Response Diversity and Resilience in Social-Ecological Systems

by Paul Leslie and J. Terrence McCabe

Recent work in ecology suggests that the diversity of responses to environmental change among species contributing to the same ecosystem function can strongly influence ecosystem resilience. To render this important realization more useful for understanding coupled human-natural systems, we broaden the concept of response diversity to include heterogeneity in human decisions and action. Simply put, not all actors respond the same way to challenges, opportunities, and risks. The range, prevalence, and spatial and temporal distributions of different responses may be crucial to the resilience or the transformation of a social-ecological system and thus have a bearing on human vulnerability and well-being in the face of environmental, socioeconomic, and political change. Response diversity can be seen at multiple scales (e.g., household, village, region), and response diversity at one scale may act synergistically with or contrary to the effects of diversity at another scale. Although considerable research on the *sources* of response diversity has been done, our argument is that the *consequences* of response diversity warrant closer attention. We illustrate this argument with examples drawn from our studies of two East African pastoral populations and discuss the relationship of response diversity to characteristics of social-ecological systems that can promote or diminish resilience.

Introduction

We start with an observation that is unsurprising, perhaps painfully obvious, but with implications that bear further investigation. The observation is that not everyone responds to changing circumstances in the same way. Our claim about the implications of this is that variation in behavior and, more specifically, variation in responses to changing circumstances, is itself important; the existence of variation, how it is distributed or patterned, may have enormous implications for the functioning and resilience of a social-ecological system (SES). This variation must be considered in addition to behavior reflected in central tendencies or prevalence.

We do not imply that social scientists or ecologists have ignored variation. Quite to the contrary, scientists regularly document and use variation to ascertain relationships, including causal relationships. Indeed, this is the basis for much statistical analysis. Typically, however, the focus of such analysis is on the causes of variation: Why do some people get sick but others do not? Why do some forest patches resist infestations while others succumb? Why do some communities welcome outsiders more than do others? We argue for paying attention to the consequences of variation as well, because such variation may be crucial to the functioning and adaptive capacity of a system. We suggest that the resilience of an SES may in some cases depend on variation—the diversity of responses within components of that system—as much or more than on the typical or mean responses.

Our intent in this paper is to argue for the relevance of within-population response diversity for the functioning, resilience, and change of social-ecological systems. To that end, we describe the concept of response diversity as it has been used and our extension of it and its relationship to resilience and associated ecological concepts; present two examples drawn from our studies of East African SESs, chosen to illustrate the range of ways in which response diversity can be integral to the dynamics of the SESs and can be crucial to their persistence and/or transformation; explore the implications of response diversity for resilience and adaptive capacity in those two cases and, more generally, with an eye toward how response diversity is relevant to attempts to operationalize or assess resilience through accessible indicators.

Response Diversity and Resilience

"Resilience" has been used in several different ways, including as an evocative metaphor in discourse on sustainability and as a quantity that is potentially measurable in a specific SES

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(Carpenter et al. 2001). Holling (1973) defined ecosystem resilience as the amount of disturbance a system can absorb and yet remain within the same state or domain of attraction—that is, retain the same controls and relationships among elements of the system. Application of the resilience concept to human systems is more recent, and definitions are evolving. Adger (2000) treated social resilience as the ability of human communities to withstand shocks to their social structure arising from environmental variability and economic or political upheaval. In the context of SESs, resilience is taken to mean more than simply the persistence of ecological relationships or of social structure and identity but also the adaptive capacity to respond to the opportunities and constraints that are presented by perturbations (Folke 2006). Recent definitions thus add a more explicit concern with flexibility and adaptive capacity. Walker and Salt (2006), for example, define resilience as the capacity of a system to absorb disturbance and reorganize while undergoing change in a manner that allows for the persistence of system function, structure, and feedbacks. This definition fits our usage here.

Within a given ecosystem, several different species may perform a particular function—for example, pollination, nitrogen fixation, seed dispersal, short-grass grazing, or degradation of woody biomass. This is referred to as functional redundancy (sometimes also called ecological redundancy). Functionally redundant species may contribute to the same process within an ecosystem but respond differently to changing circumstances. In standard ecological usage, response diversity (RD) refers to the range of reactions to environmental change among species that contribute to the same ecosystem function (Elmqvist et al. 2003). For example, in the face of global warming or a long-term drought, do all species in a given region that eat a certain sort of vegetation shift their range and go locally extinct? If so, there will be very different consequences for the ecosystem than if some of those species are more tolerant of change. Elmqvist et al. (2003) provide an impressive range of examples of response diversity within functional groups in the face of disturbance, across temporal and spatial scales, including seed dispersal by fruit-eating species (e.g., diversity among flying foxes in response to cyclones); plants in rangelands (diversity among grass species in grazing tolerance); freshwater consumers of organic waste (diversity in sensitivity to acidification and organic pollution); and coral reef grazers (consequences of depleted diversity among algae grazers). They argue that RD is important for ecosystem renewal and reorganization following environmental perturbation or change—that is, RD can have an important influence on resilience.

Functional diversity is related to but distinct from functional redundancy. Functional diversity arises when different species that perform a similar function exploit different aspects of a habitat. For example, different grass species all tap water in soil but do so at different depths. These species thus all contribute to evapotranspiration (an important part of the water cycle), but their contributions to evapotranspiration will be more or less sensitive to changes in rainfall or groundwater levels. Walker, Kinzig, and Langridge (1999) demonstrate how functional diversity among grass species promotes resilience of rangelands in the face of changes in climate and grazing pressure; Carpenter et al. (2001) point to this as a specific example of how biodiversity enhances adaptive capacity. The relationship between biodiversity and ecosystem function is complex (Griffin et al. 2009; Naeem et al. 2009), but functional redundancy and functional diversity are both generally seen as promoting resilience. The relevance of RD to functional redundancy is explicitly recognized, as in Elmqvist et al.'s examples cited above—RD among the entities that constitute the functionally redundant group means that a given ecosystem function is more likely to be maintained in the face of shocks to the system. But RD has not generally been seen as linked to the effect of functional diversity. Our discussion below will suggest that RD can, in fact, produce functional diversity and may thereby be important to resilience through a previously unappreciated pathway.

In all of the examples mentioned above, RD refers to differences among species; discussion of the phenomenon is couched in terms of the species, or local population of the species, responding as a whole. Although the possible importance of other units is at least implicitly recognized by some, when ecologists talk about RD or functional diversity, they tend to focus on differences among species. Humans are a single species but one characterized by enormous behavioral flexibility. We thus expand the concept of response diversity to include heterogeneity in human decisions and action that affects one or more of the same SES functions; we wish to call attention to the importance of such within-population diversity.

Case studies of resilience or change in SESs tend to examine human behavior in terms of general trends or modal behavior for the population, community, or some segment of the population (e.g., commercial fishermen). They tend not to focus explicitly on variation within those entities in how people respond to challenges or changing situations. An exception to this generalization is discussion of innovators. But even this is typically done from the perspective of evaluating the consequences of the alternative behavior, with the implicit assumption that the innovation may replace former practices, or a focus on what will happen if that replacement occurs. Thus, in such examples the analysis of the system may acknowledge diversity in behavior, but the diversity is seen as transitory, and the consequences of the existence of the diversity itself are not considered. What happens if actors do change their behavior over time in response to changing conditions but not all individual actors do so in quite the same way? What might be the consequences of such diversity for SES resilience?

Definition and Boundaries of Social-Ecological Systems

The above discussion is couched in terms of ecosystems or SESs; it would be well to consider more explicitly the definition and difficulties of this concept. It is common to define

an SES in terms of its components—species, geophysical characteristics of the landscape, social actors, institutions—and the relationships among those components. The choice of components is invariably shaped by the problem at hand. If we are interested in the behavior of a system—its stability, persistence, resilience, and possible transformations, it becomes necessary to consider aspects of the SES that affect the continuity of key components and relationships over time. Indeed, a central concern (perhaps the central concern) in the study of complex adaptive systems is how to analyze and understand, within a single coherent framework, both change and stability or persistence of those systems, including the ostensibly contradictory possibility of persistence through change (Martin and Sunley 2010). Two aspects of SESs that Cumming et al. (2005) identify as essential for understanding the dynamics of those systems are innovation and system memory. As we shall see, innovation and memory are not only conceptually important but also become practically useful in attempts to evaluate SES resilience.

The many definitions of SESs in the literature (e.g., Berkes, Colding, and Folke 2003; Glaser et al. 2008; and many papers published by the Resilience Alliance) generally entail setting spatial and/or functional boundaries for an SES. This challenge parallels that facing earlier ecosystem studies, especially those that incorporated human populations in the ecosystem being studied. The boundary problem was an important part of the critique of the ecosystem concept in anthropology and other social sciences (e.g., Moran 1990). In the two cases detailed below, the boundary definitions were shaped by the specific foci of the research projects. These definitions are set out within the project descriptions.

Assessing Resilience

Over the past decade, much has been written about what contributes to resilience and adaptive capacity (Adger 2006; Folke 2006; Gunderson and Holling 2002; Janssen and Ostrom 2006, Walker and Salt 2006), but empirical analysis of resilience remains much rarer than conceptual exploration of the concept. This is so in part because resilience is difficult to measure, long periods of observation may be required, and it may be problematic to make generalizations about causal relationships within complex systems in the context of historical contingency and path dependency. Indeed, resilience is more properly seen as an emergent property of a complex system than as a directly measurable characteristic (Robinson and Berkes 2010). Consequently, it has been suggested (see, e.g., Bennett, Cumming, and Peterson 2005; Cumming et al. 2005) that surrogates—attributes of SESs that have been identified as enhancing resilience and adaptive capacity and that are more readily assessed—be utilized in place of attempts to directly measure resilience.

The notion of system identity is useful for structuring the search for and consideration of surrogates. A system's identity is seen not only in terms of the crucial components of a system and the relationships among these but also institutions and processes that affect the continuity of those components and relationships over time (Cumming et al. 2005). As noted above, two general categories of variables that affect continuity are system memory and innovation. System memory refers to the ability to store and retrieve knowledge, which can create flexibility in problem solving and can enhance resilience (Berkes, Colding, and Folke 2003; Berkes and Seixas 2005). Faced with disturbance of the SES, be it environmental fluctuation or shifting political-economic circumstances, knowledge of how similar conditions were dealt with in the past, and the outcomes of such actions, can be enormously useful. Experience and memory can thus promote resilience. Note that memory is broader than individual recollection—it may be collective, residing in cultural practices or institutions. That institutions and social networks as well as elders or other local experts serve as repositories of knowledge and experience is well recognized (Folke, Colding, and Berkes 2003). Innovation, more broadly including experimentation and learning, in some ways complements system memory. Carpenter et al. (2001) argue that the adaptive capacity of an SES is related to mechanisms that generate novelty and learning. Innovations are perhaps most often seen as helping to facilitate or even drive the transformation of an SES, but they may also serve to maintain system identity by promoting new ways of retaining old relationships and system components. We will return to consideration of surrogate indicators of resilience following our description of two case studies.

Two Examples

We illustrate our arguments about the importance of response diversity with two concrete examples. Both derive from our long-term studies of East African pastoral populations—the Ngisonyoka Turkana of northwest Kenya and Kisongo Maasai of northern Tanzania—and the SESs of which they are a part. Both studies focus on understanding how people cope with risk and uncertainty, but differences between the two cases point to the range of ways in which RD may be important to understanding the dynamics of SESs. The Turkana example focuses on long-standing, "traditional" behavior; the Maasai example entails response to a relatively new and rapidly changing set of challenges. In the Turkana case, RD is seen as integral to ongoing processes by which the SES functions; in the Maasai case, the importance of RD is seen in direct impact on land use/land cover with likely consequences for biodiversity and livelihood security. In each case, understanding the nature and consequences of RD is important to understanding the SES—how it is maintained and how it may change.

Though contexts vary, nomadic and seminomadic pastoralists typically face social, political, economic, and ecological environments characterized by strong, often unpredictable fluctuations. How pastoralists cope with environmental fluctuations and changing circumstances, especially when they

are unpredictable, is crucial for understanding not only persistence of the human populations in these habitats but also for understanding human action within the social-ecological systems, with implications for both human well-being and biodiversity.

Turkana: Response Diversity and Persistence

Turkana District lies in the Great Rift Valley in northwest Kenya, bordered by Sudan on the north, Uganda on the west, and Lake Turkana to the east. The Ngisonyoka, who inhabit an area of roughly 10,000 sq km in the southern part of this district, are one of 19 territorial sections (*ngitela*) of Turkana. They are nomadic herders in one of the more arid habitats occupied by pastoral populations. The Turkana SES was the focus of the South Turkana Ecosystem Project (STEP), a long-term, multidisciplinary study during the 1980s and 1990s that involved anthropologists, ecologists, and a variety of other scientists. The STEP scientists recognized the difficulty of setting boundaries to the ecosystem being studied and decided the aims of the project would be best served by using the sectional boundaries as recognized by the Turkana themselves to define the ecosystem. Results of this project, along with detailed description and discussion of the Turkana SES, can be found in Little and Leslie (1999) and McCabe (2004).

The Ngisonyoka are almost wholly dependent on livestock for their livelihood, so the propagation and maintenance of herds is the key to persistence of the Ngisonyoka population and society. In ecological terms, the Turkana SES is a non-equilibrial system (Ellis and Swift 1988), which means that important drivers of system dynamics are not themselves influenced by cybernetic relationships (primarily negative feedback) with other elements of the system. The most salient driver of the SES is rainfall. The timing, amount, and local distributions of rainfall are highly variable and unpredictable. Poor rainy seasons are common, and multiyear droughts can be expected at least once or twice a decade. The difficulties presented by climatic fluctuations are compounded by fluctuations in the biotic and sociopolitical environments, most importantly livestock disease epidemics and intertribal livestock raiding.

Mobility and herd diversity. The means by which Turkana have managed to cope with the fluctuations and unpredictability and to persist in this challenging environment was a central concern of STEP. Perhaps the single most obvious strategy, one that is common to most dry-land pastoralists, is mobility—livestock are moved in response to the temporal and spatial variability of rainfall and consequent forage. Indeed, Turkana are among the most mobile of pastoralists, moving frequently in response to changing conditions.

Another, perhaps less obvious, key is the Ngisonyoka practice of keeping a variety of livestock species, including cattle, camels, and goats, plus smaller numbers of fat-tailed sheep and donkeys (the latter primarily for transport). Although multispecies herding is common among pastoralists, this is a wider range of livestock than is typically found in pastoral groups. Dependence on multiple species requires more labor and complicates herding strategies, as the species have different needs in terms of forage and water, but there are a number of advantages. For example, cattle and camels tap different energy pathways that differ in timing and flux (Coughenour et al. 1985): cattle can take advantage of energy available in the rapid flush of grasses during rainy periods and propagate these large but ephemeral pulses to people through increased milk production, while camels browse in trees and tap vegetation characterized by less dramatic peaks but longer duration. The livestock species constitute a functional group of domestic herbivores that convert vegetation to human food. More generally, then, the primary benefit to keeping multiple species is that it allows Turkana to take advantage of RD of livestock to environmental fluctuations. If productivity of goats is compromised by, say, an epidemic of caprine pleuropneumonia, the cattle continue to produce; if drought conditions suppress cattle fecundity and milk production, camels may continue to yield milk; if a family's camels are stolen in a raid, their cattle, which are generally herded in a different area because of different nutritional needs, may remain safe. The same strategy of utilizing RD to mitigate effects of unpredictable disturbance is seen in diverse smallholder systems—for example, Polynesian polyculture (Colding, Elmqvist, and Olsson 2003). The importance of herd diversity to livelihood security is well recognized (e.g., Dahl and Hjort 1976; Mace and Houston 1989), but discussions of this strategy have not generally recognized the role and significance of behavioral diversity among households with respect to the resilience of the SESs of which they are a part.

Above we noted the often-cited importance of mobility to the pastoral strategy. Now consider the importance of the variation among families in their herd movements. Turkana do not migrate like wildebeest—great herds moving in the same cycle in more or less the same directions at the same time. Although it is certainly possible to make useful and statistically valid generalizations about Ngisonyoka migration patterns, there is much individual variation. Not all herders move to the same place or even the same sort of place; indeed, in some cases, one herder might move his family or herds to a place recently abandoned by another herder, an apparent confirmation of the dictum that "one man's trash is another's treasure." For example, three of the four families followed during a detailed study of herd movements carried out from 1980 to 1982 (see McCabe 2004) moved to areas of higher primary productivity as the dry season advanced and vegetation dried up (as is expected in general for Ngisonyoka). But one did just the opposite, moving to areas of lower productivity as conditions worsened. That herder was able to do this because his herding strategy emphasized camels, which could exploit the browsing available along dry watercourses in places where grazing livestock would have little suitable food. This pattern kept his herds out of competition with

those of other herders; it also reduced the likelihood of loss due to raiding at a time when others were at increased risk (the areas of higher productivity tend to be closer to their major enemies).

The preceding example points to two sources of heterogeneity in movement. These are structural differences and differences in perceptions of risk and opportunity.

1. Structural differences. RD is encouraged, even demanded, by differences in herd composition and labor availability, in the context of differing livestock species' requirements. To some extent a herder's livestock "portfolio" changes due to environmental stochasticity, but different herders tend to emphasize different species. This specialization is not generally to the exclusion of other species but rather a matter of degree, reflecting personal preferences based on experience and knowledge and on contingencies such as inheritance and herd loss.

2. Differences in perceptions of risk and opportunity. One herder may choose to minimize exposure to predators (hyenas, lions) or to raiding from neighboring groups, even if the safer areas are much poorer in suitable grazing/browsing. Another herder may risk loss of animals (and family members) to raiding in order to take advantage of resources in dry season refuges closer to enemies rather than to lose large numbers of animals to starvation or drought. Thus, some herd owners tend to follow what can be characterized as an aggressive movement strategy while others follow a more cautious strategy (McCabe 2004). Bollig (2006) also discusses risk-prone and risk-averse mobility patterns in response to drought and epidemics among Pokot (neighbors of Ngisonyoka). Differences in perceptions of risk and opportunity, and in ultimate herding strategies, arise in part from different personal experience, contingency, and differential tolerance of hazards such as drought, disease, and raiding. Turkana herders do not jointly decide on overall movements or distribution of herd composition to arrive at an optimum mix for the population as a whole. Individual herders are aware of what many others are doing, but their decisions are their own—the RD is produced at the individual level.

These are some of the sources of diversity in herd composition and movements. There are certainly others, and together these are a necessary part of a full understanding of the Turkana SES. However, our primary concern here is with the consequences of this diversity.

RD and the efficacy of social networks. Despite the mobility, multispecies holdings, and sophisticated herding strategies practiced by Ngisonyoka, major losses of livestock are common. Families can expect to lose large portions of their herds to drought, disease, and raiding, and to experience such losses repeatedly (see Leslie and Dyson-Hudson 1999; McCabe 2004). In the face of such events, a key to success, or at least survival, is social networks (kin and exchange partners), which are crucial both for immediate support in the aftermath of disasters and for subsequent restocking. Examination of this phenomenon leads to an appreciation of the importance of intraspecies RD to the persistence of families and ultimately to the resilience of the Turkana SES.

Social networks with mutual obligations for exchange or redistribution of livestock (and, to a lesser extent, redistribution of dependents; Leslie and Dyson-Hudson 1999; Johnson 1999) are indispensable for restocking following disaster and for other purposes such as assembling bridewealth (which is unusually high among Turkana). But the efficacy of this mechanism depends on RD that serves to spread risk—including the diversity seen in herd movement and herd composition noted above. A consequence of a mix of strategies among members of a network is a hedging of ecological bets: if people move to different places with different characteristics, it is less likely that all in a herd owner's social network, all of his exchange partners, will have devastating losses at the same time. Potential aid is thus more assured. Although there is a moral obligation to help a close relative or exchange partner if at all possible, restocking transactions depend on "donors" having sufficient numbers of the needed species (McCabe 1990).

For example, two brothers-in-law, Angor and Lori (names altered), emphasized different livestock species and practiced divergent movement patterns. Angor specialized in goats, which can reproduce quickly and can shift forage types as conditions require, and kept fewer cattle and camels, while Lori emphasized cattle production. In one particularly severe drought Lori was forced to take his animals to locations where grass was available, but that area was also close to the border with the Pokot, traditional enemies of the Ngisonyoka. In one large Pokot raid Lori lost almost all his livestock. Although Angor's cattle moved to a similar location and were also raided, Angor survived this stressful period because of his large herds of goats, which were kept elsewhere. As a key member of Lori's network, Angor took care of Lori and his family over a 2-year period and also helped him restock. Without Angor's help, restocking would not have been possible, and Lori and his family would in all likelihood have had to try to survive outside of the pastoral system.

In contrast, Apu took over as principal herd owner when his brother Loper died suddenly. Loper had been quite successful, with a growing family and large livestock holdings. For a variety of reasons, Apu did not maintain the extensive network that Loper had cultivated. Loss of all of the family's camels and most of the small stock in a large raid, followed by loss of cattle to drought and disease in the following years, left the family in dire straits. Lack of a viable network precluded restocking, and family members dispersed. The ultimate failure and dissolution of the family was the product of several factors, including repeated losses to raiding and disease and questionable management decisions, but the lack of a sufficient exchange network was an important part of the constellation of conditions leading to the failure. These cases are described in greater detail by McCabe (2004). The point here is not just that Lori's network existed while Loper's dis-

sipated but that the diversity of strategies in the Angor-Lori case enabled the recovery.

Livestock exchange networks include many kin (agnatic and affinal) but also many nonrelatives, and Turkana take care to cultivate relationships with others who live at some distance, who utilize different areas for wet or dry season pasture, and whose fortunes are less likely to be closely correlated with their own (Gulliver 1951 [1963]; McCabe 2004). The benefits of having widely dispersed exchange partners are recognized by the neighboring Pokot as well (Bollig 2006).

Note that we have described the Turkana SES as we saw it in the 1980s–1990s and based on reports by others (including Turkana informants) about earlier times. There have been some important changes in Turkana during the past decade, but most of the key characteristics of the SES that we observed and described persist, and in any event our observations about RD are not rendered less valid by the fact that they pertain most directly to a system in the past. Our claim, then, is that in Turkana the persistence of the human population, and therefore the resilience and persistence of the SES, depends to some degree on response diversity among individuals or domestic units.

Simanjiro: Response Diversity, Land Use, and Biodiversity

In contrast to Turkana, where tourism is minimal and government involvement almost grudging, Maasailand is of enormous importance from the standpoint of both economics and conservation. Northern Tanzania is the country's most prominent draw for tourism and a region of intense interest and involvement of national and international wildlife conservation organizations. As is the case elsewhere in Africa, parks and protected areas in northern Tanzania have stimulated significant social, economic, and environmental change. This includes the adoption of alternative forms of land use that can either strengthen or compromise SES resilience, promoting sustainability or leading to a major transformation and reorganization of the social, demographic, and ecological systems outside of and including parks (Child 2004; Joppa, Loarie, and Pimm 2009; Norton-Griffiths 1996; Wittemyer et al. 2008).

As part of a broad, interdisciplinary study of the consequences of parks, we have been studying the SES in the vicinity of Tarangire National Park (TNP) in northern Tanzania, with a specific focus on changes in land use and livelihood strategies in several communities in Simanjiro District. The communities in Simanjiro District are composed predominantly of Kisongo Maasai people, traditionally seminomadic herders who, like Maasai elsewhere, increasingly are diversifying their livelihoods through adoption of agriculture and labor migration (McCabe, Leslie, and DeLuca 2010). We treat the boundaries of the SES as being defined by the rangelands of northern Tanzania and southern Kenya occupied by the Maasai people. People and livestock migrate within this SES, and system-wide institutions govern access to resources. As with the Turkana study, the spatial extent of the Simanjiro SES is defined largely in terms of the local Maasai's perceptions and activities—primarily the areas utilized by those people for their herding but recognizing that important influences, including wildlife, other Maasai and ethnic groups, government, and nongovernmental institutions, originate from beyond those boundaries and must be considered in order to understand what goes on within the Simanjiro/Tarangire SES.

Cultivation in Simanjiro is notably different from that in other pastoral areas of Tanzania. Large plots are plowed by tractor or less frequently by oxen, and some villages have allowed outsiders to lease large areas for commercial cultivation. All of this represents a transition from traditional forms of common property to various forms of privatized or semiprivatized landholdings. The rapid expansion of cultivation has been of great concern to conservationists (Foley 2004; Msoffe et al. 2011), as the result may be to turn TNP into an island park, cutting off access of migrating wildlife to the Simanjiro plains.

Causes of the changing livelihoods and land use are complex (McCabe, Leslie, and DeLuca 2010). Population pressure—increasing human population without commensurate increase in livestock populations—is an important factor (McCabe 2003), but fear of (further) alienation of land or restricted access to resources due to conservation policy (expansion of parks, establishment of Wildlife Management Areas or other forms of protected areas) is also influential. The latter concern is fully understandable given past evictions of Maasai from Serengeti (1959), Ngorongoro Crater (1974), Mkomazi (1980s) and, especially close to home, from TNP itself (1970). Just 2 years ago there was appropriation of village lands in the Mkungunero Game Reserve adjacent to the southern boundary of TNP. Villages in Simanjiro began allocating land to individual household heads approximately 20 years ago, in some cases as an attempt to bolster legal claim to village lands and avert further losses.

In addition to the possible alienation of resources by conservation measures, proximity to the parks entails other risks—especially crop damage by wildlife migrating beyond the park boundaries (which are quite arbitrary from the perspective of the wildlife; Baird, Leslie, and McCabe 2009). These contribute to the calculus of livelihood strategies and alternatives as well.

Multilevel response diversity in Simanjiro. The Simanjiro study communities vary with regard to proximity to TNP, but all lie within the "zone of influence" of the park. Two of the four villages discussed here (Loiborsoit and Emboreet) border on TNP, and two (Sukuro and Terrat) are separated from the park by one village. Villages are spatially large, resembling a county in some parts of the United States, so village-level decisions about land use can have a significant impact on the regional SES. Not all villages are responding to changing circumstances or risks in the same way. They differ in the prevalence of new forms of livelihood and in community efforts

Table 1. Land allocation, acreage cultivated, and livestock holdings by households in Simanjiro villages, 2010

Village	Acres allocated	Total acres cultivated[a]	Acres in maize	Acres in beans	TLUs[b]
Emboreet:					
Mean	45.4	7.0	5.7	1.3	22.6
Median	50	4.5	4	0	15.5
SD	14.4	7.0	5.0	3.6	25.6
n	30	30	30	30	30
Loiborsoit:					
Mean	42.2	11.8	8.9	2.9	53.5
Median	40	6.5	6	1	26.3
SD	26.6	17.8	12.3	5.7	64.5
n	30	30	30	30	30
Sukuro:					
Mean	29.6	9.3	8.7	.6	128.0
Median	30	8	8	0	80.4
SD	10.6	4.9	4.2	1.5	157.8
n	25	25	25	25	27
Terrat:					
Mean	20.1	8.6	4.9	3.7	32.1
Median	15	7	5	3	24.9
SD	17.7	7.4	3.7	4.2	43.4
n	29	29	29	29	29
All villages:					
Mean	34.6	9.2	7.0	2.2	57.5
Median	30	6	5	0	27.7
SD	21.0	10.8	7.4	4.2	94.6
n	114	114	114	114	116

[a] One-way ANOVA, $F = 0.74$, $P = .53$.
[b] One-way ANOVA, $F = 4.91$, $P = .003$.

to manage land tenure and access to common resources (especially pasture). Livelihood diversification has been recognized as a means of risk management (e.g., Little et al. 2001) and indeed is related to resilience, but we are not concerned here with livelihood diversification per se. Rather, we point to diversity in the diversification.

Cultivation in Simanjiro can have substantial benefits but may also entail significant costs and risks. Benefits include both increased food security and the possibility of selling harvested crops (especially beans, which bring a good price) to purchase livestock and veterinary medicine and to pay for hired labor or household expenses. However, because precipitation in Simanjiro is limited and highly variable both spatially and temporally, cultivation is inherently risky. In some years rain falls in a relatively stable pattern once the rainy season begins (February to April); in some years heavy rains in February falter and may or may not return intermittently 4–5 weeks later; in other years the rains begin late and only last for a few weeks. Complete or partial crop failure, as happened in 2009 and again in 2011, either due to lack of rain at the right time (sometimes too much rain) or to wildlife predation, is common. In some years cultivation is productive for most people, and their livestock thrive; in some years crops fail but livestock do well; and in other years livestock die and crops fail. When crops fail, not only do the nutritional and economic benefits not materialize but the costs of the seed and of hiring a tractor are not recouped.

Individuals respond to these opportunities and challenges in very different ways. Some households plant large fields, while others engage in limited cultivation. In years when cultivation results in a surplus, some individuals invest in livestock and veterinary medicine, while others use the surplus funds to expand cultivation.

Table 1 gives aggregate statistics for the amount of land allocated to a sample of households in each village, the area these households devoted to cultivation of each of the principal crops, and their livestock holdings (expressed in total livestock units [TLUs]) in 2010.

Table 1 reveals considerable variation both within and among villages with regard to engagement with animal husbandry. In 2010 there was more than a fivefold difference among villages in mean or median household livestock holdings (measured in TLUs). There is substantial variation among households in number of acres cultivated, with the standard deviation exceeding the mean overall. The difference among the villages with regard to the acreage cultivated by each household is not statistically significant, but there is notable variation among villages in the emphasis on beans (likelihood ratio test, $P < .001$). Sukuro cultivators invested predominantly in maize. Terrat households had the second-lowest number

of total acres in cultivation but the highest investment in beans as a proportion of land cultivated. Emphasis on beans represents a risk-prone strategy—beans are more profitable than maize when there is a good crop but are more likely to fail.

The villages differ markedly in the amount of land allocated to each household, with the median allocation in Emboreet being more than three times that in Terrat, but those larger allocations do not translate into more cultivation. Terrat had the highest ratio of cultivated to allocated land in 2010 (the ratio of median acres cultivated to median allocation = 0.47; the ratio for the other villages ranges between 0.09 and 0.17), but the amount of land households cultivate in Terrat is not especially high, falling within the range of the other villages. The high cultivation to allocation ratio is thus due to smaller allocations. This reflects diversity at the village level—diversity that has implications for potential future expansion of agriculture and for the landscape.

Additional insight into the diversity of household livelihood portfolios can be gained by examining the joint distribution of households according to both TLU and acres cultivated (AC; see fig. 1). A strong positive correlation between TLU and AC might indicate that TLU and AC rise together as a function of wealth, and variation in each is associated with overall wealth rather than different livelihood strategies. The correlation between TLU and AC for all villages together is indeed positive but not especially strong ($r = 0.23$, $P = .026$); within villages, the correlation is strong and statistically significant only in Emboreet ($r = 0.63$, $P = .004$). These data do provide evidence for different mixes of livelihoods. In Sukuro and Loiborsoit, for example, some households have well above the mean TLU but below mean AC, and vice versa. These two villages exhibit a greater range of TLU associated with a given level of AC than is seen in the other two villages.

Just why different households take different strategies (here, especially, different emphasis on beans)—how these relate to their past experience, the nature and extent of their network, and so forth, needs further investigation. Influences may be generally similar to those described for Turkana, but the influence of village or higher-level context (see below) may be additionally important. Whatever the determinants of these differences, it seems reasonable to expect that the diversity of strategies seen at the household level will affect the long-term viability of households and thus play a role in the resilience of the SES.

Overall, these data suggest that there is variation among households and among villages in mixes of livelihood strategies. The causes of this diversity must be taken up in another paper; our concern here is with the consequences of the diversity. In the context of the fluctuating climatic conditions in Simanjiro, the variation described above acts in much the same way that diversity in herd composition and mobility patterns act for the Turkana (described in an earlier section). Exchange networks are robust among the Maasai, as they are among the Turkana, and extend across villages. If crops fail for a household in a particular year, other households in the exchange network may have been successful; in a year when crops fail but livestock thrive, households with large livestock holdings help those who have few livestock and have suffered

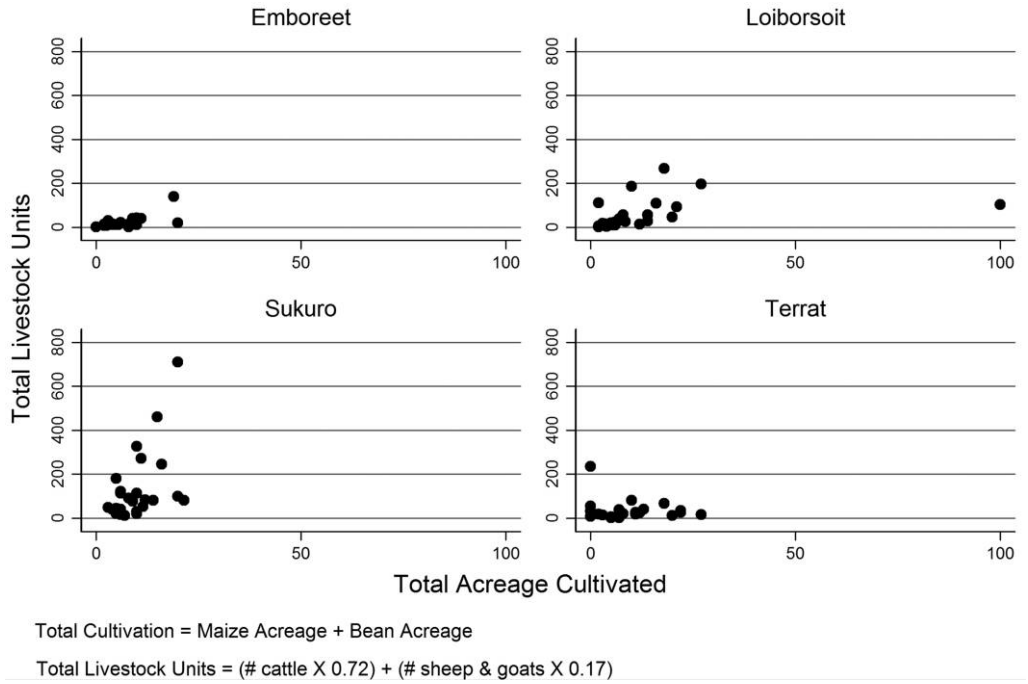

Figure 1. Total livestock units by total acreage cultivated for households in four Simanjiro villages.

crop failure. Just how the developing diversity in livelihood strategies affects the efficacy of exchange networks and, indeed, how it affects the formation of the networks, remains to be seen. We have begun a more detailed study of these networks (Baird 2012) but at this point cannot demonstrate the importance of this diversity as clearly as can be done for the Turkana case.

The consequences of variability at the village level may be even more salient for the landscape and for resilience than is variability at the household level. Each village has areas of extensive plains utilized by wildlife that migrate from TNP in the wet season, and each also has areas designated for cultivation and areas designated for livestock grazing. However, land cover and land use plans differ among the villages, and they differ markedly in their policies for the size of individual allotments and the degree of large-scale cultivation. The village of Loiborsoit has set aside large tracts of land for livestock grazing, formally maintaining that common pool resource. Terrat designated a large tract for wildlife conservation (especially to accommodate the wildebeest migration and calving) in 2008 and was joined in this endeavor by Sukuro in 2010; these villages are receiving funds from Tanzania National Parks (TANAPA) and conservation NGOs to keep the area free from settlement (Nelson et al. 2010). Instead of resisting the push from conservation, these two villages are embracing it. People are still herding their livestock as if the uncultivated land were all commons, but a major grazing area has been designated for future allocation to individuals. The stage is thus set for rapid fragmentation of grazing areas if cultivation increases. Developments in Sukuro and Terrat stand in stark contrast to village-level decisions made in Loiborsoit and especially in Emboreet, where village leaders have continued to promote cultivation in the plains and have no intention of setting aside land for conservation. Sukuro's set aside of a grazing area for future allocation to individuals further differentiates their land use trajectory from those of the other villages. Which of these diverse strategies will most benefit local people is not clear at this time. It is clear, however, that villages are responding differently to the challenges of living in proximity to the park and to potential benefits and costs of cultivating in the plains.

There are other differences among the villages that relate directly to land use and land cover. For example, Loiborsoit did not resist WaArusha cultivators (a neighboring population) from coming in and establishing farms; Terrat evicted them. Terrat did not resist a recent directive from the regional commissioner banning cultivation on the Simanjiro Plains; Emboreet has been most averse to setting aside land for conservation and is strongly resisting directives to curb cultivation on the plains. If they accede to such curtailment, people would likely move closer to the park, which would entail its own set of consequences such as deforestation.

In all of these villages in the vicinity of TNP, the overwhelming perception is that there is a significant risk of loss of land tenure due to park expansion or government-imposed changes in conservation and land use policies (Baird, Leslie, and McCabe 2009). Despite this shared perception, the villages are responding differently to the threat of further alienation of land. Some village-level conservation policy is leading to conversion of commons to private holdings allocated to individuals; in other villages it is leading to formal establishment of commons areas and/or special use areas. There is thus substantial RD at the village level.

The existence of RD at both the village and individual household levels introduces the possibility of cross-scale effects—that is, the effects of RD at one level might act synergistically with or counter to those at the other level. An example of this is seen in "preemptive cultivation." Conservation organizations (both TANAPA and wildlife-oriented NGOs) have sponsored numerous workshops and tours for village leaders to demonstrate the economic value of wildlife in an attempt to influence village-level decisions favorable to conservation. Individual herder/farmers know this and are also aware that funds are generated through conservation-related activities but may not see themselves as benefiting. They also hear some village leaders advocating the expansion of conservation measures in their community. The common perception is that the leaders are "selling" the land to conservation interests for their own benefit—not that of the community. This increases the sense of insecurity at the individual level, and a response to this on the part of some households is to secure as much land as they can and intensify land use before their leaders "sell" it to conservation. In some cases this has entailed cultivation in the midst of wildlife migration corridors even when that is not the best agricultural land (Cooke 2007; Sachedina and Trench 2009). Thus, the government/NGO effort to influence land use decisions at the village level may have been successful in promoting conservation but has stimulated insecurity at the individual level, prompting individual responses within villages that may be inimical to conservation.

As we mentioned in the introduction, we are considering the rangelands in northern Tanzania and southern Kenya occupied by the Maasai to be the larger SES within which Simanjiro is embedded. People and livestock migrate within this SES, and system-wide institutions govern access to resources. We see this as important to the discussion of response diversity at a level higher than households and villages. Although the rangelands and people are similar, Kenya and Tanzania have had divergent political histories. While Kenya first divided the rangelands into group ranches that are now being rapidly privatized, Tanzania maintained large areas for common grazing. This has important implications for response diversity. In Kenya there has been a much more rapid adoption of newer, more productive breeds of cattle and, in some cases, cattle that are more resistant to disease. These breeds have begun to be adopted by the Maasai in Tanzania. The privatization of rangelands in Kenya has fragmented the landscape making the free movement of livestock in times of stress more difficult than in Tanzania. The maintenance of

common grazing areas in Tanzania allowed Kenya Maasai to migrate with their animals during the severe drought of 2009 and again in 2011. This process would have been much more difficult had the Tanzanian rangelands been fragmented like the Kenyan rangelands. In addition, this demonstrated that the institutions that facilitate access to resources have been maintained throughout Maasailand. This might be considered an instance of RD promoting one correlate of resilience—system memory—for the larger SES, embodied in a cultural institution that would likely have disappeared had the Kenyan model been followed in Tanzania.

The potential importance of response diversity in Simanjiro. The Maasai responses to the changing conditions described above—changes in livelihoods, government policy, and village land allocation—have been developing only over the past 10–20 years but with increasing rapidity in a shifting political-economic context. As described above, RD at the village and individual levels is already becoming evident. The near- and longer-term social, ecological, and political-economic consequences of this diversity are not yet clear, and the whole situation is in flux. Because we see new elements in the SES, and new relationships among elements, this appears to be a period of reorganization in the adaptive cycle of a complex system (cf. Gunderson and Holling 2002; Walker and Salt 2006). But there is good reason to expect that the multilevel RD reflected in changing land use/land cover in Simanjiro will have consequences for biodiversity and the evolving SES more broadly. The diversity of uses (variety of crops, set asides for pasture or for wildlife) itself can affect both biodiversity and the viability of traditional and new livelihood pursuits. This can be illustrated by taking a more abstract approach.

Consider a hypothetical landscape experiencing the introduction of a new land use and consequent change in land cover. There is a potentially huge difference between a case where all units or agents (say, households or villages) do the same thing to the same degree and a case where those same units respond differently—for example, all landowners devoting 20% of their land to fruit trees versus 20% of landowners devoting all of their land to orchard while 80% devote none. The pattern of diversity makes a difference.

Figure 2 depicts two alternative distributions of the same amount of "transformed" land—strongly clustered versus highly dispersed—and illustrates why such differences might be important. Holding the proportion of the area transformed constant, as the dispersion of patches increases, the mean area of patches decreases, and the total edge (perimeter) of patches increases.

The clustering of disturbance affects landscape characteristics and has implications for biodiversity. Species richness can be influenced by the spatial pattern of land transformation, particularly fragmentation and habitat loss (DeFries et al. 2005; Fahrig 2003). Conversely, clustering of transformed patches may achieve the minimum size of habitat needed by a new or recolonizing species to maintain itself,

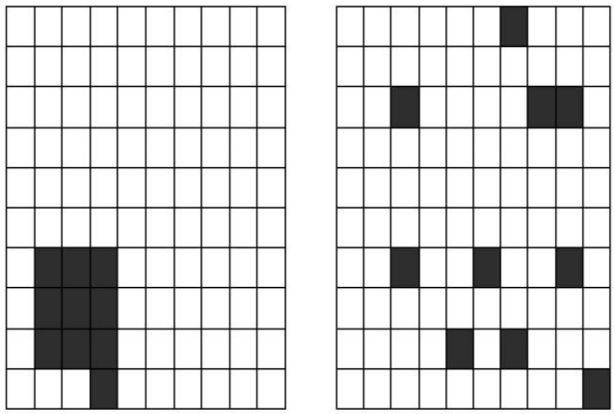

Figure 2. Alternative spatial distributions of a given total amount of disturbed or transformed land.

and the edges of patches may represent transition zones or ecotones, which are often associated with higher biodiversity. The distribution of transformed land affects the "permeability" of the landscape—whether migration corridors remain intact or whether sufficient stepping stones of suitable habitat are maintained—and thereby the isolation of local populations. Thus, the balance between local extinction and recolonization, and opportunities for colonization by new or invasive species, are functions of the pattern of transformation (Hansen and Rotella 2002; Sinclair 1998). The spatial distribution of disturbance may affect not only wildlife but domestic species as well, through adequacy of and access to common pasture or other resources, and thus affect social institutions and the SES as a whole.

This is a very simple illustration (just one new type of land use), but it hints at how use diversity and the clustering and prevalence of various uses may interact. Consider a more general situation, with a hypothetical landscape characterized in terms of three landscape-level variables: saturation (the proportion of landscape cultivated), clustering (the degree to which, say, agricultural plots are clustered or dispersed), and use diversity (the diversity of agricultural fields or alternative uses). All of these variables can affect biodiversity and may interact in various ways in their effects on biodiversity. Figure 3 illustrates our expectation that as the saturation of agricultural land use in a previously nonagricultural area increases, biodiversity at first increases and then declines. The increase results mainly from creation of a mosaic of habitats and ecotones. As the landscape becomes increasingly saturated with land devoted to agriculture, we expect biodiversity to decline because of reduced environmental heterogeneity. However, we expect that the relationship between saturation and biodiversity is also affected by the diversity of land use, as indicated by the three curves for different levels of use diversity. Greater use diversity may imply greater habitat di-

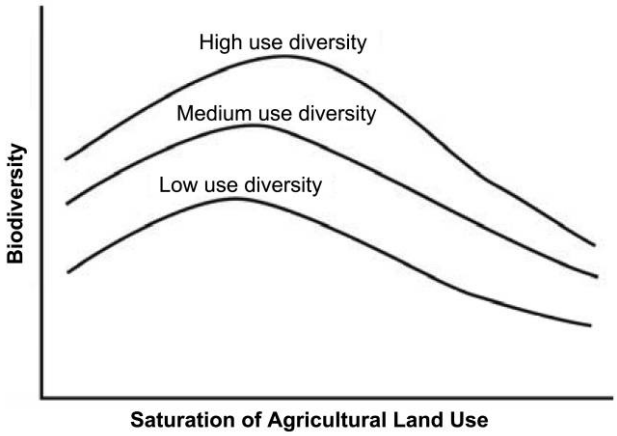

Figure 3. Expected influence of intensity of land use on biodiversity, for different levels of use diversity.

versity. Thus, our expectation is that higher use diversity can to some extent compensate for higher saturation of land use.

However, the effect of clustering depends on the level of "intensity" or prevalence of change (saturation). Figure 4 depicts our expectation that in a landscape that is highly saturated with agriculture (or other specific use), the degree of clustering of farms (or of any land use) will not have a strong effect on biodiversity because there will be little difference between maximum clustering and a random or a uniform distribution of land uses. At lower saturation, clustering may be quite important as it fragments habitats and generates microenvironments of sufficient size to affect the distribution and populations of various species.

Empirical evidence for the importance of saturation and clustering to the trade-offs between food security and biodiversity and conservation is accumulating. For example, Phalan et al. (2011) find that optimal solutions to the ongoing arguments over alternative approaches to reconciling needs for increasing food production and for preserving biodiversity—simultaneously using an area for agricultural production (though at lower intensity) and for conservation (land sharing) versus devoting some land to more intensive production while setting other land aside for conservation (land sparing)—depend not only on the species of interest but also on the patterns of alternative land use/land cover within a landscape mosaic.

This discussion illustrates how the variation in land use (and thus RD) is itself important. The diversity of uses—variety of crops, set asides for pasture or for wildlife as described for Simanjiro, and so forth—is likely to affect biodiversity. The biodiversity in turn will have implications for the success or viability of various land uses—for example, by influencing crop damage and predation, and by stimulating changes in opportunities for tourism, hunting, and restrictive conservation policies. Policies or practices that vary among villages are now producing variation in the distribution of land uses within and among villages (e.g., pasture commons in Loiborsoit; a wildlife area in Terrat).

Thus, it is reasonable to expect RD to affect resilience, but the relationship between spatial heterogeneity and system stability is complex, and the specific consequences will not always be obvious. Even restricting attention to just rangelands, spatial heterogeneity can be destabilizing in some systems but enhance stability and resilience in others (see Janssen et al. 2002), and the relationship may depend on temporal variation in rainfall and on grain of the landscape (Boone 2007). Whatever the relationship in a given case, it is clear that the degree and pattern of spatial heterogeneity can be important and that multilevel RD can influence that pattern. It can do so directly, as saturation and clustering of various land uses are potentially influenced by decisions at the individual or household level, village level, and higher levels. There may also be less obvious, more indirect consequences of RD—for example, through influences on family formation. Landscape change may be more sensitive to the number and composition of households than to population size per se and more sensitive when households are distributed widely than when they are clustered (Rindfuss et al. 2007).

Far more than biodiversity is at stake. The consequences of not setting aside common use areas for grazing could be momentous, resulting in significant transformation of the SES. Pastoral systems function as extensive systems; allocation of land to individuals, which is happening in different ways in different Simanjiro villages, fragments the landscape and could easily compromise the viability of the pastoral system. Conversion of commons to private holdings might lead to increased risk of poverty and/or greater inequality in wealth, even if allocations are equitable, by encouraging the breakdown of traditional redistribution mechanisms. On the other hand, under some circumstances inequality may be beneficial to the successful management of remaining commons. Those with greater interest and power might coerce others into

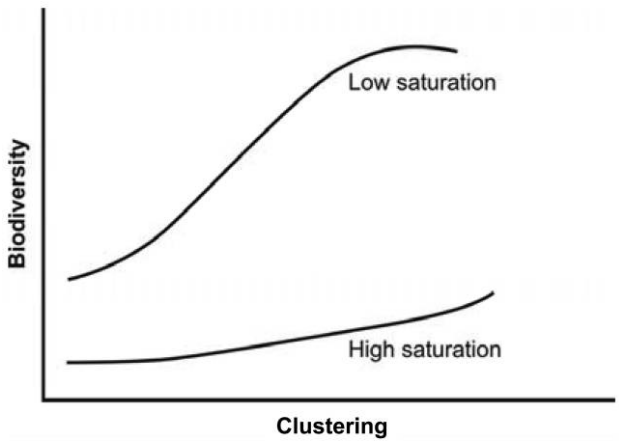

Figure 4. Expected influence of spatial clustering of land use types on biodiversity, for different levels of land use saturation.

maintaining commons (Ruttan and Borgerhoff Mulder 1999). However, in cases where inequality of wealth means that some individuals benefit more from maintenance of the commons than do others, those individuals may gain from seeing to it that the good is provided or maintained even if they have to bear the cost themselves (the "Olsen effect"; cf. Bardhan and Dayton-Johnson 2002).

Response Diversity and Indirect Indicators of Resilience in the Two Case Studies

Although a number of authors have discussed the resilience of pastoralist social-ecological systems (e.g., Homewood and Rogers 1991; Niamir-Fuller 1998; Robinson and Berkes 2010), none to our knowledge has explored the role of response diversity in those systems. Further, Robinson and Berkes (2010) noted recently that there have been few attempts to operationalize measures or surrogates of resilience in pastoralist SESs, and they go on to do so for a pastoralist system in northern Kenya, paying close attention to the social elements of the system. Our paper here contributes to filling the gap that they note, but our aim is more general, and our argument about the relevance of RD to resilience pertains to other SESs as well as to pastoralist/rangeland systems.

Our description of response to environmental change and uncertainty on the part of Ngisonyoka Turkana and Kisongo Maasai, be it to climatic fluctuations, new political-economic developments, or long-term trends, points to a variety of ways in which RD may be related to the functioning and resilience of those SESs. In Turkana, we argue, the system "works" (or at least persists) in part because of RD—persistence of the human population and their nomadic pastoral livelihood depends on the diversity of responses to repeated environmental challenges (climatic, biotic, sociopolitical). Resilience and persistence of the SES is to some extent a consequence of response diversity. The most obviously crucial diversity is seen in herd composition and herd movement. As explained in the introduction, two categories of variables that affect the continuity and thus the identity of an SES are system memory and experimentation or innovation. Although Turkana is by no means a timeless, unchanging place, the responses we describe are largely responses to well-known risks and circumstances and reflect long-standing practices—born of experience and memory rather than experimentation (but see below for an exception to this).

In contrast, the responses in Simanjiro to the developments associated with Tarangire National Park and conservation policy are just now taking shape, and the options, risks, and opportunities are not nearly so well known to the people who must cope with the changes. Already it is clear that there is RD at both the village and household levels (further diversity is also seen among subvillages—administrative subdivisions of villages—but is not discussed here). The institutional context is in flux, but the developing patterns of land use and livelihood strategies stand to be extremely important for the Tarangire-Maasai Steppe SES, which embraces the park with its highly valued biodiversity and the study villages but extends much further. Resilience of the current SES, or the character of its transformation to an alternative state, will to some extent be shaped by RD.

The Simanjiro case also points up the possibility that RD may be observed at different levels and that what goes on at different levels may interact in ways that are important for the dynamics of change in the SES. From the perspective of conservation interests, decisions concerning land use taken by some Simanjiro households are in conflict with actions taken at the village level. Antagonistic effects across levels might be expected when the benefits accruing to decision makers at the different levels depend on opposing or incompatible outcomes. Cross-scale interactions are likely to be common in complex systems, but it is difficult to generalize at this point about how RD may influence such interactions.

In these two cases we find ample evidence of RD to environmental change and challenges, including well-known environmental fluctuations and newer constraints and opportunities, and see reason to believe that RD is relevant to the resilience of both of these SESs. As noted earlier, measuring resilience is problematic, so demonstration that phenomena, including those that we describe here as instances of RD, affect resilience can be difficult. Carpenter et al. (2001) point out that in order to evaluate the resilience of a system, it is necessary to specify "resilience of what, to what?"—that is, what state within the system is of interest and what perturbations are most important. Only then can appropriate surrogates for resilience be chosen. Table 2 sets out an attempt at specifying these considerations for the Turkana and Simanjiro SESs. Perturbations include events or conditions that have occurred in the past and may be expected (by researchers and/or local people) to recur. There certainly may be other system states and perturbations of interest and, consequently, other resilience surrogates; those listed simply reflect concerns that have been central to our research. Our aim here is not to evaluate the resilience of either system; rather, it is to point out that RD is relevant to appropriate resilience surrogates and may be an integral aspect of them. We do so while keeping an eye on how specific surrogates included in table 2 fall within the categories of factors that influence system identity—especially memory and innovation.

Turkana

Our long-term research with nomadic Turkana makes clear the ubiquity of episodic herd loss and the importance of social and exchange networks both for coping with such loss and for family building. We argued (above) that diversity of management strategies of families (with regard to species mix and movement) contributes to the ability of the Ngisonyoka to cope with environmental perturbations and that RD reflected in differences of management strategies within exchange networks further enhances the viability and utility of these net-

Table 2. Surrogate indicators of resilience for Turkana and Simanjiro social-ecological system (SESs)

	Turkana	Simanjiro
System state (resilience of what)	• Adequate livestock/human ratios	• Secure livelihoods for local population • Biodiversity (wildlife) maintenance
Perturbations (resilience to what)	• Herd loss from drought, disease, raiding	• Herd loss from drought, livestock disease • Conservation policy (park expansion, land use restrictions) • Immigration • Land use/land cover change
Resilience indicators (surrogates)	• Extent of exchange networks • Diversity of management strategies (species mix, movement) of families • Diversity of management strategies within exchange network • Expansion of family networks to settlements and towns • Innovative defensive formations	• Diversity of livelihood options open to families • Accessibility of resources (water, pasture/browse) to livestock and wildlife • Distribution of authority/power regarding land use (property rights) among interest groups • Distribution of costs and benefits of conservation and tourism • Maintenance of institutions that facilitate restocking by redistribution of livestock and mobility and resource access across sectional boundaries

works. These arguments need not be reiterated here. However, our description and discussion was based on Ngisonyoka families that were still in the nomadic sector. Additional evidence for the importance of the networks is seen by looking beyond these families. Studies of settled Turkana living in several of the small towns along the Kerio and Turkwel rivers in south Turkana show that the principal reason for settlement is loss of livestock (from drought, disease, and raiding) coupled with inability to restock (Brainard 1991; Campbell et al. 1999; McCabe 1990), an inability tied to an inadequate social network. The contrast between northern and southern Turkana during an especially severe drought in 1979–1981 is also instructive. A breakdown of traditional drought-coping institutions and practices in northern Turkana, arising from the extended drought and exacerbated by intensified intertribal raiding, resulted in mass movement to famine relief camps. Extended residence in relief camps weakened the traditional exchange networks and the ability to restock (McCabe 1990). South Turkana (including Ngisonyoka) also suffered from the same drought, but there were no famine relief camps, and traditional institutions remained intact. The resilience of the Ngisonyoka relative to their neighbors in this case is attributable in part to the greater herd diversity (the north has extensive grasslands and, with less area favorable for camels, is more heavily dependent on cattle) and to the ability to maintain networks for mutual aid. Diversity of location, herd movement strategies, and herd composition of members of an exchange network increases the likelihood of being able to negotiate livelihood-saving exchanges or loans of livestock and temporary relocation of dependents. Comparison of nomadic and formerly nomadic Turkana is most directly relevant to viability of the family or network, not the resilience of the SES as a whole. Indeed, some "failure" and movement out of the pastoral sector (and subsequent opportunities for restocking and reentry to the pastoral sector) are an integral part of the SES. Nevertheless, since persistence and viability of domestic units and their herds is central to the SES, one would expect that a marked decline in the extent and diversity of exchange networks would signal compromised resilience of the SES. Maintenance of that institution signals maintenance of system identity and resilience.

Turkana have engaged the risk of livestock raiding for a long time. However, during the years following our active fieldwork in Turkana, this old threat escalated rapidly in intensity and severity as automatic weapons became more readily available in northern Kenya. In response, a new form of social organization called an *arum-rum* emerged. In this arrangement, many households came together each night within a set of fortified fences that were actively guarded throughout the night. The *arum-rum* had a leader, and all participating households moved across the landscape together, which meant that large numbers of livestock were competing for forage in a limited area. Thus, in a trade-off for security, some Turkana herd owners were sacrificing better access to forage for their livestock and had to move more often. Others chose not to join an *arum-rum* and continued to herd as they had been. The *arum-rum* system is clearly a case of innovation and reflects RD to the intensifying risk of raiding.

Simanjiro

The Simanjiro case is complex and, as mentioned previously, is changing rapidly. Some resilience surrogates suggest that the Simanjiro SES is under considerable stress and that the resilience of the system is being eroded. Others suggest that the SES is quite resilient and can be expected to persist into the future.

Biodiversity is an important determinant of system identity

in many cases because of the ecological links among species and the ecosystem services these species collectively provide. But it is especially important in Simanjiro because of the additional, enormous importance of wildlife diversity for tourism and the national economy and as a salient influence on land use policy. There is a general consensus that biological diversity tends to enhance resilience of ecosystems when it entails redundancy within functional groups (e.g., herbivores, pollinators) and results in the presence of species with overlapping functional diversity (Walker, Kinzig, and Langridge 1999; see especially Maestre et al. 2012 on ecosystem function in drylands). As noted at the outset of this paper, RD within functional groups (inter-species RD) is likely to contribute to resilience (Elmqvist et al. 2003). In some contexts it makes sense to consider diversity of livestock and crop species along with that of wildlife, and indeed alteration of traditional patterns of livestock husbandry can be detrimental to wildlife (e.g., Gregory, Sensenig, and Wilcove 2010). The description of Simanjiro in the preceding section indicated some of the ways in which RD within or among human communities might affect biodiversity, directly and indirectly, and thereby influence resilience. Patterns of species loss can be crucial; any influence of RD on fragmentation, minimal habitat, and other landscape characteristics can be important for local extinction or replacement of species and the impact of invasive species. Disturbing reports of precipitous declines in wildlife numbers both within and outside of TNP (Foley 2004) indicate compromised resilience of the Simanjiro SES. It is too early to tell how the changing land use and land cover patterns in Simanjiro (including the new set sides for wildlife in some villages) will affect biodiversity and just how the environmental, ecological, and economic trade-offs will affect the SES, but it seems clear that RD will play a role in these processes.

Another resilience surrogate listed in table 2, the distribution of costs and benefits accruing from conservation and tourism, also suggests that the current SES is at risk. Although villages are benefiting from funds generated by wildlife-based tourism or directly from TANAPA, most of these funds are being captured by village elites (Sachedina 2010), so the pressure to extend agriculture has not been reduced as much as might be expected with more equitable distribution of benefits.

Nearly all Maasai in Simanjiro who are part of our ongoing research are engaged in both raising livestock and cultivation, but the options for mixed livelihood strategies are to some extent moderated by government land use policies and the Maasai's reaction to these, as well as by individual household resources. Preliminary analysis of recent survey results shows marked differences in herd size at the household level and at the village level, and also much variation in the amount of cultivation (see table 1). Although almost all fields are plowed by either tractors or oxen, the size of fields varies greatly. This is true for individuals, subvillages, and villages. Land use policies vary by village and subvillage. This is seen in the degree to which village land is allocated to individuals and in the amount of common grazing lands and land set aside for conservation. Land allocations vary from a few acres to thousands of acres. There is also variation in the willingness of villages to lease land to outsiders and in the extent to which village lands include some large commercial farms.

Accessibility of resources, another surrogate indicator included in the table, has changed markedly in recent decades. The most obvious change has been loss of the right to enter TNP and use water and other resources within the park, including Silalo Swamp, long a crucial drought refuge. The partial ban on cultivation in the Simanjiro Plains represents another sort of restriction on resource utilization. These restrictions clearly compromise the ability of families to cope with environmental and political-economic perturbations, though they may have beneficial effects on biodiversity. On the other hand, we witnessed the influx of many livestock and herders from northern Tanzania and southern Kenya migrating into Simanjiro in response to the recent drought. While this may seem to make the SES more vulnerable by depleting local resources, it indicates that Simanjiro remains part of a much larger system whose long-term survival depends on access to distant resources in times of stress. The fact that this traditional Maasai institution remains viable despite the privatization and fragmentation of lands is a strong indication of a resilient SES and a demonstration of the importance of system memory embedded in traditions. This is an interesting example of a latent or "cryptic" resilience-enhancing mechanism—we could not tell whether or not it was still there until it was called for. The recent drought shows that it is, but continued privatization could jeopardize its efficacy.

The practice of granting access to water and pasture to hard-pressed Maasai from other sections is a specific example of system memory. More generally, RD may serve to maintain awareness of and experience with a range of alternatives for coping with perturbations, making it more likely that other actors can effectively adopt a given response in the future if need be or if preferable. This represents both memory and learning. Shifts of livelihoods or other changes may entail loss of relevant knowledge and experience or a shift in what knowledge is relevant. For example, herders who have recently adopted farming may have limited access to advice on crop mixes, when to plant, or what to do about outbreaks of pests. This may render not only the pursuit of new livelihoods less efficient, it may also compromise the adaptive capacity of the actors and the resilience of the SES. The loss of memory or change in the relevance of stored knowledge links this system attribute with another that is also related to resilience—experimentation or innovation.

In general, RD can represent a source of experiments or tests of novelty and can facilitate learning. Each variant in a new context may serve as an experiment that can be evaluated and emulated or avoided by others (households, village leaders, or other decision makers). More experimentation (greater RD) may be expected when experience with a particular challenge is limited. Maasai and Turkana herders have faced the problem of livestock disease for a long time and generally

know what can be done for prevention or treatment (although there may be important differences arising from institutional sources, such as availability of veterinary services). In contrast, the Kisongo Maasai response to conservation-related challenges (especially potential alienation of land) is quite variable—the Simanjiro villages are clearly engaging in experiments in land allocation, taking diverse approaches to achieving goals common to all four villages: securing land tenure and access to resources. Further experimentation is seen at the household level, with different mixes of crops, including sunflower and sesame along with the more usual maize and beans, and investment in different breeds of cattle and in use of veterinary drugs. The Kisongo here are facing a relatively new problem, and the best strategies or all possible strategies are not known.

In both the Simanjiro and Turkana examples, the pattern of response and the variation should evolve with time and experimentation, creating experience and learning. RD is clearly part of such experimentation, and the examples and discussion presented here suggest that in general RD will enhance resilience. However, the possibility that RD could in some circumstances compromise resilience should not be dismissed. For example, continued conversion of rangeland into cultivated land could negatively impact grazing of both wildlife and livestock. Maximizing RD could result in patterns of fragmentation, as illustrated in figure 2, which could reduce access to grazing for both wildlife and livestock and induce significant changes in biodiversity. In some cases, greater uniformity in response might keep out "invasive" influences (e.g., invasive species, commercial farming, or mining interests). More generally, not all innovations or experiments work out—they may entail costs to individuals, families, networks, biodiversity, or the SES as a whole.

Conclusions

The primary purpose of this paper is to draw attention to the relevance of response diversity for the functioning of social-ecological systems, with a particular focus on the consequences of RD for resilience. Our argument is not that RD always creates change nor that RD is always adaptive. RD may promote and shape change, but it can also be essential to maintaining stability and enabling persistence of elements within the SES (as seen clearly in the Turkana case). RD may be crucial to understanding both change and stasis and is thus central to understanding the functioning of SESs in general. More specifically, the diversity of responses of people within an SES to environmental fluctuations, shocks, and uncertainty is important to the efficacy of the response, the persistence of the population, human impact on the environment, the process of experimentation and learning, maintenance of system memory, and SES resilience.

This diversity occurs at multiple levels, which may interact with one another. The ways in which RD at different scales relates to system dynamics within and across scales, as reflected in heuristics such as the adaptive cycle or panarchy (see Gunderson and Holling 2002; Walker et al. 2006), bears further investigation.

A secondary purpose of this paper is to contribute to answering the need to operationalize "resilience." To that end, we identified variables that can serve as surrogate indicators for the resilience of certain central system states of both the Turkana and Simanjiro SESs.

We did not set out to fully evaluate the resilience of these SESs—doing so would require additional fieldwork and another full-length paper. Our discussion of the demonstrated and likely effects of these surrogates clearly shows the relevance of RD to evaluation of the resilience of these SESs in the face of salient perturbations (e.g., herd loss from drought, disease, and raiding; conservation-driven shifts in access to resources and land tenure). The central importance of RD in these cases suggests that attempts to operationalize resilience in other contexts should consider the potential, even likely, relevance of RD to appropriate surrogates in those SESs.

Numerous authors have noted that human homogenization of landscapes has decimated entire functional groups of species, rendering ecosystems more susceptible to disturbance and consequent regime shifts (Elmqvist et al. 2003; Folke, Colding, and Berkes 2003; Gunderson and Pritchard 2002; Scheffer et al. 2001). RD within and among human communities introduces the possibility of "heterogenization" of the landscape in some cases, which could in turn either increase or decrease species diversity at given scales, with concomitant implications for resilience.

As noted in the introduction, both functional diversity and functional redundancy (ecological redundancy) are related to resilience, but RD has not generally been seen as linked to the effect of functional diversity. The examples we have presented here show that intraspecies and intrapopulation RD can produce functional diversity as well as mediate the consequences of functional redundancy for resilience. Functional diversity can be seen among the multiple livestock species kept by Turkana and in the new livelihood options in Simanjiro; both are in part products of RD. Such functional diversity should help ensure maintenance of elements of the SES in the face of perturbations. Thus, multilevel RD is related to the roles of both functional redundancy and functional diversity in system resilience and adaptive capacity.

Finally, understanding the role of RD is important not only for understanding what affects resilience (positively or negatively) but also for how resilience and related properties of systems evolve—or perhaps more properly how the processes, structures, and interactions that confer resilience evolve. Further, the need for exploring and understanding the causes and consequences of RD does not ride on the fate of resilience theory, which is a work in progress. Whether resilience theory thrives, is altered radically, or dissipates in favor of other approaches, understanding SESs will entail understanding the role of RD in those systems. The bottom line is that response

diversity is an integral part of the dynamics of social ecological systems and should be so considered.

Acknowledgments

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Comments

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Leslie and McCabe's paper presents a very welcome catalyst for a profound discussion of the merits of and challenges to the resilience concept in ecological anthropology. While discussions of resilience have long been pertinent in ecology, and in earlier decades in psychology, anthropology has abstained from an in-depth discussion of resilience. This is the more astonishing, as most ecological anthropologists (and most anthropologists in general) would claim that some cultures master challenges in a more sophisticated way than others, or that—through the ages—some societies are marked by profound stability, while in others instability of many cultural features is evident. Leslie and McCabe's attempt to highlight the contribution of response diversity (RD) to an understanding of resilience in social-ecological systems is an effort to single out the relation of one key variable (RD) to resilience. Such an effort rests on a number of pertinent premises: (1) there is a need for some kind of systems approach, dealing not with narrowly defined, closed systems (in an earlier Rappaportian style) but spatially comprehensive entities in which ecological and social variables are interdependent despite varying degrees of self-organization; (2) in order to research the linkages between resilience and other social and cultural variables, longitudinal data are necessary; (3) only a comparative effort can elucidate causal linkages; (4) research must reflect processes at multiple scales and linkages between those scales; and (5) human agency must be linked to structural features of a society. These premises make anthropological research on resilience different from ecological (and also psychological) approaches, where resilience is often treated in a nonhistorical, single-case, and functionalist manner.

The definition of surrogates for resilience is a necessary first step to make the concept operational. Further clarity and comparativeness would be gained if the surrogates chosen were the same in both cases. The dissimilarity of surrogates throws up some questions. For example, is biodiversity, given as a key surrogate for Simanjiro, not also important for the Turkana case (e.g., the diversity of grasses and also of fauna)? Would "accessibility of resources" not count as an important variable for both systems? Why is the "expansion of family networks to settlements and towns" (see table 2) taken as a surrogate for the Turkana case, while the implications of labor migration are not further considered for Simanjiro households? In the Turkana case many surrogates refer to the household level, while in the Simanjiro case surrogates mostly focus on village and intervillage scales. Further comparativeness would be gained if surrogates addressed the same levels. This would, perhaps, then highlight whether Turkana society seeks resilience more at the household level while the Simanjiro Maasai seek resilience at the village level (if at all). We believe that analysis could be refined if scales (household, village, region) were included more stringently and the choice of surrogates made more explicit. This brings us to a brief second point: it appears to us that the discussion of resilience would be furthered if the relation between resilience of systems and vulnerability of households and individuals was focused on consistently. In Turkana, we observe a relatively resilient social-ecological system (SES), while failed pastoralists apparently drop out and migrate to towns in large numbers, where they usually live in misery (Dyson-Hudson and Meekers 1999).

The fact that land use/land cover change is marked as an important perturbation in Simanjiro, but not listed as a potential perturbation in the Turkana case, prompts our last concern: if we were to stretch the time line somewhat to include the nineteenth century, then the Turkana case would also have shown profound land use changes, marking the transition of a mixed pastoral-foraging and, in some cases, small-scale agro-pastoralist economy (Oropom, Siger) to a highly specialized pastoral economy (Lamphear 1988). Would this change be conceptualized as a perturbation, or even as system shift? This raises the question of the time span of our analysis: how long does an SES have to endure before we speak of a "resilient" SES? Furthermore, we are challenged to define how profound changes must be in order to acknowledge the breakdown of the old and the emergence of a new system. From our own research in East Pokot (Kenya), where we observe dynamics that are, to some extent, comparable with the case of Simanjiro (Bollig 2006; Greiner 2012), we tend to conclude that the recent land use changes brought about by wildlife conservation and sedentary cultivation are clear indicators of a breakdown of the former SES (specialized pastoralism). If we accept this position, then the question arises: what time horizon of newly emerging, highly complex SES is sufficiently deep to allow us to make assumptions regarding its resilience? Despite these reservations, we do see

important elements of a new ecological anthropology here, which reemphasizes agency and social organization as formative elements of social-ecological systems and which has the courage to formulate generalizations.

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The authors make an important contribution to human ecology by applying the biological concept that response diversity can influence ecosystem resilience to understand human responses and their effects on their social-ecological systems (SESs). This paper utilizes data from their studies of Turkana pastoralism in northern Kenya and Maasai agro-pastoralism in Tanzania. The authors clearly demonstrate that both groups show diverse responses within their own populations to stressors of climate and land competition (with other herders, game parks, agricultural production). However, I am not certain that the authors make a clear case that the outcomes of these responses contribute to "resilience" of the social-ecological system, defined by the authors as "capacity of a system to absorb disturbance and reorganize . . . that allows for the persistence of system function, structure, and feedbacks."

Let us take the two cases separately. The authors point to a diversity of strategies employed by Turkana herders to environmental and political stresses (i.e., competition and raiding) that include herd mobility and herd diversity (keeping mixed species), which reduces competition with other Turkana herders and consequently conserve the range for further pastoralism. I found similar behavior among neighboring Ariaal (mixed Samburu/Rendille) pastoralists in northern Kenya. Here larger communities undergo periodic fission and fusion, breaking into smaller communities concentrating on different types of livestock—camels, cattle, or small stock—going their separate ways during dry periods and reaggregating during wet seasons. I proposed that Ariaal, with greater species diversity, were more "resilient" to drought than either the highly specialized camel-keeping Rendille and cattle-keeping Samburu (Fratkin 1986). But it is not clear how or if these responses, in both the Turkana and Ariaal cases, contributed to resilience in their SESs. Where Turkana response diversity may reduce competition on grazing resources in situations of low population density, this could easily change with new stresses of increased population pressure or ethnic competition leading to overutilization and resource decline, something of which the authors are strongly aware. As among the Turkana, there is violent competition between various pastoral groups east of the lake (Rendille, Ariaal, Gabra, Boran, and Somali), which has led to a constriction of the grazing range and an increase of sedentarization in small towns, resulting in a nonresilience in the pastoral system (Fratkin and Roth 2005). The authors state clearly that outcomes or consequences to the SES could be negative as well as positive; they also agree it is difficult to measure resilience in these contexts.

The Maasai case in Simanjiro, Tanzania presents a clearer, albeit more complicated picture, than the Turkana. Maasai in both Tanzania and Kenya have recently changed their production system from mobile pastoralism to more sedentary agro-pastoralism, where they face environmental stresses of drought but also political, economic, and legal pressures involving land ownership, changes in livelihood, restrictive government policies, and the impact of conservation and tourism organizations that are largely unknown to the Turkana. The authors show a wide diversity in Maasai responses in their comparison of four distinct communities; they present findings that support their premise that response diversity indeed affects the wider SES, which must satisfy both agricultural production while maintaining biodiversity for wildlife conservation. The authors show a variety of possible outcomes—increased trading in both communities or taking advantage of incomes from conservation efforts—some of which set the stage for further cultivation, sedentarization, and further altering of their environment.

While some of the outcomes suggest "resilience"—the ability of the system to adjust and maintain livelihoods—are these in the long run sustainable? To what degree can one predict resilience? One must ask what will happen as human and livestock populations grow, as irrigated farm production increases, and availability of open pasture decreases? What will happen as new and larger stressors such as global climate change kick in? The Maasai plains have already experienced problems with water availability, brought about in part by the shrinking of Mt. Kilimanjaro's glacier and in part by the aggrandizement of water resources by commercial farms including export-driven floriculture. While their "response diversity" indeed leads to changes in the SES, is it one of resilience or further degradation? The authors attempt to predict these changes, and that is a positive gain of their insights.

In all, the authors make an important contribution that allows us to model diversity responses and environmental outcomes that are applicable not only for pastoral and agropastoral communities but could easily be extended to other production systems. They also provide a model to predict future land use, both for increasing food production and preserving biodiversity, as well as for understanding resource use and outcomes of rapidly growing urban and periurban areas in Africa and other areas in the developing world.

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The paper asks how "diversity" of behavioral responses relates to "resiliency" as an attribute of a social-ecological system

(SES), that is, its capacity to bounce back after disruption. But can the systems perspective presented here overcome the intrinsic circularity associated with adaptive models, or does the notion of resilience merely restate that systems are in place and function? What aspects of an SES should reflect resilience, and how can this approach avoid the homeostatic assumption that it is an idealized stable state that should be restored?

Clearly there are systematic links between grassland ecosystems, mobile livestock production, family-based herding, community-organized landholding and exchange networks, and a broader set of cultural institutions and normative practices. But to what aspects of "the system" do diversity and resilience apply, especially if its social, institutional, and spatial dimensions make it a diverse and "open system" with movement across fuzzy and porous boundaries? If it be the land-livestock-herder nexus (addressed by the Turkana STEP project), how should shifting government policies, international markets, new and contradictory forms of resource tenure, increasing loss of land to foreign investment and government appropriation, and increasingly fragmented forms of land use and diversified livelihoods be taken into account? Are these factors inside or outside the system in question?

Recurrently, the paper falls back on a time-tried trope of the "traditional" to depict pastoral patterns of land use and herding practices. It is reasonable to contrast recent innovations (e.g., mechanized agriculture) to practices that have much greater longevity, but why should practices that respond adaptively to economic and ecological constraints (i.e., rapid dry season herd mobility) be termed "traditional," implying reliance on cultural memory rather than instrumental responses? Kisongo Maasai use of Simanjiro is as opportunistic and institutional as repetitive. Depicting as "traditional" pastoral strategies that are highly adaptive, effective, and evolving disarms pastoralists in the eyes of policy makers and the public by implying that their practices are reflexively habitual, nonrational, and immune to modification based on experience, none of which, I am sure, the authors intend.

Several observations suggest that lower diversity responses may also support resilience! The behavioral approach here emphasizes the individual as a unit of analysis, but in pastoral land use the action unit is usually the household or family within a neighborhood social context. As McCabe has demonstrated for the Turkana, diversity exists within a family-based "firm" that subdivides when herds are "split" and moved to specialized pasture areas. Pastoralism itself optimizes resiliency, given arid environmental oscillations and shocks, with grassland vegetation and livestock serving as "shock absorbers," mitigating the effects of extreme variations in heat and rainfall. As the paper points out, both multispecies herding management and mobility are aspects of response diversity that enhance the resilience of pastoral-rangeland systems. These approaches operationalize the old adage, "don't put your eggs in one basket." But other herders specialize in single species and one ecological zone, or choose to minimize mobility (less nutritious grazing offset by lower livestock energy expenditures). Either high- or low-diversity options may prove effective, so putting your eggs in one basket may pay off with efficient restoration of a system under conditions of stress!

Building social networks often enhances diversity by creating multiple social linkages. But some herders minimize diversity by limiting their social networks, following Polonius's advice to "neither a borrower nor a lender be"! Gulliver (1955) contrasted low Samburu bridewealth that led to continuing network demands by in-laws with high Turkana bridewealth transfers that led to virtual severance of ties. The authors report a modest positive correlation between livestock wealth and acres of land under cultivation, implying that livelihood diversification among northern Tanzanian Maasai is beneficial. But research among some southern Kenyan Maasai suggests that benefits from intensifying livestock production sometimes outweigh diversified livestock-crop pursuits. Accordingly, despite the occurrence of benefits from a type A strategy of increasing diversification in livestock species and splitting herds, herd mobility, social networks, and mixed livelihoods, there is a less diversified type B strategy that under some conditions may be equally adaptive. So the thesis that response diversification normally leads to greater resilience within a rangeland pastoral SES may identify only one of several strategic pathways that work at the systems level.

Perhaps having type A and type B alternatives available actually demonstrates response diversification! But then resilience would operate independently of diversification. Maasai adoption of mechanized agriculture in Simanjiro may be a strategic response to a Tanzanian policy and regulatory framework that provides incentives for agriculture and denies secure land rights for pastoral land use, but this policy diminishes both livestock and wildlife numbers, undermines local nutritional security, and degrades rangeland vegetation quality and biodiversity. While recognizing why pastoralists have diversified into agriculture in a counterproductive regulatory environment, seeing this as contributing to resilience would seem to dull the conceptual sharpness that the notion promises. The Tanzanian land use and regulatory regimes in fact diminish rangeland social-ecological system resilience on every important measure, which is worth emphasizing in the interest of addressing the more "applied" policy implications of this fascinating comparative study.

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Leslie and McCabe expound with great clarity the concepts of functional diversity and response diversity as key components of social-ecological complexity. Past applications of ecological concepts of resilience to complex social-ecological

systems (SESs) have failed to deal adequately with human agency or with its components/correlates of human innovative imagination, anticipation and planning, capacity for collective action, and for creating inequalities (Davidson 2010). Leslie and McCabe go some way to address this, theorizing response diversity among individuals within human groups as a key dimension shaping resilience. They focus on outcomes rather than causes of response diversity, emphasizing resilience and adaptation, and point to ways of operationalizing measures of resilience to document persistence or reveal stress leading to impending crisis.

The interpretation of Turkana strategies in resilience terms is convincing but begs questions as to how mapping a well-documented pastoralist system onto a new conceptual framework advances understanding. The suggestion that "resilience of an SES may . . . depend on variation—the diversity of responses within components of that system—as much or more than on the typical or mean responses" echoes the insight that savanna ecosystems are better characterized by their variability than by their mean (Western 1975). Pastoral strategies—mobility, multispecies herding, individual herding movement decisions, social networks—have long been understood in terms of risk management, and their variations widely documented. Beyond relabeling, as resilience surrogates or indicators, various measures of the adverse outcomes these strategies seek to buffer (see table 2: loss of biodiversity, of herds, of access to key resources), what does this framing add to the state of knowledge? Leslie and McCabe's simple model of alternative household- and village-level land use decisions predicts outcomes of different patterns of land use choice and change. The postulated initial increase and later decline of biodiversity with distance from settlement (see figs. 3, 4) has been documented empirically and analyzed in depth for the Kenyan side of their focal northern Tanzania/southern Kenya Maasai SES (Ogutu et al. 2010; Western and Gichohi 1993).

In fact, might overlaying resilience frameworks onto these systems actually constrain understanding? Leslie and McCabe consider not only persistence through change but also transformation; some aspects of the Tanzanian Maasai system suggest it is undergoing "a period of reorganization in the adaptive cycle." They see household and village response diversity as a potential key to persistence of this system through change. Parallel work has detailed the variety of household-level livelihood strategies and village-level land uses bearing out the wide array of opportunities, choices, and returns from different activities (Homewood, Kristjanson, and Trench 2009; Homewood, Trench, and Brockington 2012). Leslie and McCabe make clear that Maasai are responding to "a relatively new and rapidly changing set of challenges," concluding that "some resilience surrogates suggest that the Simanjiro SES is under considerable stress and that the resilience of the system is being eroded. Others suggest that the SES is quite resilient and can be expected to persist into the future." Could their outcome-based approach be obscuring understanding of the broader processes at play here? Leslie and McCabe acknowledge the very different situations of each village, particularly in terms of the scale and immediacy of land loss threats. But in line with their focus on response diversity, they portray the variety of local choices as "experiments in land allocation." Alternative analytical frameworks would see these more as short-term tactics adopted by hard-pressed players. Using individual land allocation or conversion to cultivation as tenure strategies looks like a weapons-of-the-weak move in a series of unequal contests against powerful forces (the state; international conservation agencies; external, often global investors[1]) driving increasingly widespread and well-documented land grabs (Homewood, Trench, and Brockington 2012; Igoe and Croucher 2007; Sachedina 2008; Sachedina and Trench 2009). The scale of those land grabs—locally in Simanjiro, throughout East Africa and the Horn (Catley, Lind, and Scoones 2012), more broadly across African rangelands (Wily 2012), and globally (Fairhead, Leach, and Scoones 2012; Lambin and Meyfroidt 2011; Zoomers 2010) suggests some East African arid and semiarid lands' SESs may be nearing endgame. Political ecology, rather than resilience frameworks, may be the more immediately pertinent framing here. Are the influxes of outsiders in times of stress a sign of persistence or an indication of growing failures of reciprocity and control (Nkedianye et al. 2011)?

African pastoralist SESs may have been resilient for millennia in managing their arid land biophysical environment and production system. But current rates of loss of land and key resources confront the Maasai pastoral SES (and increasingly the northern Kenyan Turkana system too[2]) with perturbations so overwhelming that collapse and transformation seem more likely than persistence through change. The present work clearly takes resilience thinking forward, but resilience thinking has yet to add significantly to established insights from alternative frameworks into the workings of pastoral SES.

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Ecologists have recently learned that response diversity sometimes indicates the existence of more than one stable state. This point was brought home by the discovery of alternate stable states in Dutch lakes. For decades, excess fertilizer

1. YouTube clip of August 2009 Maasai evictions by hunting companies in northern Tanzania; http://www.youtube.com/watch?v=i-FP2gRvziw.

2. Sudan-Kenya pipeline construction, maintenance, and ongoing security arrangements are set to impact northern Kenya rangelands. The construction of a major resource city near Isiolo will have far-reaching effects on this water-limited environment and on tenure of and access to land and key pastoral resources; http://transitions.foreignpolicy.com/posts/2012/07/11/south_sudans_pipe_dreams.

flowed into the lakes, triggering algae blooms and eutrophication. But simply reducing the amount of fertilizer entering the lakes was not enough to restore them to clarity. It turned out that alternate stable states existed, one turbid and the other clear. In ecology, such alternate stable states or attractors are known as "regimes." The effects of nutrient flows depended on which regime a lake was in, so generalizing across all lakes obscured these differences. Once the existence of alternate regimes was recognized, a simple intervention was sufficient to restore the lakes to health. Temporarily removing the fish allowed sediment to settle and zooplankton populations to increase, whereupon water clarity could be improved by reducing the amount of fertilizer flowing into the lakes.

Over the past decade, studies of ecosystem dynamics, especially long-term ecological research, suggest that ongoing change and variability are actually typical. Nonlinear transitions between regimes are characteristic of lakes and rangelands, and there is growing evidence that these occur at all scales up to the planetary. This discovery led to a shift from the investigation of equilibrium or near-equilibrium states to the study of stability boundaries for different regimes. Regime shifts in ecosystems like lakes are hard to miss, since they produce visible changes in the biotic community. Moreover, the dynamic behavior of natural ecosystems—their inner workings—are relatively clear-cut. But what of tightly coupled social-ecological systems (SESs)? It is possible, perhaps likely, that the interaction of social and ecological components could produce alternate stable states. If we assume that interactions are linear, evidence for the presence of alternate steady states will be mistaken for noise. If more than one attractor is hidden in the data, it can only be discovered by cross-scale comparisons.

I offer an example from Bali. Rice paddies are shallow artificial lakes that are brought into existence by the collective action of groups of farmers. While the farmers are nominally in control, ecological processes impose constraints on the timing and spatial scale of collective action required to sustain the rice crop. The farmers are organized into groups called subaks, which have their own internal dynamics. If more than one attractor existed in this coupled SES, how would we know?

Farmers were surveyed in eight subaks along the Sungi river in western Bali. The farmers in the upper four subaks responded more positively than downstream farmers to all survey questions, including the efficacy of sanctions; the ability of the subak to carry out irrigation maintenance, perform rituals, and conduct meetings; and the overall condition and resilience of the subak. Importantly, we also found that the patterns of interaction among key variables were dramatically different between the two groups: for example, the ratio of landowners to sharecroppers was significant for the downstream subaks but not their upstream neighbors. Similar results were obtained from the "dictator game." While the upstream and downstream groups experience similar social and environmental conditions, they respond to them in different ways. The more successful upstream subaks flourish in a small but deep basin of attraction. Confident in their collective ability to meet any challenge, they are exceptionally public-spirited. Their neighbors downstream cluster around their own attractor, revealing that muddling through can also be a steady state, with different dynamical relationships among state variables than in the upstream group. Figure 5 shows the two basins of attraction from the survey responses. The first two principal components account for 90.9% of the variance in the responses of farmers in the upper subaks, and 94.4% for the lower subaks, and the separation between the two basins is significant at four sigma. The transition pathway between the two regimes for a hypothetical subak is dominated by the efficacy of sanctions and the ability of the subak to mobilize its members for agricultural labor. The functional significance of these variables is obvious; they are plausible as drivers pushing subaks toward one or the other regime, and the depth of the respective attractor basins provides information about how difficult this journey may be (Lansing et al. 2012).

Failure is also an option: subaks and their rice terraces are presently vanishing at a rate of about a thousand hectares each year. Thus, there are at least three attractors for the subaks, each with its own dynamics. Intuitively, it is not surprising that the coupling of social and ecological dynamical systems does not converge on a simple linear equilibrium. If, as in this case, multiple attractors may be hidden in the data, cross-scale comparisons of response diversity are necessary. As in the Dutch lakes, response diversity may be the key to mapping the boundaries between regimes. Analytically, the boundaries of a regime, its basin of attraction, defines its resilience. As Leslie and McCabe show, response diversity can have very different meanings depending on the underlying dynamical relationships in an SES. An appreciation of the inherent potential of nonlinear dynamics should sharpen the focus of future empirical research on SESs.

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I commend the authors for presenting such intriguing and exciting ideas. They start from such a deceptively simple premise—that people exhibit varying choices and behaviors in response to similar stimuli and challenges and that the consequences of such variation may be important—and draw out some unexpectedly profound implications for sociocultural viability, ecological sustainability, and persistence of social-ecological systems (SESs). The innovative nature of this paper reflects the authors' commitment to doing longitudinal, rigorous, empirical, and interdisciplinary research. In trying to understand complex SESs, they draw from strong ethnography and ecological theory; in the past, applications of eco-

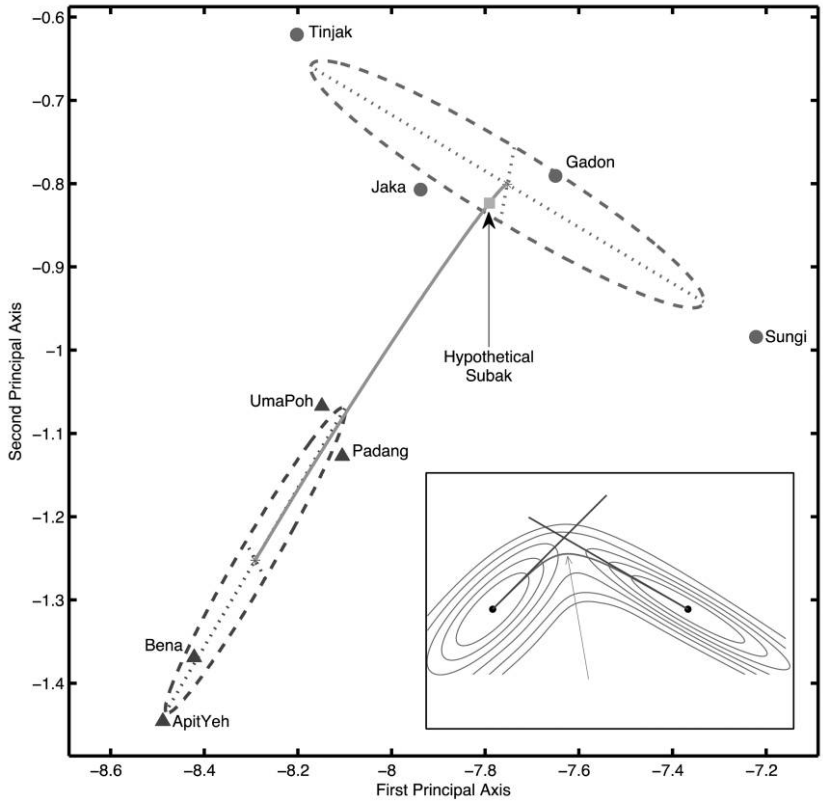

Figure 5. Ellipsoids depict the potential wells within the 11-dimensional principal component space. A 2D representation of the minimum energy pathway between the two equilibria indicates the most probable transition pathway for a hypothetical subak undergoing a regime change. A color version of this figure is available in the online edition of *Current Anthropology*.

logical concepts to understanding human societies have met with mixed results and engendered skepticism. I consider the authors' application of concepts such as response diversity, functional (or ecological) redundancy, and functional diversity to SESs as having significant potential.

My research takes place in a very different SES, that of Native Amazonian communities in northeastern Ecuador. And like all anthropologists, as I was reading the case studies presented here, I was thinking about how the patterns and observations compare and contrast with the communities I know best. Reading this paper introduced new nuances that I did not consider before. After all, the value of a new framework is its ability to cast familiar things in a new light, to help inspire new questions and perspectives, and to challenge old assumptions. Among the Waorani (also spelled Huaorani) of Ecuador, the external pressure looming largest is neither tourism nor conservation/protected areas (although these forces are relevant) but large-scale oil extraction (Lu 2012). I have watched different Waorani households react in a myriad of ways to these forces: some—a few—have moved deeper into the forest, while others have done the opposite and relocated along oil roads. Most able-bodied adults accept wage labor opportunities from both national and multinational oil companies, mostly involving menial work with machetes, but also preparing food for oil workers, acting as community health promoters, and providing canoe transport. Some Waorani predominantly take advantage of oil company roads and trucks to bring them closer to markets, health services, and educational opportunities (Doughty, Lu, and Sorensen 2010), but they also use them to expedite travel to neighboring communities and to access different hunting zones within their territory (Franzen and Eaves 2007). As a result of oil development, households who, a year ago, did not have electricity now own flat-screen televisions and refrigerators.

When I share these observations with my students, the predominant reaction is one of disappointment and fatalism; comments about the "loss" and "disappearance" of Waorani culture abound. The image of the "ecologically noble savage" wielding a machete to cut seismic lines sparks cognitive dissonance. The authors provide another perspective to examine these processes, one not infused with romanticism and essentialization. What if, instead of a discourse of cultural homogeneity and modal behaviors, we can instead talk about how the Waorani are taking diverse approaches to securing their livelihoods, experimenting with new economic opportunities and technologies, and seeking to become more fa-

miliar with the behaviors and values of outsiders? And that rather than being "corrupted" as a result, these behaviors place them in perhaps a better position to assess other possibilities not currently in their realm of experience, with some practices or items deemed valuable and kept, while others are rejected? In oil extraction, the Waorani face a relatively new problem, and the best or all possible strategies for dealing with that problem are not known; perhaps the response diversity that they exhibit may foster both system memory and innovation. Of course, this is not to say that oil extraction has no deleterious impacts on indigenous people—when oil causes ecological degradation that undermines the Waorani resource base, exacerbates social inequality that results in conflict and declines in reciprocity, and exposes people to chemicals and contaminants that lead to illness—the viability of the SES is called into question. The authors offer a concrete benefit by providing this language of response diversity with which to discuss such patterns of change, and they challenge us to be more thoughtful in specifying the system state, perturbations, and relevant indicators of resilience.

The authors' mention of cross-scale effects, patterns of land tenure, and perception of and exposure to risk grabbed my attention. While it is beyond the scope of this current paper, I wanted to know more about Turkana and Maasai power dynamics, gender and ethnic relations, social organization, common property institutions, political entanglements with local and state government, and so forth. These factors, and many others, clearly have roles in better understanding the causes and consequences of response diversity, and I hope that the authors give us a subsequent paper addressing this theme.

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This paper does several things well: it defines clearly the importance of paying attention to response diversity, it locates the issues squarely at the interception of ecology and anthropology in accessible language for both communities, it is theoretically very robust in its discussion of the various relevant ecological theories, and it highlights particularly well the importance of paying attention to social-ecological systems in understanding sustainability and system resilience.

While I would have liked to see more ethnographic and ecological data presented to back up the paper's arguments, I am familiar enough with the Turkana Ecosystem Project and its publications to know that the claims made in this paper are soundly backed by empirical evidence collected over several decades. When the authors speak of stock diversification as one way to achieve response diversity, they speak from a very large body of journal articles and their superb synthesis books. Most of us familiar with the pastoral human ecology literature recognize much of what they say—now spoken in a distinct ecological form of discourse. This is helpful to anthropologists who are less thoroughly familiar with the technical language of ecology. When they speak of mobility diversity, we can recall the work not only of the Turkana researchers but also the work of Barth and many others who have long pointed out how pastoralists do not all go in the same direction—some follow rumors of better pastures to the east, others hear that they might be north, and still others go south, in what might seem like a totally disorganized manner that Leslie and McCabe frame in an insightful way to point out how some of these groups will achieve what they seek and that those who do not can count on the social network to help them rebuild their herds if their chosen strategy fails.

This mobility diversity and stock diversification is a product of system memory and learning over generations, including an assessment of risk and opportunities that each path offers to the band and the larger group. The cost of having less diversity in stock and in mobility is nicely compared in the paper, as are forgoing the social support that is essential over the long term to build up herds likely at some point to be diminished by lack of pasture and precipitation, by raids from competing herders, and by diseases that decimate the herds. To achieve success, or at least herd maintenance, pastoral groups need to balance system memory with innovation, as the open pastures are ever being closed to them by governments intent on settling them and by changing social and political relations with huge consequence as to where it is safe to take herds. The escalation of violence has been growing, and it is an ever-growing part of the calculation that herders must make each time they move. The escalation of murderous raids and the pressure from governments to settle pastoral peoples in East Africa are changing the landscape and the viability of a pastoralist way of life. This paper touches on these issues, while maintaining a focus on the social-ecological system and its functioning and persistence. It is a very stimulating paper.

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In a world struggling to cope with accelerating rates and multiplying drivers of social and ecological transformation, it is essential that anthropological scholarship takes an integrative approach that seeks to understand both the causes and implications of such multifaceted change occurring at multiple scales. Among the more notable contemporary efforts to develop an integrated multidisciplinary approach to understanding these dynamics of transformation within complex social-ecological systems is the Resilience Alliance (Folke 2006; Gunderson and Holling 2002; Walker and Salt 2006). Increasingly, the health and well-being of ecosystems, and the

people whose livelihoods depend on the natural assets and services that their environment provides, are framed in terms of the resilience of these social-ecological systems to perturbations and disturbance, through adaptive responses or innovations that enable systems to maintain their core values and functions.

In few of the world's social-ecological systems are the primacy of resilience and adaptability as pronounced as in East Africa's semiarid savannas and rangelands. The ecology of these systems, as it has come to be better understood over the past several decades, is to a large degree defined by the unpredictable, "nonequilibrium" oscillations in rainfall and associated availability of vegetation and water (Behnke, Scoones, and Kerven 1993). The natural resource governance and livelihood strategies employed by the pastoralist communities that inhabit these landscapes are adaptively designed to foster resilience in the face of such conditions, by enabling people to cope with challenges such as drought, disease, coexistence with wildlife, as well as even less predictable external political and institutional variables (e.g., Mwangi and Ostrom 2009).

Today much research around pastoralists in East Africa focuses on how communities and individuals are coping with increasing or new forces of change, particularly those linked to climatic conditions, and the degree to which different societal interests related to global environmental concerns, national economic processes, and local livelihoods are influencing each other. Central to this research agenda are transformations in property rights, from collective to individual tenure regimes (Mwangi 2007), and in livelihood strategies, from pastoralism to more integrated strategies involving, in particular, agricultural cultivation and wildlife tourism (Homewood, Kristjanson, and Trench 2009).

Leslie and McCabe introduce a different and important perspective into this discourse around changing livelihoods and the transformation of social-ecological systems among East African pastoralists, by examining, through the lens of "response diversity," the role of local, intracommunity heterogeneity and variation in how people respond to threats, crises, and changes, and how this in turn influences the resilience and potential future pathways of the systems that they inhabit. They highlight the critical role played by local diversity in the long-term persistence of pastoralists in these complex and unpredictable systems, focusing, for instance, on the variations in individuals' herding and mobility strategies among the Turkana in northern Kenya, as well as in responding to more recent changes, as in the case of Maasai communities facing externally influenced conservation policies and land pressures in northern Tanzania. A key insight offered by this work is that response diversity "can represent a source of experiments or tests of novelty and can facilitate learning" and that such experimentation is a key to innovation in the face of change, which is in turn central to the resilience of systems as a whole.

This focus on the role of response diversity in enabling experimentation, learning, and innovation has clear practical implications for engaging with key social and ecological development and conservation challenges in dynamic systems such as these. In order to foster resilience and adaptive capacity in the face of growing social, climatic, and political change and perturbation, encouraging heterogeneous local responses that facilitate experimentation and learning is essential. For example, the Northern Rangelands Trust is achieving notable progress in generating both improvements in livelihoods and in environmental conditions in pastoralist areas of northern Kenya through the establishment of "community conservancies," which have now expanded to cover nearly 20,000 km^2 in the region (Glew, Hudson, and Osborne 2010). Notably, these conservancies, as governance entities, are entirely undefined in legal terms, using different organizational structures and statutory instruments in different communities according to local context. In other words, these new local rangeland management bodies, which address a wide range of issues, including zoning livestock pasture and developing tourism enterprises, as well as wider concerns such as security, are evolving organically and in an experimental manner. Lessons emerging from such experimentation can feed back into policy design, for example, as with current efforts to design new land legislation required to implement Kenya's new (2010) constitution.

By contrast, Tanzania does possess a formal statutory mechanism for developing similar community-based conservation activities (known as "wildlife management areas"), but since these were rolled out a decade ago, their relatively rigid, one-size-fits-all institutional model has proven difficult to adapt to pastoralist land use systems without recurrent conflicts and local dissension (Goldman 2003; Igoe and Croucher 2007; Nelson et al. 2009). Such inflexible external impositions impede the kinds of local innovations and adaptations that, as Leslie and McCabe illustrate through the lens of response diversity, are increasingly critical to building resilient social-ecological systems in the face of ongoing and often escalating local and global shocks and changes.

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The article by Leslie and McCabe is a significant contribution to the practical application of resilience theories and fills an urgent gap in development work. Adaptation to climate change rests on the theory that increasing resilience is an adaptive tool; however, we have very few means to not only test this hypothesis in social-ecological systems but even fewer means to monitor impacts. The article helps us to understand both.

The article also enhances our understanding of pastoral systems, both those largely unaffected by change and those

in its throes. Mobility and herd diversity of two very important forms of diverse responses that the pastoral systems have developed over millennia. Recent environmental, policy, and economic changes have reduced the diversity of these two responses for pastoralists, resulting in increased poverty and land degradation; that is, less resilience. A recent study in Namibia (Barnes, MacGregor, and Alberts 2012) also concludes that highly diverse pastoral and semicommercial production systems are likely to be more resilient in the long run in the face of climate change than commercial, sedentary, and single-species livestock enterprises.

Another way that the article helps to advance our thinking of pastoralism is by looking at the role of response diversity (RD) within the system. Pastoral systems were characterized by a singular merging of individualistic behavior (what Behnke, Scoones, and Kerven 1993 called "opportunistic grazing") and social safety nets, without which the individual household would not have remained resilient over the years in the face of spatial, temporal, and social uncertainty. While many have recognized the importance of individual behavior attuned to ecological stresses, very few look at how the diversity of individual responses within the system helps either the individual or the society as a whole.

The article puts forth the hypothesis that increasing RD will also increase resilience. This would hold true if all responses were effective and efficient in addressing drivers and stresses of change. However, we know that in SES, this is not necessarily the case. Individual responses may or may not be effective, and some may have detrimental consequences on other responses. Furthermore, there is a risk in carrying the correlation too far—too high a diversity in responses (very high RD), in fact, may bring us too close to chaos and a lack of a coordinated response to stress, which would reduce resilience. The authors can consider whether war and conflict is an extreme expression of a highly diverse response (e.g., the case of recent conflicts of pastoralists in Darfur over land and water).

The authors recognize in their concluding section that RD is not always adaptive. I would go even further: increasing RD is only meaningful in creating more resilience if the response is efficacious and able to stimulate more innovation and experimentation.

As for a practical application of RD, it is particularly important to consider which responses are supportive of increased resilience, and which are not, and to increase the range of options of effective responses available from which the decision maker can choose. If applied to the case of pastoralists, one would then surmise that the more diverse the set of available and effective responses, the more resilient the system.

Finally, proxy or surrogate indicators are common in development practice; however, we have few tools to help us choose the right indicators. Further investigations along this line of thinking would help us to better understand the dynamics of rapidly changing systems such as the one described for Simanjiro, northern Tanzania, and, given that it is a more typical case of pastoralism today, help to apply it elsewhere.

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Leslie and McCabe argue that response diversity (RD) is likely an important support of social-ecological system (SES) resilience. This argument, and its instantiations among the Turkana and Maasai, is supported by my observations among the nomadic pastoral tribes of Iranian Baluchistan (Salzman 2000). Their productive system was based on livestock, grain and date palm cultivation, hunting and gathering, and importing external wealth through predatory raiding prior to 1928 and through migrant labor until the 1980s, supplemented and ultimately replaced by trading and smuggling. The diversification was general, but, as Leslie and McCabe emphasize, there were different emphases between individuals and communities on different livestock species, on livestock versus cultivation, on mobility strategies, and on extraterritorial enterprise, and so forth. This meant that the SES could maintain continuity in the face of drought years (two in five). If some people and communities, and some productive activities, did poorly, others did better.

My observations also support Leslie and McCabe's emphasis on "traditional institutions" that provide the support for the SES by compensating for individual and community losses. Exchange networks among the Turkana are one example, and open pastures among the Maasai are other. These are more than just "memory"; rather, they are normative obligations grounded in the culture (a term that does not appear in the paper). These normative obligations are collective and are the foundation of individual decisions and relationships, community decisions, and regional relations. While there is much room for variation at the individual, community, and regional levels, they all presume shared normative perspectives and obligations.

I would go a bit further and argue that response diversity is facilitated and made possible by institutional diversity, which I have referred to as "institutionalized alternatives" (Salzman 1978*a*, 1978*b*, 1980). People's activities are grounded in institutionalized knowledge and practice. Productive activities are not just spur-of-the-moment turning to tasks; they are based, in the case of pastoralists, on an established cultural heritage of animal husbandry, which includes knowledge of animal species and their needs and, in the case of nomads, a technology of mobility that includes knowledge of, and equipment for, mobile housing and transport. The same is true for cultivation, for predation, for smuggling, for exchange practices, and for sharing obligations.

The "alternatives" are often built in to institutionalized or

customary practices based in the culture. Pastoral economies can be subsistence oriented, or market oriented, but are usually a bit of both, increasing either subsistence consumption or selling, depending upon the circumstances. Here response diversity can be individual, by community, regional, or SES. But it is also based on established, that is, institutionalized, cultural knowledge and practice of both subsistence consumption and market sale. The same is true of production and nomadism, mentioned above. A further example, at the organizational level, would be segmentary tribes with chiefs, a form typical in Iranian Baluchistan and widespread through the Middle East. (Africanists who do not wish to acknowledge tribes should recognize that Middle Easternists take a different view.) Segmentary organization encourages a form of decentralized, egalitarian decision making, while political office, such as chiefship, encourages centralized, hierarchical decision making. In practice, depending upon the circumstances and inclinations of the individuals and lineage communities, decision making can shift between one mode and the other. This provides considerable flexibility for the SES in the face of physical and human environmental variation. Perhaps it is difficult to integrate the concepts of "culture" and "institution" into the interdisciplinary vocabulary of RD and SES resiliency, but leaving implicit what is foundational can only lead to obscurity.

Reply

We thank all the commentators both for their thoughtful and thought-provoking critiques and for their commendations. The responses to our article fall into two partially overlapping categories: those revolving around the application and utility of ecological concepts and approaches—primarily response diversity (RD) and resilience—and those concerning the case studies we present and pastoralism more generally. There is general agreement among the commentators that our article contributes usefully to thinking about social-ecological systems (SESs) and more specifically to implementing a resilience perspective; there is somewhat less agreement on the utility of that approach. There is not sufficient space here to address all of the diverse specific comments contributed, many of which are well taken. We focus on those that we see as the most productive to engage, either because they raise compelling (sometimes vexing!) problems or because they represent common perceptions or misapprehensions.

It seems worth reiterating at the outset several points that we apparently did not make sufficiently clear in the article. Although much of our discussion is couched in terms of resilience and complex adaptive systems, our intent was not to evaluate the resilience concept. Our central argument concerns response diversity, which we see as relevant to understanding the dynamics of SESs regardless of whether or not the focus is on resilience. While we obviously believe that "resilience thinking" is useful for stimulating discussion and insight about how SESs work and hope that we have contributed to answering the often expressed need to operationalize "resilience," our general claims about RD will hold whether or not the resilience concept survives. Those claims are (1) that RD, the variability in response to changing conditions (perturbations, opportunities, etc.) is itself important—beyond the average or modal response—and (2) relevant diversity is to be found at multiple levels that can interact with one another.

We believe that it is important to consider the consequences of RD in any approach that acknowledges, explicitly or implicitly, that human action takes place within some sort of system, whether the emphasis is ecological, political-economic, local, or global, and whether or not the resilience perspective is ultimately refined and more widely adopted or deemed to have outlived its usefulness and dropped.

It was not our intent to measure the resilience of any particular SES nor to compare the resilience of the two cases presented as examples. Rather, we discuss the Turkana and Simanjiro cases because they jointly illustrate a wide range of ways in which RD can be relevant to the functioning and dynamics of SESs.

Bollig and Greiner raise a number of excellent points. One is that comparability of the Turkana and Simanjiro cases would be enhanced if we used the same, or more, overlapping sets of surrogate indicators. This point is cogent; expansion of social networks into settlements and towns in particular might provide for informative comparison of the two cases. As desirable as greater comparability of surrogates would be, however, as noted above, our primary aim here was not a comparison of the relative resilience of these two SESs. Doing that adequately would entail presenting a good deal more data (some of which we have, some of which we do not at this point) and analysis—a worthy endeavor for another time and place. Were we to do so, it would indeed be advantageous to utilize, to the extent possible, the same surrogates. But even with substantial overlap in chosen surrogates, it would become clear that some indicators are of much greater importance in one SES than in the other. For example, biodiversity is certainly a notable aspect of the Turkana SES, but it is far more salient in Simanjiro because of its close link to government and NGO concerns, the national economy, and therefore to policy and action that affect many aspects of the SES. Biodiversity is tied much more closely to the interests and actions (including investments in infrastructure, coercive regulation of land use, etc.) of entities outside the regional ecosystem (an influence emphasized by Homewood, Fratkin, and Nelson) in Simanjiro than in Turkana, where other interests dominate. Niamir-Fuller also brings up the question of surrogate indicators, pointing out the need of development practitioners for better tools or guidelines for choosing appropriate indicators. This need is, of course, felt by practitioners of basic science as well. As we noted in the paper, a number

of authors have suggested ways of identifying appropriate surrogates (e.g., Bennett, Cumming, and Peterson 2005; Carpenter et al. 2001; Robinson and Berkes 2010). It is clear from their attempts and from our discussion that the choice of surrogate indicators is to a large degree situation specific but can benefit from both empirical experience—comparison of more case studies—and from theoretical considerations such as those we address in this article. We are currently developing an agent-based model of the Simanjiro SES that will facilitate exploration of the effects of multilevel RD on resilience and will provide an experimental path toward identifying informative surrogate indicators in this and similar contexts. Just how to strike a balance between the situational imperative, on the one hand, and the importance of comparative analysis, on the other, which Bollig and Greiner argue is needed if we are to get at causal linkages, is a significant challenge, one worth careful attention.

Another question raised by Bollig and Greiner is that of scale, in both spatial/organizational and temporal dimensions. Our focus on village-level responses in Simanjiro was not intended to suggest that individual or household level RD is not important there, as it is in Turkana; indeed, we do address that level in Simanjiro. We emphasize village-level decision making in Simanjiro because it has emerged there as having potentially great implications for livelihoods, land cover and biodiversity, and more, and because RD at that level is becoming clear. Such has not been the case in Turkana. We also focus on the village level in Simanjiro because there we see a clear instance where responses at the household and higher levels might interact with one another and even have contradictory effects, and the potential for such interactions is one of the central arguments about RD that we wish to make. The question of appropriate time scale can be a significant challenge within a resilience framework. Bollig and Greiner are quite right that expanding the time frame for analysis will often (perhaps always?) reveal perturbations in or reorganization of SESs, the potential for which may not be clear from more temporally constrained analysis. At the very least, keeping spatial/organizational and temporal scale in mind serves as a reminder that long-term resilience of an SES does not imply lack of hardship. This is clear from the vulnerability of individuals and households who are forced out of the pastoral sector and into towns or settlements, as Bollig and Greiner point out, and from the widespread failure of pastoral systems throughout East Africa due to disease and warfare during the period between 1883 and 1902. The former represents a common, persistent feature of the SES in Turkana and elsewhere, and might be considered an element of that system; the latter represents much rarer and extreme perturbation, affecting the dynamics of entire SESs and perhaps stimulating major changes in them.

Homewood takes issue with the utility of the resilience concept and asks the eminently reasonable question of what our perspective adds to what is already understood about pastoral systems and also raises the more worrisome question of whether our approach might obscure insights that a political ecology perspective would highlight. Lu's observation that "the value of a new framework is its ability to cast familiar things in a new light, to help inspire new questions and perspectives, and to challenge old assumptions" is relevant here, and other commentators (Moran, Nelson) seem to find utility in our approach as well. Even so, it is indeed possible that similar understanding (or research questions born of recognized need for better understanding) could have been reached via alternative frameworks. But many of those alternative frameworks might benefit from considering RD. That would apply to any framework that recognizes that people (as individuals or groups) act within the context of some sort of system. Our primary claim is that RD is relevant and sometimes essential for understanding SESs, not that the resilience concept (or, more broadly, complex adaptive systems) provides the best approach to understanding SESs in all cases. There is scientific value in pursuing a question or investigating a phenomenon from multiple perspectives, even if doing so in a specific case does not overturn or substantially augment understanding based on other perspectives. Such confirmation of previous conclusions lends confidence in that understanding and may help avoid tossing empirical babies out with theoretical bath waters when yet other perspectives are propounded.

Is political ecology more pertinent to our examples than is a resilience framework, as Homewood suggests? Nothing that we say should be taken to diminish the importance of taking the political-economic context into account. That context (both within and from "outside" the SES, however defined) is surely important, in multiple ways. Most relevant here, the political-economic context affects RD by shaping constraints and opportunities. It may often be relevant to the consequences of RD as well, since the decisions and actions that constitute the RD themselves have subsequent effects, direct and indirect, and those play out in the political-economic context.

Beyond pertinence, Homewood posits the provocative possibility that our "outcome-based approach" might even obscure understanding of the broader processes at play. We do not, and would not, suggest that an outcome-based approach is sufficient (outcomes here being the consequences of RD). Identifying those outcomes may point up the need to better understand the causes of RD, and both these causes and the consequences of RD may be shaped by the political-economic context. The variety of land allocation plans and policies being implemented by Simanjiro villages indeed may be to some extent "short-term tactics adopted by hard-pressed players," as Homewood suggests, implying that they are forced rather than voluntary or spontaneous, but they are nonetheless experiments. The point is that there is RD in those tactics. Might not our approach then actually help clarify the broader processes at play and how they might interact? Thus, RD may be part of the political-economic context, or at least in many cases will be shaped by that context. In the long run, the

consequences of RD may influence what a political ecology approach ascertains, as may other aspects of the ecological relationships that comprise the SES. One criticism of political ecology has been "Where's the ecology in it?" Although ecology is certainly not difficult to find in the work of Homewood and her collaborators, our focus might help deflect that critique in some cases. The bottom line is that political ecology certainly is pertinent here, and may be indispensable. We do not see political ecology and resilience/complex systems approaches as mutually exclusive; rather, one can inform and enrich the other. Indeed, Homewood's question, "Are the influxes of outsiders in times of stress a sign of persistence or an indication of growing failures of reciprocity and control?" may point to an instance where political ecology and resilience frameworks can be mutually informative.

Galaty and Niamir-Fuller note that higher RD does not invariably lead to greater resilience and is not necessarily adaptive. We agree and said as much, although we might have made this point more forcefully and fully. Some specific responses within an observed range of possibilities may indeed be maladaptive, as might be an overabundance of alternative responses (if, for example, the benefit of a certain response, or the benefit of having a certain set of complementary responses, depends on a "critical mass" of actors—e.g., households, villages, companies—responding in a similar way. Such might be the case for creating markets or economies of scale). Further, Fratkin is quite right that behavioral strategies, including attendant RD, that have enhanced resilience and persistence now or in the past may not ensure long-run sustainability as conditions change. Nonetheless, we think that RD will frequently if not generally enhance resilience and that it does so in two distinct but related ways. RD can lead to innovation and experimentation (as emphasized by Nelson and Niamir-Fuller), but diversity of responses within a range of well-established, long-used options (institutionalized alternatives, in Salzman's terms) may also be crucial to resilience—for maintaining resilience, not just creating new pathways to it.

Salzman wishes to emphasize the role of institutional diversity further, arguing that RD can be enabled by institutional alternatives. That is quite correct, and perhaps we did not emphasize sufficiently the potential importance of institutional diversity, but we do see institutionalized alternatives as setting the stage for individual-level (or higher-level) options that result in RD. In this light, institutional diversity is one of the causes or molders of RD. Similarly, we did not intend to obscure the importance of culture for SES resilience. As Salzman notes, it has been difficult to integrate the concept of culture into ecological theories. This has been one of the goals in our long-term studies in Turkana and Maasailand; we recognize both the challenges in this and its importance in bringing an anthropological perspective to the study of resilience in SESs. But our primary focus here is on the consequences of RD, and culture and institutions most obviously affect the causes of RD—they are an important part of what shapes and perhaps maintains RD. That said, the consequences of RD might work to maintain or to change culture and institutions.

We are gratified that several of the commentators see this paper as moving resilience thinking and ecological anthropology forward. The case studies we present are surely of greatest interest to those whose work focuses on pastoralists, and their observations nicely augment our examples. Salzman sees a role for RD among nomadic pastoralists in Baluchistan that parallels what we describe for East Africa. Nelson contributes further observations on East African pastoralists but adds an intriguing observation concerning diversity at the national level with regard to community-based conservation measures. He contrasts the diversity of community conservancies in northern Kenya with the government-imposed rigidity of such conservancies in Tanzania, arguing that the former encourages heterogeneous local responses while the latter constrains RD among local communities. The diversity of options in Kenya promotes experimentation and learning and has resulted in improvements in livelihoods and environmental conditions.

We are especially happy to see responses that affirm the relevance of our ideas concerning RD to a wider range of populations and SESs. Lu argues for the utility of considering RD in assessing changing livelihood patterns and social relationships as Waorani hunter-gatherer horticulturalists take advantage of (or avoid) concomitants of the recently arrived oil exploration and extraction industry in the Ecuadorian Amazon. Lansing provides a more theoretical comment but one grounded in his long-term study of rice farming in Bali. His example explicitly supports our implicit argument that variation in many cases should be considered as signal rather than noise and points to the possibility of using RD (across scales) as a means of detecting attractors and consequently understanding multiple stable states and the variables likely to underlie regime shifts in SESs. We hope that our focus on the nature and consequences of response diversity will stimulate applications in other contexts as well.

—Paul Leslie and J. Terrence McCabe

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