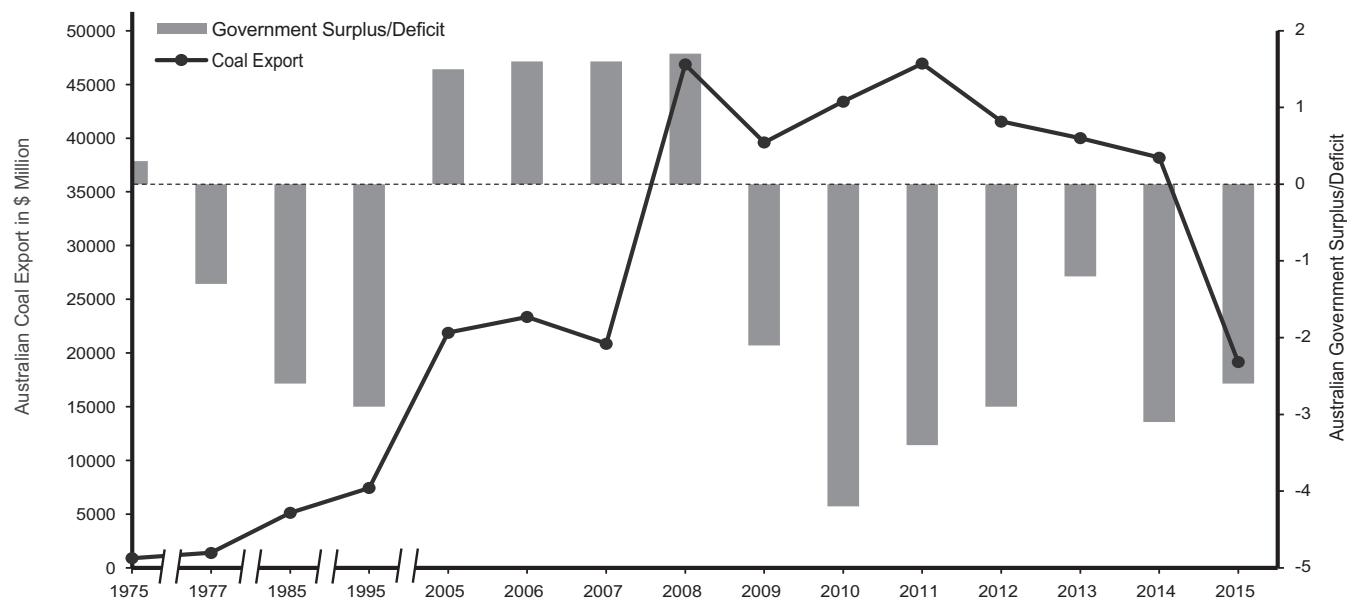


Fig. 4. Multiscale drivers of change. In 2004, an unprecedented coal boom commenced in Australia, fueled by economic growth in China and India. In 2008, the global financial crisis caused the AAA credit rating for Queensland and Australia to be downgraded, triggering public spending cuts. Both Queensland and Australia were increasingly dependent on the coal industry to avoid recession. In 2011, the boom ended altogether, accompanied by more public spending cuts. The coal industry successfully campaigned for environmental deregulation to maintain profit levels. Economic drivers of change substantially influenced public and private actor goals and dynamics.

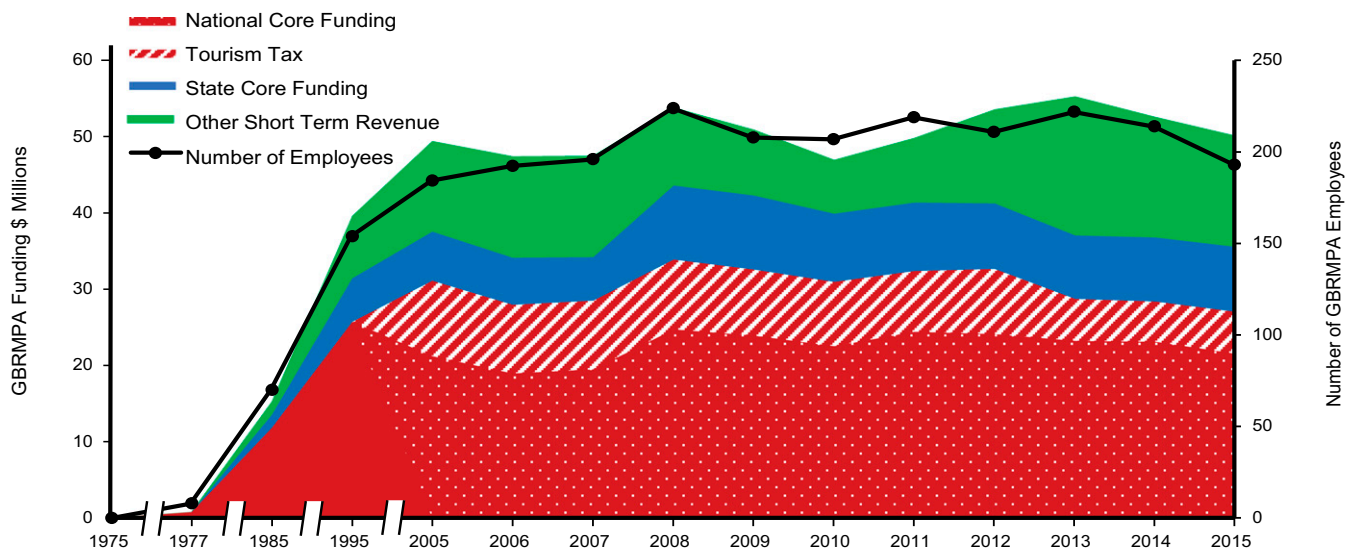


Fig. 5. Stabilization of core agency revenue and employment. When an existing regime (as exemplified here by the core agency, the GBRMPA) remains constant in the face of a major contextual shift, incremental changes can still occur. Such changes can facilitate regime drift. The stability of the core agency can inadvertently mask regime drift.

minister. Despite these changes, the GBRMPA, along with the national and state governments, continued to assert that a sound system of governance, stakeholder engagement, and other management processes were in place (39).

Structural Stability Combined with Further Regime Change. A second contextual phase-shift occurred in 2012 when a large international ENGO, the UNESCO World Heritage Committee (WHC), expressed extreme concern about proposed developments and so undertook a reactive monitoring mission to assess these threats. The Committee concluded that the GBR could be placed on the World Heritage In Danger List unless the Australian government ensured its proper management and protection. In response to these concerns, the GBRMPA and the national and state governments started a comprehensive strategic assessment. This assessment became the basis for the development of a 2050 Plan for the GBR. During this period, a political shift to the right occurred at both state (2012) and national (2013) levels, with both new governments inheriting a budget deficit. The combined political change and budget deficit precipitated a second series of staff and funding cutbacks for most management agencies associated with regime implementation. Funding for the GBRMPA also plateaued, and the agency became more reliant on short-term funding when addressing the significant new stressors for the GBR.

As the mining boom slowed and resource prices plummeted, applications for the expansion of land clearing, ports, and shipping routes increased. Mining and shipping advocacy coalitions became far more vocal in asserting that regulatory processes and ENGOs were stalling development and affecting the job market. They increased their campaign for environmental deregulation to maintain growth trajectories and employment levels. During this time, both the Queensland and Australian governments made new appointments to the GBRMPA Board. These appointments were publicly criticized as favoring mining interests over other matters but were upheld, thereby influencing public perception of the legitimacy of the Board.

At the national level, a new Offsets Policy was introduced by changing the provisions in the 1999 EPBC Act. The policy claimed to streamline development approvals by requiring developers to undertake compensatory actions for the negative environmental impacts of their development. Those granted

approval by the Department of Environment for developments on the GBR were required to make an offset payment into the new Reef Trust (also administered by the Department of Environment) to supplement the funding of catchment-wide actions to improve water quality. No mechanisms were developed to minimize the potential for undue industry influence in this arrangement; therefore the development approval agency (the Department of Environment) also became the recipient of significant development compensation funds from industry. The creation of the AUD\$40M Reef Trust also resulted in an AUD\$2.8M reduction from the 2014 federal allocation to the GBRMPA. Offsets and net benefit concepts came to underpin the 2050 Plan.

In 2013, the updated Reef Plan was released, citing continued positive progress toward targets but also guided by scientific advice that poor water quality was continuing to have a detrimental effect on reef health. However, the new state environment minister was criticized for failing to enforce the Great Barrier Reef Protection Amendment Act 2009 (which sought to control diffuse-source pollution from farming in the GBR catchment) and pursuing voluntary industry self-regulation instead. A number of other acts that promoted sustainable coasts and catchments were either repealed or amended to facilitate development. New planning provisions also were introduced to permit dredging below the high-water mark to allow economic development and to permit development of urban areas, tourism, ports and airports, aquaculture, and other activities in areas of high ecological significance. In addition, a series of actions dismantling national climate policy were launched, culminating in the 2014 repeal of the carbon price and Emissions Trading Scheme. The disbandment of the Department of Climate Change and other cuts to many environmental and climate-related programs and research followed, including cuts to programs relating to renewable energy. The state and national governments jointly proposed legislation to devolve national environmental assessment and regulatory powers to the states.

Despite UNESCO concern, further port expansion and dredging for coal export were approved by the Australian government in 2012. The disposal of dredge spoil in the GBR World Heritage Area also was approved by the GBRMPA, leading to a loss of public trust in and damage to the reputation of the GBRMPA. The approval was endorsed by the state government

in 2014. Both approvals were granted, subject to offset conditions. ENGO protests over the approval of another new coal mine (one of the largest in the world) in the GBR catchment triggered the Australian government to establish a parliamentary inquiry investigating the financial status of ENGOs. The Australian government also proposed repealing Section 487 Part 2 of the EPBC Act 1999 to restrict ENGOs from making appeals against the approval of major developments. At the same time, another major restructure and downsizing of the GBRMPA occurred, triggering the departure of many scientists on staff. The national and state governments continued to claim that a comprehensive foundation of existing legal protection and management remained firmly in place and that governments were regularly reviewing and updating legislation to ensure that new threats and issues were addressed efficiently and effectively as they arose (40, 41). Interviewees counterclaimed that the overarching goal of the regime had shifted from conservation to sustainable use.

Different Types of Change and Regime Outcomes. The typology of regime change developed from the existing literature (12, 21, 33, 34) was expanded and verified with interviewee as well as documentary and participant-observation data (Table S2).

In the early phase of regime adjustment (2004–2012), five types of low-visibility change occurred (Table S2). First, additional reporting and planning requirements (the 5-year outlook reports, strategic assessment, and long-term plan) increased the GBRMPA's knowledge of emergent problems (e.g., as a result of the boom). However, these requirements also incurred additional costs to the agency. Second, a transfer of certain agency powers to the national environment minister, the transformation of the intergovernmental oversight council into an informal body, changes to the agency board model and makeup, and internal restructuring all combined to reduce the independence of the GBRMPA. Third, the regime became increasingly dependent on short-term external funding, compared with the more secure and longer term funding available in previous phases. This change in funding security compromised the ability of many management agencies to exercise their authority comprehensively; interviewees stated that the effects included loss of corporate memory, staff burnout, problem slippage, and a reactive approach of management to problems. Fourth, the scale of impacts radically increased policy demand as the supply, updating, and strengthening of new and existing policies and arrangements began to plateau. Fifth, existing regulatory provisions came to be loosely applied in development approvals and permits; interviewees cited limited enforcement of the rezoning as well as reluctance to manage activities outside the actual bounds of the park (e.g., urban development). The management of these activities was perceived by interviewees as being outside the GBRMPA's control and too political to touch. Although there was no real effect on structure—the core management agency appeared the same, and the broader regime's agencies and policies continued to remain intact—interviewees believed that these changes weakened the effectiveness of the regime. These earlier changes corresponded with regime drift, whereby an existing regime remains constant in the face of a major contextual shift (Figs. 3 and 5) (33).

In the later phase (2012–2016), interviewees confirmed five types of more visible regime change (Table S2). First, both the national and state governments persuaded stakeholders that the EPBC Act 1999 (Commonwealth) and the GBR Strategic Assessment could be enhanced through new offsets and net benefit policies, which opened a direct path to circumvent existing provisions designed to avoid harmful development. Second, intergovernmental agreements to delegate environmental assessment to the states and reduce the capacity of ENGOs directly challenged the oversight structures and procedures provided by key actors. Third, a number of complementary policies, laws, and institutions were dismantled. Fourth, new actors emerged at the

state and international levels to provide additional oversight. Fifth, new resources were redirected to address some of the local pressures on the regime. These later changes were viewed as substantially modifying the structure and effectiveness of the regime. They were symbolic of the push and pull between regime conversion and regime realignment.

A Governance Crisis and Feedback Effects on Structure. As contextual shifts and changes to regime effectiveness occurred, the degree of decentralization within the system also changed (Fig. 2). Originally, the GBRMPA Chair and CEO, plus its Board and staff, worked in conjunction with environment groups, scientists, and local and regional stakeholders to dominate the structure of the regime. However, between 2006 and 2011, the core of the polycentric arrangement shifted away from these original and central actors toward higher level and fewer key operators, the GBRMPA Chair and CEO working in conjunction with the national environment minister (Fig. 2). By 2013, after a political shift to the right at both national and state levels, the core of the polycentric arrangement had moved even further away from the original gatekeepers of the regime toward new and much more economically and politically powerful operators: the GBRMPA Chair and CEO now working in conjunction with the national environment minister and organized industry interests (Fig. 2). This upward shift reduced the decentralized reach and plasticity of the regime and increased government control to facilitate resource development. Although the structural density appeared constant, with the national and state governments continuing to assert that the governance of the GBR was adequate, others argued that the regime was in crisis. This contention was amplified in 2015 as more political attention focused on the GBR. The attention only intensified as the UNESCO WHC deliberated over a potential In Danger listing, with increased international lobbying by big ENGOs (e.g., the World Wildlife Fund), and with the prospect of the looming state election. A new state ports strategy, which promised no new port development and no capital dredging, was devised. However, public dissatisfaction with the management of the GBR and the state government's broader administration contributed to voters' rejection of the first-term state government in early 2015. The replacement government created a new post of State Minister for the GBR, and the national government mobilized a global diplomatic effort in the foreign capitals of UNESCO WHC members to ensure that the GBR was not listed as being in danger.

These measures culminated in the UNESCO decision to not list the GBR as being in danger, pending a 2016 assessment of progress toward the newly released Reef 2050 Plan. The Australian government was required from then on to adhere to specific reporting requirements to avoid annual reporting or a future In Danger listing. The polycentric structure of the regime was both fragmented and rescaled: The GBRMPA was still the core agency in a structure that now revolved around the national environment minister and organized industry interests at the national scale and around international environment groups, scientists, and UNESCO at the international scale (Fig. 2). Interviewees noted that policy coalitions changed during this period, as international ENGOs and UNESCO reasserted themselves.

The national environment minister claimed the 2015 UNESCO decision not to list the GBR as in danger as a major political coup. This development was short-lived when, in 2016, the GBR experienced the worst climate change-induced coral bleaching event ever recorded (26). Despite scientific outcry, the Australian government successfully lobbied UNESCO to remove the GBR and other Australian sites from its draft report on World Heritage and Tourism in a Changing Climate and promised to divert AUD\$1 billion from the Clean Energy Finance Corporation to the GBR Fund to address water-quality issues and thereby enhance the resilience of the GBR to climate change. These developments

demonstrate the continued but variable evolution of the polycentric regime over time.

Discussion: Understanding the Robustness of Polycentric Environmental Governance

Regime Context and Effectiveness as Additional Influences on Regime Robustness. The results reported in this paper highlight the susceptibility of polycentric governance to multiscale drivers that stimulated at least 10 types of regime change (Table S2). Although there were some increases in effectiveness, reductions in effectiveness, both accidental and deliberate, were more pronounced over this time (12, 34). In the early phase (2004–2012), four types of accidental reductions occurred. In the later phase (2012–2016), three types of deliberate reductions occurred. These changes were both enabled and constrained by multiscale drivers (e.g., regional proximity to mineral resource extraction, regional political backlash against conservation, political change at the state and national level, and the global economic crisis). Knowledge of the susceptibility of polycentric systems to changing context and effectiveness can provide sustainability science with a strengthened basis for understanding regime robustness. The need for such knowledge suggests that sustainability science does not currently use models to understand or communicate these changes (42, 43). By fostering such knowledge, possibilities such as drift, conversion, and realignment may be proactively factored into the evaluation and adaptation of polycentric regimes rather than occurring by accident or surprise (44, 45).

The Masking Effect of Structure Within a Shifting SES Context. Application of a structure–context–effectiveness framework reveals how structural stability in a polycentric governance regime can coexist with major changes in a regime's context and effectiveness. In this case, the defining characteristic of the early change period (2004–2011) was that regime effectiveness diminished while the appearance of structural density was maintained through the consistency of core actors and arrangements. In some cases, the decline in effectiveness resulted from accidental atrophy or negligence. In others the decline occurred because successive governments at both the national and state levels made rational decisions to shift away from conservation to economic development objectives by deliberately pursuing phased and indirect reduction (Table S2). Being conscious of deep political opposition to the overt destabilization of the regime (34), this change was pursued in ways that were difficult for stakeholders to recognize or seek to reverse. Seemingly accidental reduction can be particularly damaging if it occurs with little opportunity for public scrutiny, and it also can pave the way for reducing opposition to more deliberate reduction at a later stage. The GBR case also highlights the fact that drift and conversion are masked—and even enabled—by the institutional density that is assumed to fortify and protect polycentric regimes. Indeed, drift (through blocking necessary change) and conversion (through creating new goals) are attractive tactics for multiscale interests who want to maintain the appearance of supporting environmental governance regimes while actually sidestepping the rules. The explicit preference for more deliberate reduction emerged only when the political benefits of reduction grew larger than the political costs and the political costs of the status quo were greater than the political costs of reduction. When this shift occurred, reduction became overt, and rather than engaging in blame avoidance, the reductionists began to engage in deliberate (real and symbolic) reduction as credit-claiming exercises. The repeal of the Clean Energy Act 2011 (Commonwealth), for example, became a vote-generating exercise in Australia's 2013 national election.

Responding to Shifts in Context and Effectiveness. There are important studies that categorize polycentric regimes according to

different configurations (e.g., polycentric, fragmented, centralized–coordinated, and centralized rent-seeking) at a certain point in time (19, 22). However, very little work has examined how particular polycentric regimes move between different configurations over time. The GBR case shows that regimes can change polycentric configuration temporally (Fig. 2). Indeed, by the late-2000s, after backlash against management decisions, the decision-making independence of the core actor (the GBRMPA) became considerably constrained. This phenomenon parallels a global trend whereby successive governments have outwardly appeared to enhance polycentricism through decentralized and community-based policies while actually pursuing other forms of more direct and monocentric rule (46). At the same time, informal and formal power relations both within and outside the regime shifted, accompanied by a fragmentation of the regime and additional problems of coordination and regulatory capture (Fig. 2). Not until 2012 did relatively dormant international actors, including international NGOs and the WHC, step in to play a higher level coordinating role. These dormant caretakers used capacities and strategies very different from those involved in de novo policy innovation and institutional design. They also were composed of more than simply the usual assemblage of local and regional stakeholders, who are often the target of institutional design rules. These coalitions comprised thick and highly connected networks of international actors with the organizational ability to monitor the entire multiscale regime over the long term (Fig. 2). They sought to resist drift by ensuring that the regime was updated to reflect the new operating environment and to correct conversion by ensuring that the regime was realigned with its core goals. Detailed consideration of changes to regime structure and regime context and effectiveness was central to their approach (Fig. 1). The understanding of and response to these governance actors highlight that a broader definition of robustness exists in practice and includes notions of independence (of the core agency from politics and exogenous pressure), implementation resources (to achieve the goals of the regime), flexibility (reassessing and updating the regime at regular points in time to reflect changes in context), consistency (with ancillary organizations and policies), full use (complete and proper application of available regime mechanisms), and oversight (empowered and independent watchdogs). Attention to these dimensions provides important insight into how actors in a polycentric regime can enhance their anticipation of and response to changing contextual circumstances (45).

Conclusions

Public good problems are complex, uncertain, and multiscale. Polycentric governance is widely hailed as the solution. This article offers evidence that a solely structural approach to design and implementation of polycentric environmental governance may be easy to catalog but is not sufficient to secure on-ground outcomes. Instead, a solely structural approach tends to overestimate the progress made in achieving regime goals. In this case, multiscale drivers precipitated both accidental and deliberate changes in the context and effectiveness of the regime. Accidental change, when combined with a complex but stable structure, masked regime drift and caused further and more deliberate change. This change increased the vulnerability of the regime, with significant implications for environmental outcomes. The rapid trajectory of regime drift and conversion also challenges the general assumption that structural density and internal inertia in polycentric regimes can moderate the effects of change. Therefore, it is centrally important to anticipate change in designing and implementing polycentric environmental governance.

The need for sustainability science to comprehend such change is vital, because global economic pressures and national political shifts continue to influence countries to pursue deregulation and general governmental retreat. However, many studies of large-scale polycentric governance systems remain

snapshot analyses of initial structural design success. There has been little systematic analysis of the longitudinal robustness of polycentric regimes. Clear analysis of the vulnerability of polycentric governance to both changing effectiveness and the masking effects of structure provides international sustainability science with a strengthened basis to understand complex SESs. The evolution of sustainability science thus will depend considerably on the internalization of context and effectiveness in understanding the robustness of SESs over time.

Materials and Methods

Findings are derived from the following primary data sources: documentary review ($n = 231$), in-depth, confidential interviews ($n = 22$), key-informant

interviews ($n = 10$), and participant observation ($n = 7$). Secondary economic, demographic, economic, and employment data were drawn from organizational records ($n = 77$). A detailed explanation of methods is available in *SI Materials and Methods*. See *Tables S1* and *S2* for a detailed catalog of changing GBR regime context, structure, and effectiveness over time.

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