



# Emergent sustainability in open property regimes

Mark Moritz<sup>a,1</sup>, Roy Behnke<sup>b</sup>, Christine M. Beitz<sup>c</sup>, Rebecca Bliege Bird<sup>d</sup>, Rafael Morais Chiaravalloti<sup>e</sup>, Julia K. Clark<sup>f</sup>, Stefani A. Crabtree<sup>d</sup>, Sean S. Downey<sup>a</sup>, Ian M. Hamilton<sup>g,h</sup>, Sui Chian Phang<sup>g</sup>, Paul Scholte<sup>i</sup>, and James A. Wilson<sup>j</sup>

Edited by Bonnie J. McCay, Stockton, NJ, and approved November 1, 2018 (received for review August 27, 2018)

**Current theoretical models of the commons assert that common-pool resources can only be managed sustainably with clearly defined boundaries around both communities and the resources that they use. In these theoretical models, open access inevitably leads to a tragedy of the commons. However, in many open-access systems, use of common-pool resources seems to be sustainable over the long term (i.e., current resource use does not threaten use of common-pool resources for future generations). Here, we outline the conditions that support sustainable resource use in open property regimes. We use the conceptual framework of complex adaptive systems to explain how processes within and couplings between human and natural systems can lead to the emergence of efficient, equitable, and sustainable resource use. We illustrate these dynamics in eight case studies of different social–ecological systems, including mobile pastoralism, marine and freshwater fisheries, swidden agriculture, and desert foraging. Our theoretical framework identifies eight conditions that are critical for the emergence of sustainable use of common-pool resources in open property regimes. In addition, we explain how changes in boundary conditions may push open property regimes to either common property regimes or a tragedy of the commons. Our theoretical model of emergent sustainability helps us to understand the diversity and dynamics of property regimes across a wide range of social–ecological systems and explains the enigma of open access without a tragedy. We recommend that policy interventions in such self-organizing systems should focus on managing the conditions that are critical for the emergence and persistence of sustainability.**

complex adaptive systems | coupled systems | common-pool resources | property regimes | ideal free distribution

Current theoretical models of the commons assert that common-pool resources can only be managed sustainably with clearly defined boundaries around both communities and the resources that they use (1). In these models, open access, or the failure to exclude users, inevitably leads to a tragedy of the commons due to unchecked resource use. However, in many social–ecological systems, open access does not lead to resource overuse (2–5). For example, in the Logone Floodplain of Cameroon, pastoralists have open access to common-pool grazing resources, but there is no evidence of overgrazing or rangeland degradation.

Here, individual movement decisions lead to an ideal free distribution of grazing pressure over available grazing resources (6). Multiple lines of evidence from ethnographic analysis, spatial analyses, and agent-based modeling show that this open property regime works as a self-organizing system without central or collective management of resource use and is efficient, equitable, and sustainable (7). Similar properties characterize other open-access systems, including among pastoralists in Turkmenistan (2) and foragers in the desert of Western Australia (8), in which current resource use is sustainable, because it does not

<sup>a</sup>Department of Anthropology, The Ohio State University, Columbus, OH 43210; <sup>b</sup>Department of Anthropology, University College London, WC1H 0BW London, United Kingdom; <sup>c</sup>Department of Anthropology, University of Maine, Orono, ME 04469; <sup>d</sup>Department of Anthropology, Pennsylvania State University, University Park, PA 16802; <sup>e</sup>Instituto de Pesquisas Ecológicas, 47 - 12960-000 Nazaré Paulista, Brazil; <sup>f</sup>American Center for Mongolian Studies, Philadelphia, PA 19104; <sup>g</sup>Department of Evolution, Ecology and Organismal Biology, The Ohio State University, Columbus, OH 43210; <sup>h</sup>Department of Mathematics, The Ohio State University, Columbus, OH 43210; <sup>i</sup>Développement des Espaces Economiques et Naturels Tai et Comoé, Deutsche Gesellschaft für Internationale Zusammenarbeit, BP 7172 Abidjan 01, Côte d'Ivoire; and <sup>j</sup>School of Marine Sciences, University of Maine, Orono, ME 04469

Author contributions: M.M. designed research; M.M., R.B., C.M.B., R.B.B., R.M.C., J.K.C., S.A.C., S.S.D., I.M.H., S.C.P., P.S., and J.A.W. analyzed data; and M.M., R.B., C.M.B., R.B.B., R.M.C., J.K.C., S.A.C., S.S.D., I.M.H., S.C.P., P.S., and J.A.W. wrote the paper.

The authors declare no conflict of interest.

This article is a PNAS Direct Submission.

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<sup>1</sup>To whom correspondence should be addressed. Email: [moritz.42@osu.edu](mailto:moritz.42@osu.edu).

This article contains supporting information online at [www.pnas.org/lookup/suppl/doi:10.1073/pnas.1812028115/-/DCSupplemental](http://www.pnas.org/lookup/suppl/doi:10.1073/pnas.1812028115/-/DCSupplemental).

Published online November 28, 2018.

compromise use of common-pool resources for future generations.

Here, we outline a theoretical model that describes the conditions under which sustainability emerges in open property regimes. We argue that sustainability can emerge in the absence of central or collective management as a product of the resource-use strategies of individual users—or more formally, that sustainability is an emergent property of a self-organizing complex adaptive system (7). Here, we define complex adaptive systems as systems “in which large networks of components with no central control and simple rules of operation give rise to complex collective behavior, sophisticated information processing, and adaptation via learning or evolution” (9).

Our theoretical model integrates multiple frameworks. Theories of the commons provide the terminology that we use to describe the users, governance system, resource units, and resource system as well as the overarching question of what makes social-ecological systems sustainable (1, 10). Evolutionary frameworks of behavioral ecology and niche construction enable us to generate hypotheses of individual decision making and the dynamic feedbacks between individual resource use and ecological processes, respectively (11, 12). A resilience framework explains how different configurations of resource use can result in different outcomes or property regimes (13, 14), and complexity theory helps us explain how dynamic feedback between processes in human and natural systems results in nonlinear dynamics that can make open property regimes sustainable (9, 15).

We used a transdisciplinary approach, which not only integrates and synthesizes methods and theories from different disciplines but also integrates concepts from the cultural communities that we have studied, to compare eight empirical cases from a range of social-ecological systems, identify eight critical conditions (CCs) for the emergence of sustainability in open

property regimes, and explain how changes in boundary conditions (BCs) may push open property regimes either to a tragedy of the commons or to other types of property regimes. Our empirical cases draw from a wide range of subsistence economies and ecosystems, including pastoralists in the Logone Floodplain of Cameroon (5), pastoralists in the Darkhad Depression in northern Mongolia (16), pastoralists in the Gökdepe District in Turkmenistan (2), freshwater fishers in the Pantanal wetlands of Brazil (17), shellfish gatherers in the mangrove swamps of Ecuador (3), subsistence foragers in the desert of Western Australia (8), swidden agriculturalists in Belize (18), and commercial lobster fishers in Maine (19) (Fig. 1). The case studies were selected, because they represented a wide variety of social-ecological systems that have been studied by the authors and/or other researchers for a decade (e.g., swidden agriculturalists in Belize, shellfish gatherers in Ecuador) or more (e.g., commercial lobster fishers in Maine, mobile pastoralists in Cameroon) and/or for which long-term social and ecological data were available that allowed us to develop and support our argument about the emergence of sustainability in open property regimes.

### Theoretical Model

Our integrative theoretical model offers several hypotheses predicting the conditions under which resource use is sustainable with open access to common-pool resources. Central or collective management is unlikely and open-access tenure regimes are more likely where there are few economic gains from defending exclusive use. Theory in behavioral ecology suggests that the benefits of defending exclusive access to resource patches are greater where there are high levels of exploitation competition and where resources are found in dense, discrete, and predictable patches in both time and space (20). However, when the spatio-temporal distribution of resources is highly variable, sustainable

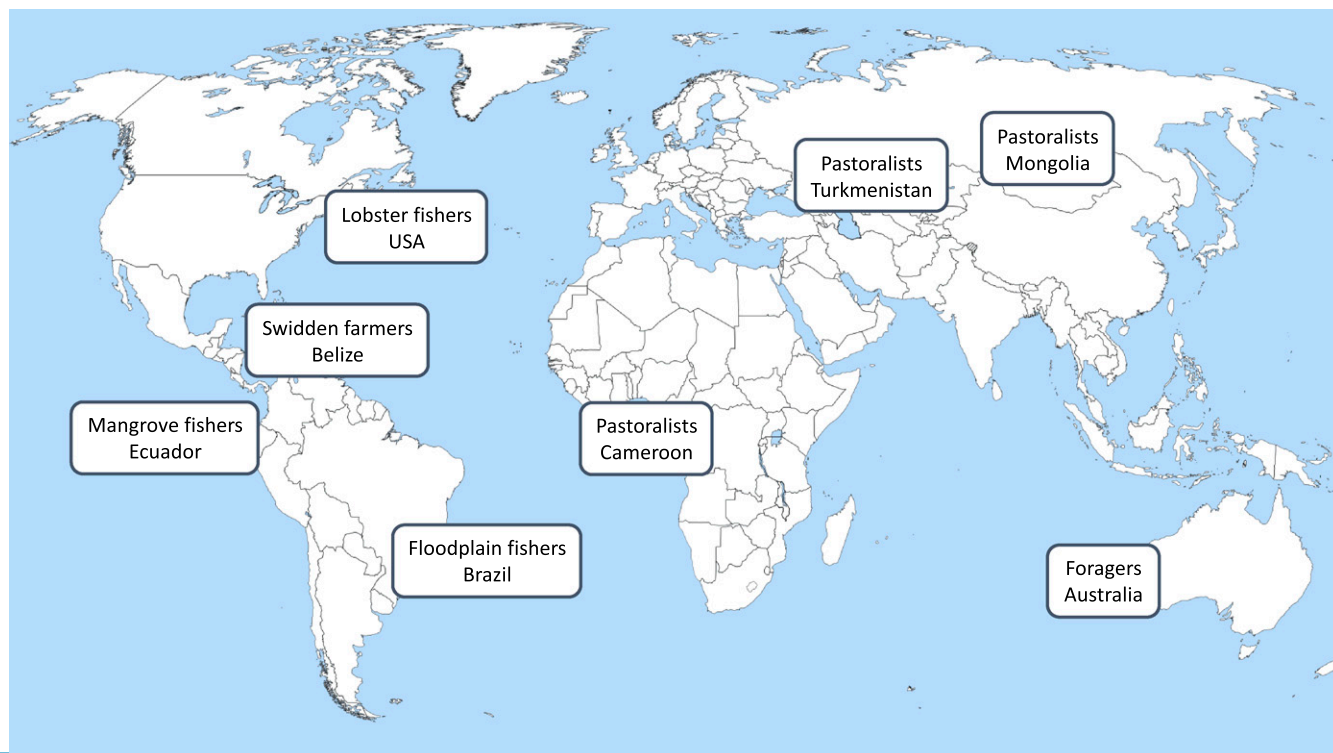


Fig. 1. Location of cases.



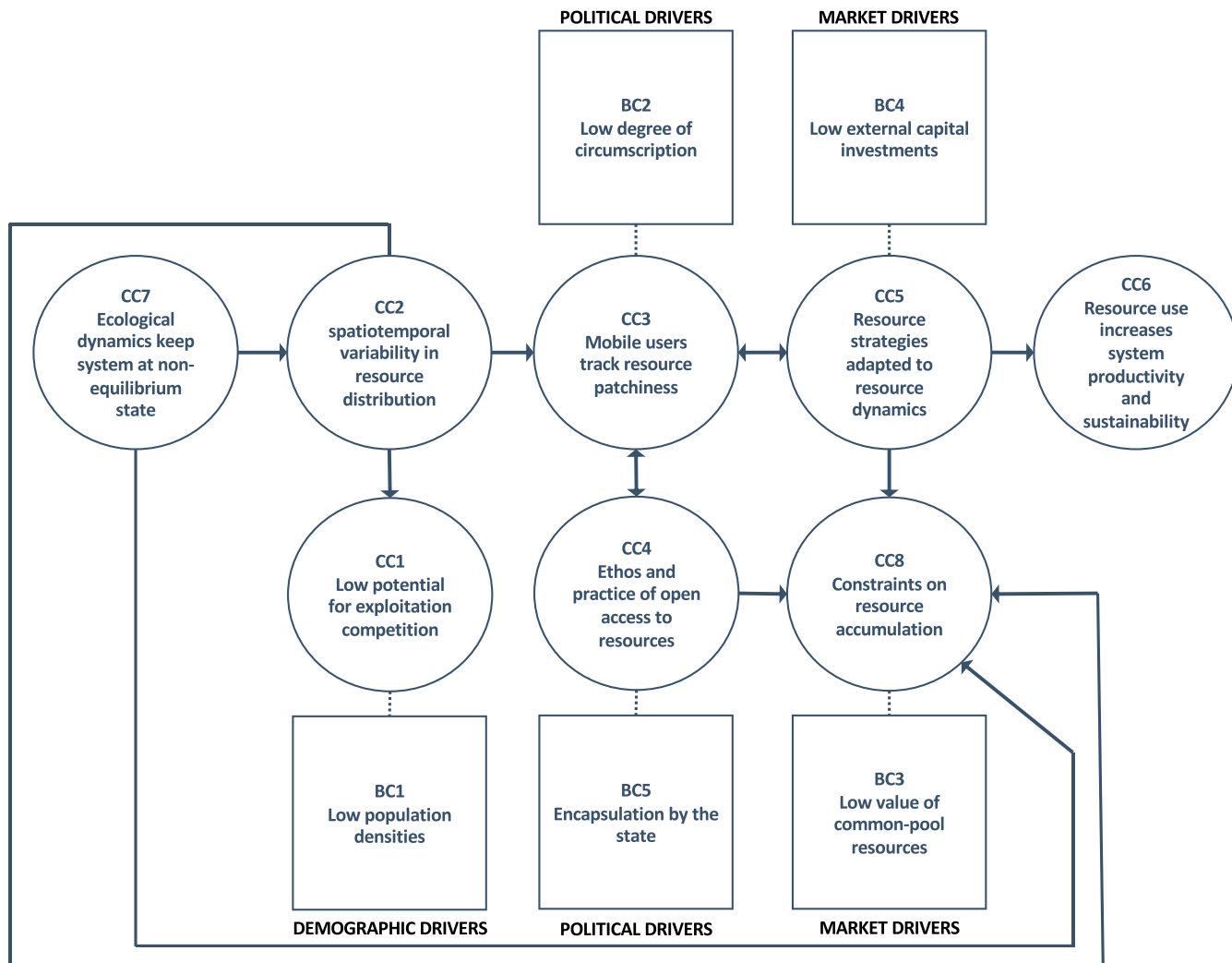


Fig. 2. Theoretical model with interactions between CCs and BCs.

grass so as not to unintentionally threaten any sacred sites until information about their location has been obtained from local site owners. After consultation, anyone can burn or hunt anywhere that they choose. As such, the tenure system regulating use of natural resources functions more like open property than common property: unlike common property systems, there are no boundaries delineating one community's foraging region from another or bounded social group collaborating to exclude others from that region.

**CC5: Resource-Use Strategies Are Adapted to Resource Dynamics.** In all of our cases, feedbacks between social and ecological systems create a dynamic coevolutionary interaction in which social processes shape the ecological system and ecological processes shape the social system (12). In practice, users gain knowledge of the dynamics of the resource system through processes of individual and social learning, which allow them to fine-tune their resource-use strategies to the particulars of the ecological system. While individual experience is certainly a major factor in this learning process, in each of our cases, users also gain information about resource dynamics and the state of the resource system from the success or failure of other users through a process that involves both direct observation and networks of socialization

and communication in which people share experiences, knowledge, and information in much the same spirit of generosity as they would share material resources. Importantly, this process of information gathering and sharing leads to future changes in behavior. In the Pantanal Floodplain in Brazil, to optimize the search for the best fishing spots, people openly share the location of good fishing spots during iced tea drinking sessions but also validate this information through direct observation of fishing catches (17). In Belize, swidden farmers carefully study weather patterns and discuss the timing of clearing, burning, planting, and harvesting events in the agricultural cycle. Information about key environmental dynamics is also gained while participating in labor groups to help other farmers with agricultural activities or by observing, for example, that other farmers are burning by the quantity of smoke in the air on a given day. Farmers use this information to plan where they will clear their next fields (18).

**CC6: Resource Use Increases System Productivity and Sustainability.** In many of our cases, sustainability is a function not just of the intrinsic productivity of the resource system or the strategies of its users but also, of the positive inputs of the resource users themselves, which make the system more productive. In grassland ecosystems, pastoralism often leads to localized shifts in productivity



and plant diversity as animals disturb soil, prefer certain vegetation over others, and locally increase soil nutrients through manure deposits (25). In Mongolia, grass productivity around established pastoral camps is higher than in areas around more recent camps, indicating that pastoral use, including manuring by flocks, may increase grass productivity. An alternative possibility is that established camps have better grazing, because they selected the best sites. Nevertheless, in both explanations, long-term grazing does not threaten the resource system. Similarly, research suggests coevolution of grazing and floodplain vegetation across African floodplains (26). In Australia, the subsistence practices of Martu foragers center on the burning of grassland habitats to hunt burrowed animals, mainly large monitor lizards. Burning increases immediate hunting returns more than 10-fold but also, positively impacts future foraging returns by creating a diverse landscape of vegetation at different stages of recovery after the fire. These hunting fires create landscapes that provide people with higher returns over the long term due to increases in both patch productivity and reductions in patch dispersion (4).

**CC7: Ecological Dynamics Keep the System in a Nonequilibrium State.** The seventh CC is nonequilibrium dynamics, in which repeated disturbances limit harvesting capability (27). Nonequilibrium systems are driven primarily by stochastic abiotic factors, like fire, rainfall, or snowstorms, which lead to highly variable and unpredictable primary production (28). These dynamics protect system productivity by making it difficult for users to overexploit resources (29). In northern Mongolia, pastoralists in the Darkhad Depression experience extensive spatiotemporal variability in pasture productivity. While herd mortality in the winter is an annual constraint on livestock populations, unpredictable bad winter storms, known as dzuds, happen on average once every 10 years and can kill up to 80% of the herd, further reducing herds below carrying capacity (30). In our Australia case study, the sustainability of the system is maintained in part by a long recovery period before the grass becomes dense enough to carry a fire and thus, provide foragers with high hunting returns. In the swidden in Belize, biomass and soil fertility recover slowly, and this limits agricultural productivity.

**CC8: Limits on Resource Accumulation.** The eighth condition, which found in nearly all of our cases, is the presence of mechanisms constraining resource accumulation by individual users. These mechanisms can be social, economic, and/or technological and can help to minimize the risk of overexploitation of common-pool resources, although they are not necessarily “designed” to constrain resource accumulation. In our pastoral cases, the accumulation of livestock is constrained by natural growth of family herds, as there is little external capital investment in the pastoral production system to support faster herd growth. Similarly, tidal cycles dictate accessibility to the mangroves for fishers in Ecuador, and cockles and crabs are harvested by hand only during low tide. During neap tides, harvesters stay close to shore, but during spring tides, harvesters are able to travel farther out. Few fishers have access to motorized transportation, limiting the spatial mobility of harvesters, because they are unwilling or unable to pay the transport costs to more distant sites. In Belize’s swidden farms, social norms related to subsistence agriculture and labor reciprocity can limit resource accumulation (18). In Australia, the open-access policies in Martu foraging communities are underwritten by an ethos of equitability that ensures that any productive surplus or knowledge about the location of that surplus is

shared widely among all present. Martu foragers who are more productive are also more generous with their surplus, and in so doing, they foster more cooperative relationships with others (31).

### BCs and Shifts in Property Regimes

External demographic, economic, and political drivers influence whether the CCs associated with sustainability of open property regimes persist. We have identified five BCs that describe the states of external drivers that are necessary for the emergence of sustainability in these systems, including (i) low population densities and thus, low levels of resource competition; (ii) low circumscription and thus, limited restrictions on mobility; (iii) low market value of common-pool resources harvested; (iv) low capital investments (and appropriate technology); and (v) low encapsulation by the state and thus, little interference in everyday use of common-pool resources at the local level (a more detailed description of these BCs in each of the case studies is in [Dataset S1](#)). Changes in these BCs may push the system to a common property regime with social and spatial boundaries or toward a tragedy of the commons. Our case studies also illustrate how property regimes may change over time due to different processes (e.g., government interventions, incorporation in the market, population growth) that change the BCs (e.g., increase in market value of resources, increase in population density) and may facilitate a shift from an open property regime to other property regimes (or hybrids thereof) (Fig. 3 shows the position of the cases on a continuum of property regimes). The lobster fishery in Maine is a good example of a shift from open access to a common property regime, but we have also observed shifts from open to private property regimes. In the Adamawa Region of Cameroon, for example, there is a shift from pastoralism to ranching, which entails the enclosure of privately owned rangelands that used to be under an open property regime, and in rural Ecuador, individual households have created holding pens for cockle shells that are held until they reach legal size for the market.

**BC1: Low Population Densities.** Low levels of resource competition are often a product of low population densities (32). When user populations increase, there are often negative consequences for resource sustainability. For example, in Turkmenistan, the rural pastoralist population density is low but is increasing because of low urban migration and continued population growth. The grass on which their cattle graze is a scarce resource, and it is unclear how much more additional livestock the system can sustain. In the Chad Basin, the insecurity caused by Boko Haram has led to the forced migration of thousands of pastoralists and hundreds of thousands of cattle from Nigeria to Cameroon, doubling the grazing pressure in the region and increasing the resource use. There are low levels of exploitation in open property regimes, but under common property regimes with clearly defined boundaries for the user group and resource system, there are controlled levels of resource exploitation, as resource users regulate access. Thus, open property regimes may change into common property regimes under conditions of increasing population densities and more intense resource exploitation.

**BC2: Low Degree of Circumscription.** Circumscription refers to the degree to which a user group is constrained politically or physically from moving beyond its resource system (*sensu ref.* 33). Social-ecological systems are embedded in larger regional and political systems, and the extent to which these impact and/or encroach on the mobility and ability to track resources can prevent

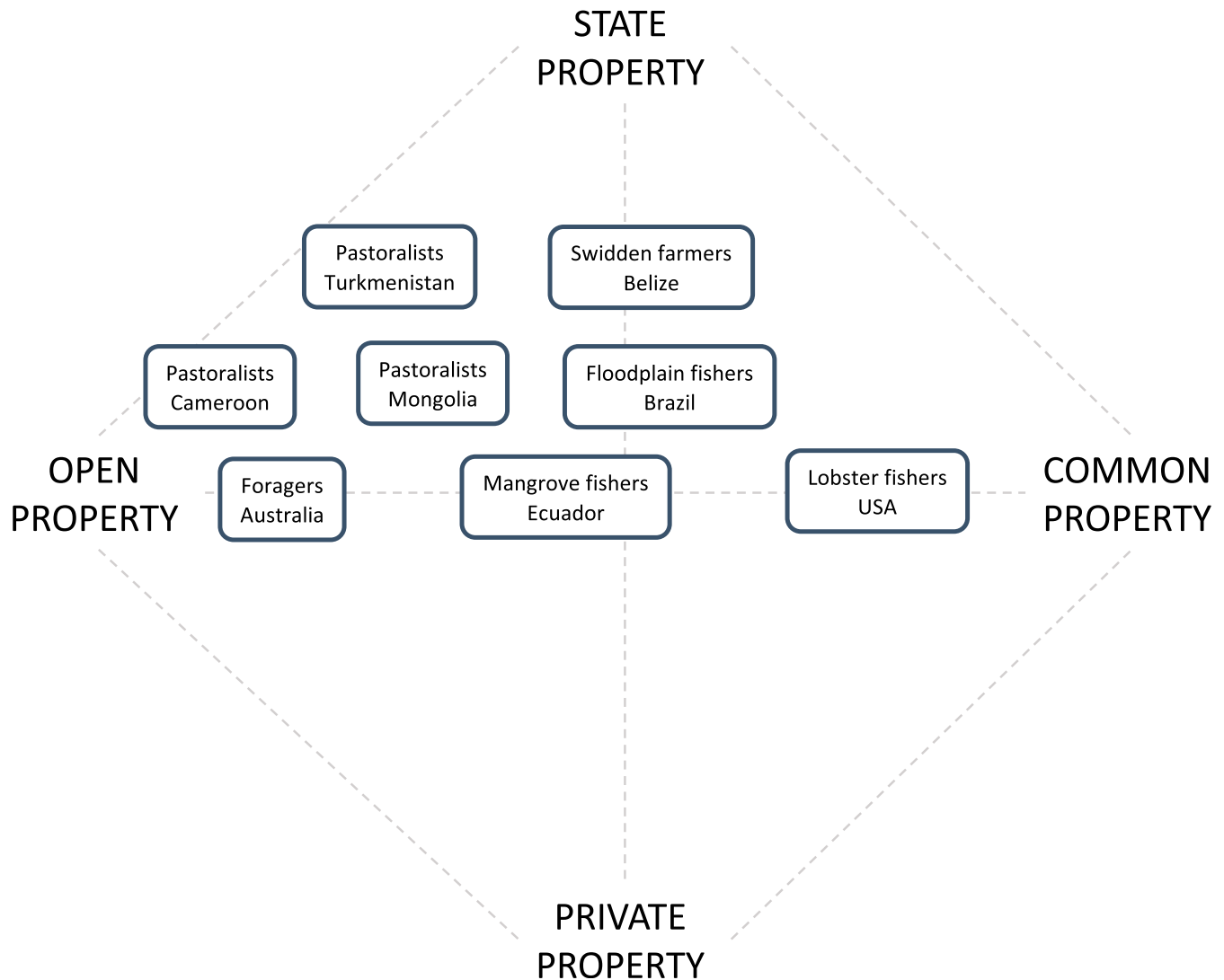


Fig. 3. Cases on continuum of property regimes.

the emergence of sustainability. For example, in the Pantanal fisheries in Brazil, the creation of seven strictly protected areas has led to economic and physical displacement of fishers, which jeopardizes their customary rotational fishing system (34). In small coastal fisheries in Ecuador, the development of shrimp aquaculture has degraded the quality of the estuarine habitat and displaced many artisanal fishers from their customary grounds (35). To address the major threats to mangroves by unregulated aquaculture and urbanization, the government began allocating collective stewardship rights to formally organized fishing associations in 2000 for mangrove conservation and fisheries management. Shellfish collectors are concerned that they are losing access to their customary gathering grounds to new kinds of enclosure by collective stewardship rights, which are only allocated to fishing associations (36).

**BC3: Low Market Value of Common-Pool Resources.** Access to markets and commodity production tends to foster more unsustainable exploitation (37). The market value of the common-pool resources in our cases is generally low, leading to relatively little competition or interest from other users. For example, the grasses that serve as forage for cattle of pastoralists in Cameroon have practically no market value, and thus, there are no

entrepreneurs cutting grass at the end of the rainy season to dry it and sell it later in the dry season as hay. In Ecuadorian mangrove fisheries, cockles, crabs, and finfish harvested in mangroves are commercially valuable, but market demand is small compared with export-oriented industrial pelagic fisheries and farm-raised shrimp. However, in Maine, lobster is the most economically valuable fishery and the backbone of the state's marine economy, making up three-quarters of the total value of all commercial fisheries landings. The high market value of lobsters is one of the reasons why the lobster fisheries in Maine shifted from an open to a common property regime (38). For swidden farmers in southern Belize, accessing markets during most of the 20th century was physically difficult, and certain forest-based products were in demand for only a few years or cyclically as development efforts ebbed (39). Growing maize is only commercially viable at low levels because of the intensive labor requirements; however, other products, such as rice, cacao, and cattle, now compete with swidden for land. This increasing demand is reducing the sustainability of the entire social-ecological system and moving it toward a future state as either a common property regime or a tragedy of the commons.



considers both social and ecological dynamics has been informing policy interventions in both Canada and Australia as part of Healthy Country, Healthy People initiatives (48). Such initiatives recognize the critical interaction between the health of ecosystems and the social and cultural wellbeing of both individuals and the societies of which they are a part—not just recognizing that healthy ecosystems make for healthier people but that healthy social structures and healthy people create more sustainable ecological systems.

While it may seem that our cases are relatively small and increasingly rare subsistence-oriented social–ecological systems in the age of increasingly telecoupled systems (49), these are modern systems that not only provide livelihoods for the people living within them but also, contribute to the global market economy (50). However, telecouplings, like the incorporation in the global market economy, may lead to changes in the CCs and BCs and may threaten the sustainability of these social–ecological systems. In particular, population growth may lead to increasing circumscription and/or competition for common-pool resources, while incorporation in the global market economy may lead to greater capital investments and overexploitation of these resources.

## Conclusion

The framework of complex adaptive system explains how sustainability emerges and persists in social–ecological systems with open access to common-pool resources. It solves the enigma of open access without a tragedy. The key to sustainable use of common-pool resources in these social–ecological systems is self-organization (i.e., the idea that sustainability emerges from individual resource use within dynamic social–ecological systems that are in non-equilibrium). We think that the principles of self-organization not only explain the dynamics of our cases but also, can serve as a guide for how to understand and support the emergence of sustainability in other situations of open access to common-pool resources.

## Acknowledgments

We thank the School of Advanced Research and Meow Wolf for their support and inspiration. This Perspective is based upon work supported by the National Science Foundation (Grants BCS-0819375, BCS-0748594, BCS-1600221, BCS-1459880, BCS-0647832, BCS-1818597, BCS-1558178, BCS-1236939, DEB-0119618, GEO-0909449, HRD-1008498, and IOS-1557836), the Wenner-Gren Foundation for Anthropological Research (Grant 8003), the National Geographic Society (Grant 8306-07), the Rust Family Foundation, the Leverhulme Trust, and EU Inco-Copernicus (Grant ICA2-CT-2000-10015). The views expressed in this Perspective are those of the authors and do not reflect those of their employers.

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