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# Rangelands, pastoralists and governments: interlinked systems of people and nature

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We analyse commercially operated rangelands as coupled systems of people and nature. The biophysical components include: (i) the reduction and recovery of potential primary production, reflected as changes in grass production per unit of rainfall; (ii) changes in woody plants dependent on the grazing and fire regimes; and (iii) livestock and wool dynamics influenced by season, condition of the rangeland and numbers of wild and feral animals. The social components include the managers, who vary with regard to a range of cognitive abilities and lifestyle choices, and the regulators who vary in regard to policy goals.

We compare agent-based and optimization models of a rangeland system. The agent-based model leads to recognition that policies select for certain management practices by creating a template that governs the trajectories of the behaviour of individuals, learning, and overall system dynamics. Conservative regulations reduce short-term loss in production but also restrict learning. A free-market environment leads to severe degradation but the surviving pastoralists perform well under subsequent variable conditions. The challenge for policy makers is to balance the needs for learning and for preventing excessive degradation. A genetic algorithm model optimizing for net discounted income and based on a population of management solutions (stocking rate, how much to suppress fire, etc.) indicates that robust solutions lead to a loss of about 40% compared with solutions where the sequence of rainfall was known in advance: this is a similar figure to that obtained from the agent-based model.

We conclude that, on the basis of Levin's three criteria, rangelands with their livestock and human managers do constitute complex adaptive systems. If this is so, then command-and-control approaches to rangeland policy and management are bound to fail.

**Keywords:** rangelands; complex adaptive system; resilience; institutions; agent-based models

## 1. INTRODUCTION

Rangelands are the semi-arid regions of the world that are too dry for reliable crop cultivation and hence used for livestock production of one form or another. They span the tropics and temperate zones, varying considerably in their vegetation and native fauna. However, leaving aside differences at the species level, the vegetation is characteristically a mixture of grasses, shrubs and trees, ranging from pure grasslands to the woodland savannas of the sub-humid tropics. Depending on the kind of rangeland, the welfare of the pastoralists who live in them is based on grazing animals (cattle and sheep), mixed feeders (browsers and grazers like camels and goats) or a combination of both.

The rangelands developed over many thousands of years under climates marked by strong seasonality and high interannual variation in rainfall. Primary productivity of the grasses varies greatly, up to 10-fold from one year to the next (Kelly & Walker 1976), and the native herbivores that evolved in response to this were seasonally migratory ungulates and equines that moved in large herds. The fluctuating pattern of food production kept herbivores at lower levels than would have been reached under constant annual rainfall, and the accumulation of fuel on a periodic basis allowed periodic fires. Fire has been an integral part of the environment of rangelands since they developed, and the net effect has been to maintain rangelands in more open, grassy states than would be achieved in the absence of fire (Scholes & Walker 1993). Fire is not a disturbance in most rangelands; it is the absence of fire that is a disturbance.

The Asian and African rangelands have been occupied by humans and domesticated livestock for hundreds, and in some cases thousands, of years. The pattern of use, however, differed little from that under the native fauna, with nomadism (emulating the seasonal migrations of native ungulates) being characteristic of the drier regions, and low populations of livestock being maintained in others. From the mid- to late-1800s, however, the rangelands of Africa, America and Australia were subjected to a marked change in the form of commercial ranching. Essentially the change consisted of introducing artificial watering points to allow for continuous heavy grazing, as opposed to the irregular, seasonal or pulse grazing which

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occurred under native herbivores, and under the grazing systems used by migratory people and other low density human populations. Commercial ranching also introduced fencing to control grazing patterns and nutrient supplementation for livestock, leading to the maximum number of animals that could be maintained (dictated by the welfare of the livestock, rather than of the rangeland).

In this paper we concentrate on the commercial rangelands. Much of what we say applies also to the large regions still used on a subsistence basis, but these regions have their own special attributes, and to keep focused we restrict our attention to privately owned or leased properties/ranches used for commercial production of cattle and/or sheep.

Our aim is to analyse such properties as coupled systems of people and nature, to explore whether or not they behave as CASs and, if so, to consider the policy implications for their future use.

Levin (1998) defines a CAS as having three essential elements:

(i) sustained diversity and individuality of components;
(ii) localized interactions among those components; and
(iii) an autonomous process that selects from among those components, based on the results of local interactions, a subset for replication or enhancement.

According to Levin, these three elements, and in particular the dispersed and local nature of an autonomous selection process, result in continual adaptation, the emergence of hierarchical organization and (notably) the absence of a global controller. The autonomous selection process amounts to a set of rules and it is this ruleset that determines the nature of the emerging structure in the system. In systems involving human society it might be tempting, in a superficial assessment, to consider the extant set of regulations as the selection process. This is what the government and bureaucracies involved would no doubt like to believe (i.e. it is they who are determining the evolution of the system). However, the ruleset in a socio-ecological system is, in fact, more complex than this. Various interest groups, with differing views on how ecosystems should be used, put informal and formal (voting) pressure on the government to change the ruleset, and one of our aims in this paper is to assess the relative roles and interactions of regulator, manager and biophysical rules.

We begin with an account of the ecology of the rangelands, the biophysical part of the system, followed by a consideration of the motives and constraints of the individual ranchers, then a brief description of rangeland governance and the basis of policy making by regulators. To do this we focus mainly on the rangelands of western New South Wales, in Australia. We then present some results from an agent-based model of such a rangeland together with the implications for related research. Finally, we discuss the implications of this work for future research into CASs, and for the future of the rangelands.

## 2. RANGELAND ECOLOGY

The biophysical component of a rangeland varies according to rainfall and soil type but, as mentioned earlier, at the simplest level the vegetation consists of a grass layer (a mixture of perennial and annual grasses plus a variety of forbs) and, in most cases, a woody plant layer of trees and/or shrubs. The perennial grasses and the shrubs can vary in their palatability to livestock. So that we can link this to the later description of the rangeland model, this account of rangeland ecology conforms to those in Perrings & Walker (1997), Ludwig *et al.* (1997) and Janssen *et al.* (2000).

Livestock production, the variable of central concern, is determined by the amount of available grass and, in turn, growth of grass is determined by the amount of available soil moisture and the effects of grazing. Soil moisture is determined by rainfall and the amount that is available to grasses depends on the amount of woody vegetation—the rates of grass and woody growth are modified by competition between themselves and each other. Establishing woody seedlings are strongly suppressed by a vigorous grass layer (Knoop & Walker 1983), but once they are established, the grasses have little effect on woody plant growth. Smaller woody plants (shrubs) have a greater inhibitive effect on grass growth per unit of woody plant biomass than do trees. Fire has little effect on grasses since it occurs at the end of the dry season when grasses are dormant, therefore removing only the above-ground, accumulated dead shoots. By contrast, fire has a severe effect on woody plants, killing many and significantly reducing the top growth of others (Noble 1997). To capture the essential dynamics of the system over time, including lag effects in growth cycles, a number of ecological processes need to be taken into account. It is this set of interacting processes, described in the following section, that gives each rangeland its characteristic behaviour, providing the basis for rangeland management.

### (a) *Reduction and recovery of potential primary production*

Change in the productive potential of the rangeland is reflected as a change in maximum possible grass production for a given amount of rain. Grass growth in response to a unit of rainfall is a function of the ecological state of the system, which is largely determined by grass biomass itself. If, through heavy grazing, drought or a combination of the two, grass biomass remains below some minimum threshold level for more than some defined time (in our Australian example we assume 1 year), there is a decline in potential production as a result of reduced water infiltration and loss of perennial grass cover. Removing grazing pressure after potential primary production has been reduced allows the system to recover, and potential production increases gradually. The extent and rate of reduced potential primary production as well as the recovery rate (with recovery being slower than reduction) are determined by the type of land system. For the purposes of our assessment, we equate these changes (captured by a single parameter in the model described later) with the loss and re-establishment of the spatial processes described in Tongway & Ludwig (1997). The actual spatial dynamics of run-off, run-on and soil nutrient status that underlie the net effects are more complex, but we can encompass them as just described.

### (b) *Changes in woody plant density and biomass*

Both the biomass and density (number per unit area) of woody plants are important in the dynamics of the rangeland. Successful establishment after germination occurs when the soil moisture is high enough for long enough to ensure that the seedlings get their roots below the grass rooting zone and with enough growth to survive the first dry season (Knoop & Walker 1983). Establishment of germinated seedlings therefore depends on the amount of rainfall and on competition from established grass and existing woody plants, and it consequently occurs only in years of above-average rainfall. Shrub mortality occurs through old age or fire, the effects of the latter depending on fire intensity and shrub size. The intensity of the fire depends on the fuel load—the accumulated grass biomass remaining after grazing. It accumulates to a maximum level, beyond which decomposition offsets the rate of accumulation.

Increasing degradation of rangelands seems to have accompanied the advances in technology in animal husbandry and water development, although there are disagreements over what constitutes 'degradation' (Abel *et al.* 2000). Nevertheless, the form of reported degradation has common features in all countries: a loss of high fodder-quality perennial grasses and their replacement by unpalatable perennials or annual grasses, lowered production through soil erosion (due to loss of grass cover), and an increase in woody plants ('bush encroachment' or 'woody weeds'). Furthermore, the degradation has occurred as irregular, episodic changes. In many cases these changes, on a management time-scale, represent alternate stable states; once a change has occurred it is difficult or very slow to reverse (Westoby *et al.* 1989). The change from a grassy to a thicket state comes about through a combination of sustained grazing pressure and a lack of fire. Periods of drought with high stock numbers bring about the death of perennial grasses, leading to reduced grass cover. When this is followed by a high rainfall season it leads to a profusion of new woody plants. If, at this point, all livestock were removed, it is possible that enough grass growth could still occur to enable an effective fire, killing the new woody plants, reducing established ones, and keeping the system in a grassy state. However, if grazing pressure is maintained, there comes a point in the increasing woody : grass biomass ratio after which, even if all livestock are removed, the competitive effect of the woody plants prevents the build-up of sufficient grass fuel to carry a fire. The system then stays in the woody state until the shrubs or trees begin to die, opening it up for increased grass growth and the reintroduction of fire. This can take 30 or 40 years.

### (c) *Livestock and wool dynamics*

Sheep numbers change through births (highly managed through controlled breeding) and deaths, both influenced by the amount of food available, as well as through sales and purchases. Additional grazing pressure often occurs through the presence of wild or feral animals (e.g. kangaroos, goats) and this can reduce both wool production and livestock numbers. Potential wool production declines linearly when green leaf biomass falls below a threshold of 75 kg $ha^{-1}$ (Freudenberger *et al.* 1999).

## 3. GOVERNING THE RANGELAND COMMONS

When Europeans first occupied Australian rangelands in the mid-1800s they practised open access rangeland use, a classic example of the tragedy of the commons (Hardin 1968). Such an arrangement may initially work while natural variability in the ecosystem maintains a slow, overall increase in stock numbers. Eventually, however, the carrying capacity (a level of stock numbers that varies in accordance with rainfall) is reached, and at that point each individual herdsman benefits from adding an additional animal while imposing the consequences on everyone (including himself). The tragedy of the commons is this rationality, that locks everyone into a system that compels them to increase stock to the point where the system collapses.

Fortunately, the tragedy of the commons is not the only possible outcome of a common resource with open access (Berkes *et al.* 1989; Ostrom 1990). There is increasing evidence that effective institutions emerge out of local interactions of the many individuals involved in common property management. Laboratory experiments have shown that subjects come to behave cooperatively when they are allowed to communicate about monitoring rules and sanctioning regimes (Ostrom *et al.* 1994). Analysis of a variety of common pool resources in different parts of the world show that among self-organized institutions there are common characteristics, such as the presence of boundary rules, authority rules related to allocation, active forms of monitoring and sanctioning (Ostrom *et al.* 1994).

In Australian rangelands, a long-term leasehold arrangement involving governmental ownership and control was eventually recommended in order to avoid the developing classic tragedy of the commons. Such a system implies that the government has a perfect understanding of the system dynamics and acts in the public interest. In practice, government intervention in the rangelands was either to impose a minimum stocking rate (to justify occupancy of leasehold land) or a maximum stocking rate (to prevent land degradation). Drought relief subsidies were a later, additional intervention, implying that the government knew what was good both for the rangelands and the pastoralists. These policies of intervention formed an institutional arrangement that contributed to rangeland problems, both ecological and economic.

The empirical evidence on self-organizing institutions gives a different perspective on common property management. Although the circumstances under which evolution of cooperation may happen are not precisely known, mutual trust among the participants is an essential component for initiating such a self-organizing process. This is a probable reason why government interventions are seldom effective—the government is not one of the original group of participants within which a trustful relationship has evolved.

Success in rangeland management varies in Australia, and the question arises as to what conditions have led to successful versus unsuccessful management. One major difference that led to many examples of severe ecological decline in western New South Wales and in southern Queensland was a government imposed policy of creating smaller property sizes. For reasons that had nothing to do with ecology, a policy of 'closer settlement' (now being reversed) led to property sizes that were often economically non-viable and that reduced resilience significantly by lowering management flexibility. Smaller property sizes require much faster response times on the part of managers to changes in external drivers. In these cases, governments imposed their policies from outside the region, with little knowledge or consultation with the pastoralists. A more devolved policy arrangement in South Australia and the Northern Territory and no sub-division of properties have led to greater trust. We will address the notion of self-organization by looking at both the institutional aspects and the role of ecosystem dynamics. In the traditional rangeland system we distinguish two types of actors: the managers and the regulators.

### (a) *The managers*

The managers in the Australian rangelands are typically long-term leaseholders of properties that for the past hundred years have been used almost exclusively for wool production. These pastoralists differ amongst themselves in their perceptions of rangeland dynamics and the consequent required management actions (Foran & Stafford Smith 1991; Buxton & Stafford Smith 1996; Noble 1997), as well as in the utility they derive from their income; some are more 'lifestyle' farmers than others. While big profits were made in the early years of the Australian wool industry, for the past few decades most pastoralists have experienced difficult financial problems.

The main rangeland management decisions relate to stocking rates (how many animals to stock relative to the amount of grass available, when and by how much to reduce numbers during droughts and when and by how much to re-stock after good rains—and whether to do this by breeding alone or through buying in more livestock), water points, and whether and when to use fire as a tool to reduce woody weeds. In terms of animal management, pastoralists make decisions with regard to animal breeding and animal health. Finally, they make financial decisions about whether and how much money to borrow to purchase animals or necessary infrastructure (pumps, etc.), and how to manage their debt. The managers vary considerably with regard to their abilities in making these decisions, and they adopt different strategies, for example the 'reactor' strategy (tracks the rainfall and trades) versus the 'constant' strategy (conservative, constant stocking rates) (Foran & Stafford Smith 1991). The constant strategists seldom, if ever, experience a 'drought' (requiring drought subsidies), while reactor strategy neighbours (receiving the same rainfall) experience frequent droughts. In the absence of drought subsidies they make severe losses at intervals, but provided they are able to start up again, they actually make more profit over a multi-decadal time-frame, despite any rangeland degradation (reduction in rainfall use efficiency).

### (b) *The regulators*

Regulation of rangeland managers differs greatly around the world, but in a general sense, regulation policy ranges from being highly constraining at one extreme, aimed at preventing overstocking and degradation, to laissez faire at the other, either motivated by a strong free-market philosophy or because the government and local regulators are ineffective or not concerned. In between is an approach that puts more weight on the social welfare of pastoralists than on ecosystem welfare, marked by forms of assistance such as drought relief and other subsidies. In Australian rangelands, regulation policies have fluctuated over time in response to changes in climate cycles, markets and changes in government.

### (c) *Multiple-use common resources*

A developing trend in common pool resource management is the concept of multiple-use resources (Steins & Edwards 1999). In a single, common pool resource, such has occurred in Australian rangelands until very recently, pastoralists use the rangeland for a single commodity—wool production. In a multiple-use resource, other uses of the range become important, for example tourism, harvesting native species, nature conservation and mining. The involvement of different stakeholder groups complicates management. Steins & Edwards (1999) advocate the use of platforms for resource use negotiation. From an analytical perspective, the question is how multiple-use influences the possibility for reaching collective action. Since mutual trust is a key factor in self-organization of institutions, the use of a negotiation platform seems logical, though alternative constitutional designs might also be effective.

Abel *et al.* (2000) implemented such a platform for the western division of New South Wales in Australia. There is currently little diversity of production in the region, some stakeholders are in conflict over land and water resources, services are declining, the population is ageing and debt levels are high. The project was designed to bring about institutional changes that would foster regional resilience. It engaged different users of the rangelands—aboriginal people, agro-pastoralists, conservationists and the minerals and tourism industries—in developing visions for the future. Conflicts and possible compromises between the stakeholders were identified. An important part of the process involved workshops that led to repeated interactions between the different stakeholders, aimed at finding a 'satisficing' vision with which everyone could live. The project, which was well received by the participating stakeholders as well as government agencies, is a good example of the complexity of rangeland systems; they are not merely systems with a single user (and single interest), but involve multiple interests and uses. The study provided a basis for continued evolution of the system as it is implemented over time, with continued learning and adaptive responses on the parts of all stakeholder groups (and by the biophysical system).

## 4. AGENT-BASED AND OPTIMIZATION MODELS OF THE RANGELAND SYSTEM

Based on the above description of the New South Wales rangelands and focusing on pastoralists and wool production, Janssen *et al.* (2000) developed an agent-based model of a rangeland system. The details of the model specification can be found in that publication. In this account we restrict attention to the results for one type of rangeland, the mulga rangeland, which is susceptible to woody weed invasion.

The model describes the evolution of a system of 50 properties for a period of 200 years. The properties are

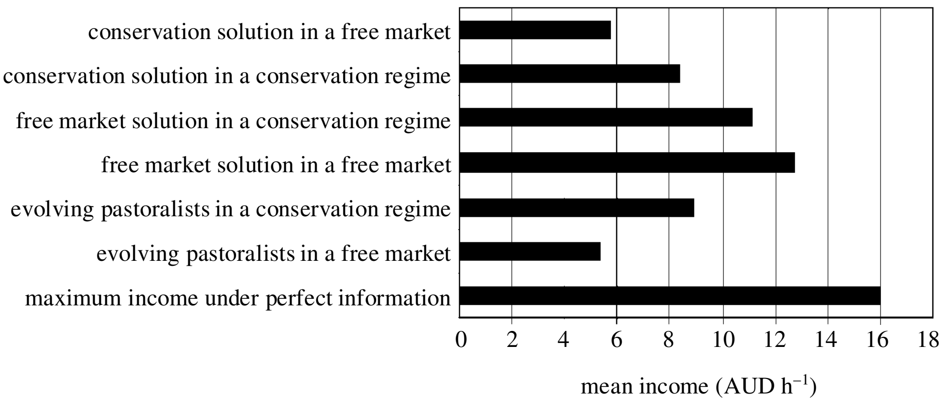


Figure 1. Mean income of pastoralists in different simulations of an agent-based model of a rangeland system over a 200 year period, representing mulga type properties in New South Wales, Australia.

populated with a heterogeneous set of pastoralists who differ in their financial and cognitive abilities, their perception of time and their lifestyles. Like an evolutionary process, pastoralists can 'die' which happens when they go bankrupt. The vacant properties can be occupied by other successful pastoralists, or by 'mutants' (new pastoralists with randomly assigned attribute values). A limiting feature of the model was that individual pastoralists do not 'learn'; they continue to apply the management decisions they are allocated. However, the system can learn, as pastoralists with maladapted management strategies die out.

Three possible types of regulation were distinguished; conservation (forced destocking at low grass biomass levels), stabilization (subsidies to pastoralists experiencing bad rangeland conditions) and a free-market style (no governmental intervention). The basic question concerned the types of pastoralists who emerged under these different regulation rules.

Two types of experiments with the model are summarized in figure 1. In the first, a random population of pastoralists evolves over 200 years under either a free-market or a conservation regime. The simulated performance of the evolving population of pastoralists as depicted in figure 1, is the average income over the 50 properties. The income in the free-market situation is relatively low because the lack of regulation led to relatively fast degradation of many properties. This was largely prevented under the conservation regime. The second experiment used the typical pastoralist characteristics that evolved during this first 200 year experiment, and again simulates a 200 year period.

Although the pastoralists under no regulation degraded their properties in the first 200 years, the type of pastoralist who evolved under those conditions deals very well in the second experiment with managing rangelands under varying rainfall and wool prices, without regulation. This is shown in the income under both the free-market and conservation regime in the second experiment, where the free-market solution (i.e. the characteristic pastoralist who evolved under a free market) leads to reasonable income levels. However, the typical pastoralist who evolved under a conservation regime was not selected on the basis of capability to survive in a situation without regulation. This leads to a low income level when the conservation solution is tested in a free-market situation. The conclusion (not surprising in hindsight) is that the institutional arrangement which is suitable for sensitive rangelands has to take into account both stimulation of learning as well as preventing the consequences of bad management.

Regulation reduced the learning process but kept the rangeland in relatively good condition while the limited learning occurred. The kind of pastoralist that eventually evolves under no regulation is a better manager, in terms of both maintaining rangeland condition and making a profit, but the evolutionary process involved more of them going bankrupt, and considerable rangeland degradation.

The pastoralists who evolved in the simulation experiments have limited knowledge of the system. When we compare their performance with those who have perfect knowledge of the system, including the sequence of rainfall, the evolved pastoralist's income is about 40% lower (compared with the optimal solution). This 40% drop in income is the cost of imperfect knowledge. However, these costs can be much higher when the management style of pastoralists and the regulation of the government are not adapted to the local conditions of the rangelands.

This exploratory modelling exercise provides some insights into the behaviour of the Australian rangelands viewed as CASs. We now explore other approaches and the hypothesis we want to address is: management styles which are successful in the longer term are adapted to local ecological and climate conditions; however, the fitness of the locally adapted management strategies can be affected by governmental regulation.

The model of Janssen *et al.* (2000) provides a starting point for simulation models that assess suitable action rules of managers and regulators across different levels of spatial and temporal scales. However, the approach is limited by not allowing real-time learning or the introduction of novel management strategies and combinations. It produces a single, most robust strategy out of a pre-defined set of strategies. What is needed is an analytical approach that includes learning, and novel strategies such that we can understand the conditions under which the system stays within some defined basin of attraction, compared with those under which it might flip to a different (often undesirable) one.

An alternative, and complementary, approach to a CAS model is optimal control. Perrings & Walker (1995, 1997, 2002) have developed such models for these rangelands, and though they provide interesting insights into management strategies, they assume perfect knowledge of future conditions. Anderies *et al.* (2002) developed an analytical model of rangeland dynamics and management, based on a reduced version of the model developed by Perrings & Walker (1995), and Janssen *et al.* (2002) have used this model as a basis for an optimization approach including rainfall variability.

The approach involves the use of a genetic algorithm to find robust solutions for rangelands with uncertain rainfall patterns. Genetic algorithms simulate an evolutionary process whereby a population of solutions (e.g. when to destock, how much to suppress fire) evolves over time by selection, crossover and mutation of 'genetic information'. The genetic information represents the values of the decision variables. The selection is based on the value of a fitness function, which in this case is equal to the discounted sum of net income over a period of 100 years. As in each generation the population of management strategies is confronted with a new set of rainfall patterns, the resulting population of management strategies performs well under a particular distribution of rainfall variability. Using parameter values which represent the system dynamics of properties in New South Wales, the Janssen *et al.* (2002) analysis found that the robust solutions arrived at by the genetic algorithm model led to a loss of about 44% of income, compared with optimal solutions where the sequence of rainfall was known in advance. Uncertainty of rainfall leads therefore to a reduction of about 44% of the potential income—a similar figure to that obtained in the agent-based model.

## 5. DISCUSSION

Returning to the discussion in § 1, our aim in this section is to explore the extent to which rangelands behave as CASs and, if they do, to examine the policy implications. Based, therefore, on the description of the rangeland systems and the results from the models presented, are rangelands and the people in them (particularly those in Australia) CASs, according to the criteria of Levin (1998)?

Regarding sustained diversity and individuality of components, the rangeland ecosystem consists of different functional types of species, both in terms of the roles they play in the ecosystem itself and in terms of their use by and value to humans. The different animal populations (commercial and wildlife) graze and browse different species of plant biomass. There are different kinds of managers and there are different kinds of regulators. (The latter, though, do not coexist, and change of regulators is more a change in regulation philosophy than change in regulators *per se*.) There is now an increasing diversity of stakeholders with different utilities in terms of the value they derive from the various ecosystem services from the rangeland.

Over time there has been a loss of biodiversity from the rangelands, mainly species of reptiles, birds and some grasses. The consequences of these losses in terms of ecosystem function are still unknown, although some have been shown to lead to a loss of resilience (Walker 1995; Walker *et al.* 1999). The extent of this loss, nevertheless, does not constitute a serious departure from the 'sustained' part of the first CAS requirement. The system may not continue to hold all the elements that some people would like, but this does not mean it does not still have a sustained diversity and individuality of components.

The changes thus far wrought in the rangeland ecosystem and in the managers, including the emergence of new kinds of stakeholders, testify to the existence of the second criterion: localized interactions among those components. The change (on many properties) from a grass-dominated system to one dominated by shrubs, together with a change in the relative economic values of sheep wool and goat meat, has seen the rapid transformation of such properties from wool producers to goat producers. The changes have not occurred through any central government policy, but rather through localized interactions responding to changes in external conditions.

These interactions have been subject, quite evidently, to the third criterion: an autonomous selection process. The 'process' involves more than one selection pressure. The relative abundance of grasses and shrubs are subject to the selection processes of fire and herbivory under varying rainfall. The selection by which farmers remain is determined by economics (which are influenced by the decisions the pastoralists have made and the differences in their lifestyles), and at another level, selection of the kinds of managers (or 'stakeholders')—wool producers, goat producers, tourism operators, and the recent development of 'biodiversity reserves' (attracting investment from the cities). There is competition between plants, between animals and between different kinds of human stakeholders, with strong interactions across all levels.

We conclude, therefore, that the rangelands with their livestock and human managers do constitute a CAS, and the main implications of this are twofold. With regard to policies for managing them, because they behave as dynamic, self-organizing systems, strict regulations aimed at equilibrium solutions are bound to fail. A command-and-control approach to trying to achieve some particular desired state will not work. What will be far more effective are policies that provide the conditions under which the system, as a whole, can learn and adapt.

The second set of implications has to do with research needs. In particular, the work in the rangelands has highlighted three main needs: (i) a better understanding of the rules that govern change and the conditions under which the changes occur; (ii) a better understanding of the links between the social and ecological sub-systems; and (iii) a better understanding of how policies at the highest levels change (i.e. how much is regulator policy determined by the states of the ecosystem and the social system in the rangelands, compared with the state of the rest of the country and the current position of the government).

Achieving long term sustainability in rangelands will require building the adaptive capacity of the social and ecological systems. Knowing how to do this—where and when to intervene, and what to do—will be enhanced most by attempting to understand the rangeland as a CAS with a view to guiding it along desirable trajectories.

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## GLOSSARY

CAS: complex adaptive system