

PASTORALISTS' RESPONSES TO VARIATION OF RANGELAND RESOURCES IN TIME AND SPACE

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Abstract. We explore the response of pastoralists to rangeland resource variation in time and space, focusing on regions where high variation makes it unlikely that an economically viable herd can be maintained on a single management unit. In such regions, the need to move stock to find forage in at least some years has led to the evolution of nomadism and transhumance, and reciprocal grazing agreements among the holders of common-property rangeland. The role of such informal institutions in buffering resource variation is well documented in some Asian and African rangelands, but in societies with formally established private-property regimes, where we focus, such institutions have received little attention. We examine agistment networks, which play an important role in buffering resource variation in modern-day Australia. Agistment is a commercial arrangement between pastoralists who have less forage than they believe they require and pastoralists who believe they have more. Agistment facilitates the movement of livestock via a network based largely on trust. We are concerned exclusively with the link between the characteristics of biophysical variation and human aspects of agistment networks, and we developed a model to test the hypothesis that such a link could exist. Our model builds on game theory literature, which explains cooperation between strangers based on the ability of players to learn whom they can trust. Our game is played on a highly stylized landscape that allows us to control and isolate the degree of spatial variation and spatial covariation. We found that agistment networks are more effective where spatial variation in resource availability is high, and generally more effective when spatial covariation is low. Policy design that seeks to work with existing social networks in rangelands has potential, but this potential varies depending on localized characteristics of the biophysical variability.

Key words: agistment; climatic variability; game theory; iterated prisoner's dilemma; pastoral opportunism; trust and cooperation.

INTRODUCTION

Forage growth and distribution in rangelands are driven by precipitation (Coughenour et al. 1985, Solbrig 1993) and tend to be highly variable spatially (Bayer and Waters-Bayer 1995), interannually (Caughley et al. 1987, Ellis and Swift 1988, Ellis 1995), and intra-annually (Rutherford 1978, Solbrig 1993). In rangeland systems where land use is dominated by grazing, low primary productivity generally results in expansive production units. The clearest examples are from pastoral enterprises with fixed boundaries. For example, in Australia, modern pastoral enterprises range between 6000 and 286 000 ha, depending on the region (Bortolussi et al. 2005). While the extensive nature of grazing areas can buffer the impact of precipitation variability (Perevolotsky 1987), the variability in rangelands occurs at macro scales (Scoones 1995), so that even the largest practical grazing area is still spatially too small to buffer resource

variation completely. This has led to pastoral opportunism: tracking variations in fodder production in time and space by matching livestock population dynamics and spatial distributions as closely as possible to feed availability (Sandford 1982). Pure opportunism, unencumbered by local social controls, has probably occurred only during the European invasions of Australia and the Americas, before private-property rights were established. In all other cases, institutions have evolved, shaped by the contradictory forces of competition for scarce resources and the mutual benefits of cooperation which enable and regulate stock movement. Most of the research on these forces has been about subsistence and common-property systems, mainly in Africa and Asia. In this paper, we use a stylized model to explore these forces in the unusual context of an essentially private-property commercial system in Queensland, Australia (see Plate 1), and in particular we explore the link between the characteristics of rangeland resource variability and the effectiveness of informal institutions.

By contrast to the modern-day Australian system, most rangelands elsewhere are under some form of

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PLATE 1. Cape York, Australia. Australian rangelands are expansive, sparsely populated areas. Resource distribution varies in time and space, and to help buffer this variation, some modern pastoralists have established informal institutions that are linked to biophysical characteristics. Photo credit: Geoff McDonald.

common-property regime with pastoralists practicing nomadism and transhumance, showing a degree of opportunism tempered by social regulation of access. Bedouin pastoralists have a system of “reciprocal altruism,” in which groups have established common-property control over subregions, but allow access to other groups when forage is locally sufficient but scarce elsewhere (Perevolotsky 1987). Further examples of such institutions include a cattle-loaning system (*kuronzera*) in southern Zimbabwe, often established through kin networks (Scoones 1992), and rules defining access to water in eastern Niger (Thébaud 2001).

Perevolotsky (1987) argues that the evolution of reciprocal altruism will occur whenever regional spatio-temporal variation is high, and that the costs of excluding other groups (loss of access to others' pastures, loss of pasture on one's own territory because stock are confined to it, and the cost of defending against outsiders), are always greater than the benefit of exclusion (that all locally grown forage is available only to local stock). He proposes that the social structure of the Bedouin predisposes the formation of small units with herding functions, side by side with broader units such as tribes. Flexible arrangements like these may be more common than strongly defended common-property regimes with clearly defined membership, allocation rules and boundaries (Ostrom 1990).

According to Scoones (1994), overlapping claims, shifting assertion of rights, continuous contestation, and negotiation of access rules dominate common-property territorial arrangements in uncertain African rangeland environments. The benefits and costs of these “fuzzy” access arrangements have been explored by Goodhue

and McCarthy (2000). Under the assumptions that some noncooperation exists, and that there is some asymmetry in access rights, their modeling suggests that fuzzy access reduces variability of and increases the total return to pastoralism, and results in lower stocking densities relative to strict territorial common-property and private-property regimes. The benefits of fuzziness are increased further if access rules are adjusted to match the prevailing rainfall. First principles and evidence support the general proposition that, on the one hand, pure private-property rights are not viable in fluctuating environments, while on the other, even nomads cannot graze freely anywhere, for overlying the biophysical landscape are contours of social control and access must be negotiated and paid for.

Australian settlers established almost unfettered opportunistic pastoralism during the initial colonization of the rangelands, and, paradoxically, destroyed the elaborate and flexible Aboriginal resource use system. In precolonial Australia, spiritual and economic connections linked each Aboriginal hunter-gatherer to a specific part of the country, and groups of related individuals with particular stretches of country (Berndt and Berndt 1981). Various institutional arrangements allowed spatial connectivity. For example, gathering was carried out by foraging units whose members came from more than one descent group, and so could forage in more than one territory (Berndt and Berndt 1981). Colonizing pastoralists appropriated tracts of land the size of small European countries. They stocked these lightly, for their holdings were not recognized by the government and they paid no rent. They often had a number of holdings among which they moved stock

according to foraging and marketing opportunities. Kidman, head of a famous pastoral family in Australia, established a company that leased satellite holdings along a climatic gradient, and he skillfully exploited fluctuations in prices and rainfall (Hardy 1969, Quinn 1995, Condon 2002). These opportunistic pastoralists had developed a financially and perhaps ecologically sustainable system, but subsequent competition for land led to the compulsory breakup of these vast and illegal holdings, and replaced the pioneering system with one of family leasehold properties (Powell and Williams 1975). These past land tenure policies resulted in property sizes frequently too small to be economically and ecologically viable by today's standards.

One way to match the scale of production to the scale of biophysical processes is land amalgamation (Perevolotsky 1987, Stokes et al. 2004). However, this requires a large investment in conditions of high uncertainty. Although this process has been happening for around half a century (Holmes 1980, Condon 2002; Stokes et al., *in press*), progress is slow. Also, while some droughts are localized at small scales others are widespread, so amalgamated properties would still not provide the flexibility needed for financial and ecological viability. Agistment is an alternative strategy that incurs low capital costs, and is flexible to changing spatial rainfall patterns. Agistment is a commercial arrangement where livestock is transferred between pastoral enterprises. Facilitated through a network of kin, friends, friends of friends, relatives, business partners, and adversaries, agistment interactions match pastoralists who have a shortage of forage to pastoralists who have an excess. Agistment is an example of how pastoral enterprises with relatively fixed boundaries on private property are able to match the biophysical process scale. Agistment arrangements are voluntary and self-regulated, so there are no official statistics on agistment activity. However, it seems that over the past 30 years, agistment activity has become more common, with most pastoralists entering into the agistment market from time to time, and using agistment not just to buffer resource variation, but also for strategic business reasons (McAllister et al. 2005, Janssen et al. 2006).

Through discussions with pastoralists in Queensland, Australia, we know that trust and past experiences are critical drivers in how and with whom individuals make agistment arrangements (McAllister et al. 2005). Generally, when pastoralists agist their livestock on another property, they expect that their cattle will not be stolen, will have access to water, and will be fed supplements. When accepting agistment cattle, pastoralists expect that only the agreed number of stock will graze their paddocks and that stock with poor temperament will not damage their infrastructure. However, even though agistment success relies on mutual cooperation, dishonored trust in agistment arrangements is not uncommon (McAllister et al. 2005). Human behavior is neither fully rational nor infallible (Ostrom 1998). Experimental

studies conducted in rural United States point to the complexity of decision-making processes, with prior experiences and group composition combining with an individual's characteristics to reach decisions (Cárdenas and Ostrom 2004). It seems that while agistment in the Queensland private-property regime allows rapid and flexible responses to spatial biophysical variation, non-cooperative behavior detracts from the success of agistment in buffering against biophysical shocks, just as it detracts from reciprocity in less formally institutionalized societies (Niamir-Fuller and Turner 1999).

This paper is about how the evolution of trust and cooperation in agistment networks is linked to the characteristics of biophysical heterogeneity (McCarthy 1998). Limits to geographic knowledge and the need to periodically re-invest in the maintenance of social relationships impair agistment interactions. These human characteristics are inseparable from the biophysical landscape, which not only truncates the agistment network but also drives the requirement for agistment in the first place. Our issue is that, because we do not understand the evolution and maintenance of agistment networks sufficiently, we are (a) missing an important element in determining the true scale of natural resource management in rangelands and (b) missing an opportunity to develop policy more in tune with informal institutions. In this paper, we use recent advances in game theory (M. A. Janssen, *unpublished manuscript*) to explore the hypothesis that evolution of trust and cooperation in agistment networks are linked to the characteristics of biophysical variation.

METHODS

Game theory models are used to explore strategic behavior, particularly where social facets are important (for a review, see Gotts et al. 2003). The core aspect of our model of agistment activity is the strategic behavior of pastoralists, where the opportunity for pastoralists to interact is determined by an uncertain biophysical landscape. Agistment involves the interaction between two pastoralists; when pastoralists interact, they "play" a one-shot game. We know that, in such cases, cooperation between egoists can evolve when players play a game for a large number of repetitions (Axelrod 1984). When interactions are only one shot, there is no strategic reason for an egoist to cooperate. However, experiments show that people do cooperate to a certain degree in one-shot social dilemmas (Frank et al. 1993). This may happen when a reliable reputation score of an opponent (Wedekind and Milinski 2000) or other pieces of information are available, perhaps based on prior face-to-face communication (Frank et al. 1993). In this paper, we build on the study of Janssen (*unpublished manuscript*) that explains cooperation between strangers based on the ability of players to learn who to trust. Players learn to recognize trustworthiness using symbols which we represent as a sequence of zeros and ones. In

TABLE 1. Payoff table of the Prisoner's Dilemma with the option to withdraw from the game.

Player A	Player B		
	Cooperate	Defect	Withdraw
Cooperate	R, R	S, T	E, E
Defect	T, S	P, P	E, E
Withdraw	E, E	E, E	E, E

Note: Symbols R (reward), S (sucker), T (temptation), E (exit), and P (punishment) refer to payoff values for various combinations of behavior, as discussed in *Results*.

this section we discuss our application of Janssen's model.

Our model consists of a population of n players. Players wishing to supply land for agistment interact with players who demand land. When players interact, individuals have three possible actions to choose from: cooperate (C), defect (D), or withdraw (W). The payoffs from agistment depend not only on what action a pastoralist takes, but also what action the pastoralist's "opponent" takes (Table 1). If both players cooperate, they each get a payoff of R (reward for cooperation). If both players defect, they each get a payoff of P (punishment for defecting). If player A defects and B cooperates, A gets a payoff of T (temptation to defect), and B gets S (sucker's payoff). If at least one of the players withdraws from the game, both players get a payoff of E (exit payoff).

An attractive feature of our application is that the actions have direct interpretation in terms of agistment. When a player supplying land defects, stock may go missing through theft or as a result of poorly maintained fences. Stock may also lose condition because supplementary feed is not managed as agreed. When the owner of the stock defects, they may agist stock poorly bred for temperament, damaging infrastructure on the land owner's property. It is also possible that, with few legally binding contracts (McAllister et al. 2005), payment expectations (timing or amount) may not be met. The most important cost of agistment, however, is the opportunity cost of not agisting. If a pastoralist is in a position to supply land, then the opportunity cost is that of lost revenue from not agisting. If a pastoralist seeking agistment land fails to agist stock, then the opportunity cost is that of overstocking, potentially leading to stock mortality, loss of stock condition, increases in supplementary-feeding costs, and land degradation.

The payoff matrix for the game is defined using $T = 2$, $R = 1$, $E = 0$, $P = -1$, and $S = -2$. The payoff matrix relates stylistically to agistment. Our interpretation is that biophysical variation incurs a cost to pastoralists of R , but agistment activity allows pastoralists to recoup those losses exactly through mutual cooperation. Where cooperation is not mutual, one player exploits the other (i.e., defects), thereby recouping more than just the cost of variation (i.e., T). Accordingly, the exploited player experiences losses greater than would be felt if they did

not agist (i.e., S). With mutual defection both players experience losses greater than would be felt if they did not agist, but logically such losses are not as great as those experienced when being exploited without exploiting, (i.e., P).

The probability of a player not withdrawing from the game and thereafter cooperating with an opponent is based on the likelihood of trusting the opponent. If both parties agree not to withdraw from the interaction, each player chooses either to cooperate or defect in order to maximize their expected returns from the game, but their objective functions are biased by an individual's aversion to exploiting others α_i and an individual's degree of altruism β_i . What each player expects to receive in monetary terms from cooperating $E[M(C)]$ and defecting $E[M(D)]$ are

$$\begin{aligned} E[M(C)] &= \text{Pr}[\text{Tr}] \times R + (1 - \text{Pr}[\text{Tr}]) \times S \\ E[M(D)] &= \text{Pr}[\text{Tr}] \times T + (1 - \text{Pr}[\text{Tr}]) \times P \end{aligned} \tag{1}$$

where $\text{Pr}[\text{Tr}]$ is the player's expected probability that the opponent can be trusted (we explain below how this probability is defined). We assume, in line with experimental evidence (Ahn et al. 2001, 2003) that there is a difference between material payoffs and the experienced utility of the monetary payoffs. The rational choice made by the players in maximizing the expected utility is based on the expected utilities for cooperating $E[U(C)]$ and defecting $E[U(D)]$:

$$\begin{aligned} E[U(C)] &= \text{Pr}[\text{Tr}] \times R + (1 - \text{Pr}[\text{Tr}]) \times (S + \beta_i) \\ E[U(D)] &= \text{Pr}[\text{Tr}] \times (T - \alpha_i) + (1 - \text{Pr}[\text{Tr}]) \times P. \end{aligned} \tag{2}$$

The parameters α_i and β_i reflect behavioral preferences. If α_i and β_i are both equal to zero, the player only takes monetary rewards into account and will selfishly and rationally defect in each interaction. However, experiments show that there is diversity in the degree of selfishness in a population (Ahn et al. 2001, 2003).

Given the two estimates of expected utility, the player is confronted with a discrete choice problem which is addressed as a stochastic decision process. The probability of an individual cooperating $\text{Pr}[C]$, depends on the expected utilities and the parameter γ , which represents how sensitive the player is to differences in the estimates. The higher the value of γ , the more sensitive the probability of cooperating is to differences between the estimated utilities:

$$\text{Pr}[C] = \frac{e^{\gamma \cdot E[U(C)]}}{e^{\gamma \cdot E[U(C)]} + e^{\gamma \cdot E[U(D)]}} \tag{3}$$

How do players learn the values of α_i and β_i of the other players, given this is not directly observable? We use the approach used by Janssen (*unpublished manuscript*), where players learn who to trust by learning to recognize what are referred to in the social science literature as symbols (Ahn et al. 2004). In agistment interactions, pastoralists look for symbols such as land and livestock condition, infrastructure development, and management approaches as indicators of how

trustworthy an opponent may be in terms of adhering to agistment obligations (McAllister et al. 2005). Players do not explicitly learn to trust individuals in our model, but rather learn the characteristics of trustworthy individuals. However, implicitly, pairs of individuals can still develop mutual trust if they learn that each other has trustworthy characteristics. Reputation is also important in determining trust (McAllister et al. 2005) but here we hypothesize that symbols are a more realistic model when trust is accessed across very large spatial scales. In our approach, the probability $\text{Pr}[\text{Tr}]$ that a player will choose to trust its prospective partner is defined as

$$\text{Pr}[\text{Tr}] = \frac{1}{1 + \exp\left(-\sum_{i=1}^s w_i x_i\right)} \quad (4)$$

where x are the values (0 or 1) of the s symbols, and w_i are the weights applied to the symbols estimating trustworthiness. If an agistment game is played, each player receives feedback, F , on the experience. This feedback is simply whether the partner cooperated ($F = 1$) or not ($F = 0$). The equation adjusting the weights is

$$\Delta w_i = \lambda \times (F - \text{Pr}[\text{Tr}]) \times x_i \quad (5)$$

where Δw_i is the adjustment to the i th weight and is bound between -0.05 and 0.05 , λ is the learning rate, F is the feedback, $F - \text{Pr}[\text{Tr}]$ is the difference between the player's level of trust in the other player and the observed trustworthiness of the other player, and x_i is the other player's i th symbol. The weights of symbols associated with positive experiences increase, while the weights of those associated with negative experiences decrease, reducing discrepancies between the amount of trust placed in an opponent and that opponent's trustworthiness.

Landscape biophysical response function

The key to representing our agistment problem as a game-theoretic model is splitting the population of players into groups representing pastoralists who, in a given time period, either (1) demand agistment land, (2) are in a position to supply land for agistment, or (3) neither supply nor demand land for agistment. Water availability driven by the quantity and seasonal distribution of rainfall, is the key environmental factor in rangelands (Solbrig 1993). Accordingly, our groups correspond to (1) dry, (2) wet, and (3) neutral biophysical conditions. The most important aspect of our biophysical model is the need to isolate and control both spatial variation and spatial covariation. To achieve this, we used a highly stylized model of a rangeland landscape.

We define our biophysical landscape as a 20 by 20 grid, with each grid cell representing a pastoral property, which we assume equates to a single and unique pastoralist. Each cell is associated with a state, which

is represented as an integer bound by -10 and $+10$. Our state represents water availability. In each generation of our model, the landscape both dries through evaporation and hydrates through precipitation. To represent evaporation, one unit is uniformly deducted from each state in the grid. At the same time, the grid-wide total deducted through evaporation is added back to the grid to represent precipitation (total rainfall).

Precipitation is not uniformly distributed. Total rainfall is added through a number of rain events and each rain event has a spatial extent which is the area affected. We assume that all of our rain events are geographically square, and define the term v_C (spatial covariation parameter) to represent the size of the rain events (e.g., 3×3 cells, $v_C = 3$, or 6×6 cells, $v_C = 6$, etc.), and this extent of rain events is user-defined and constant during any one simulation. We further assume that, when a cell is affected by a rain event, that exactly one is added to the cell's state (i.e., rain intensity is constant). The number of rain events per generation is determined by the number required to deliver the landscape's total, given the extent of each event. Note that the ratio of total rainfall to extent may not be a whole number. To avoid any rounding errors, the landscape is generated on a 40 by 40 grid or larger if required to maintain a whole ratio between total rainfall and extent. For example, if extent is defined as $v_C = 7$, then each generation of the game will generate six rain events across a 42 by 42 grid.

Spatial covariation (the relationship between neighboring cells) is generated by the size of rain events, with a rain extent of one showing zero covariation at the scale of the property, and greater rain extent increasing covariation. Spatial variation and temporal variation are generated through our interpretation of the grid through generations. Without spatial variation, no agistment takes place. Also, if we define the spatial boundary of variation as our grid, then in the absence of temporal variation, the number of pastoralists supplying agistment land will equal the number demanding land. Hence, to represent increasing spatial variation, we increase the number of pastoralists demanding and supplying agistment land (which remain equal with temporal variation). We define $2v_S$ as the total number of pastoralists in the agistment market, which is constant in all generations, so $v_S = 0$ refers to zero spatial variation. We interpret, based on our state values, the lowest v_S pastoralists as demanding agistment land and the highest v_S as supplying agistment land (when many pastoralists are at the boundary, a grid of random numbers generated at the start of the game is used to determine which are in and out of the agistment market).

Temporal variation defined at the spatial scale of our bounded grid, would be experienced as discrepancies between the number of pastoralists supplying and demanding agistment land. We could represent temporal variation by varying the ratio between the two groups

TABLE 2. List of parameters and their default values.

Parameter	Value
Number of players n	400
Number of symbols s	100
Number of generations	20 000
Iterations of game used to obtain results	10
Conditional cooperation parameter α_i	$[0, \alpha_{MAX}]$
Conditional cooperation parameter β_i	$[0, \alpha_i]$
Maximum conditional parameter α_{MAX}	3.0
Learning rate λ	0.5
Steepness γ	1.0
Spatial variation parameter v_S	$[0, n/2]$
Spatial covariation parameter v_C	$[1, 10]$

throughout time. However, here our concern is limited to spatial resource variation and hence we exclude temporal variation.

Matching players

Using our landscape model, in each time period, we populate a list of pastoralists which demand agistment land and a list of pastoralists that can supply land. We define which of these groups chooses an opponent (rather than being chosen) at random in each iteration of the game—this is the “first” group. One by one, and in an order randomized in each generation of the model, players in the first group are given the opportunity to select and reach agreement with an opponent. The player from the first group attempts to reach agreement from all players in the second group in order of the distance between itself and the opponent. When two players are matched, agreement is deemed to have occurred when both players do not choose to withdraw (W) from the game. This means they both choose either to cooperate (C) or defect (D). The alternative is that one player withdraws (W), and then a player from the first group will move down its preferences until either all attempts have failed or agreement is reached. The player from the first group takes no further part until the next generation. Where agreement is reached, the player from the second group is removed from the list of possible opponents for players remaining in the first group.

Parameter assumptions

We made assumptions about the parameters in the model (Table 2). We do not present sensitivity analysis here, but refer to Janssen (*unpublished manuscript*) who showed, as expected, that results depend on parameter assumptions. This highlights how, in this type of model where stylized assumptions are used to present theory, the usefulness is not in the values presented but rather the ideas generated.

RESULTS

To examine how biophysical variation and agistment networks are coupled, we tested the model’s sensitivity to both spatial covariation and spatial variation. In all

treatments we re-ran the model 10 times. In our model, spatial variation always induces a cost to pastoralists, but they can recoup some percentage of that cost through agistment. The total cost induced by spatial variation (not accounting for any amounts recouped) is linearly and positively related to the degree of spatial variation (this cost is $-2Rv_S$, Fig. 1a). However, we found that the greater the degree of spatial variation, the greater the percentage of the total cost of variation recouped through agistment (Fig. 1b). In other words, as spatial variation increases, agistment becomes more effective at recouping the cost of spatial variation. However, even though the effectiveness of agistment networks increases with increased spatial variation, the net impact was still to increase the overall costs.

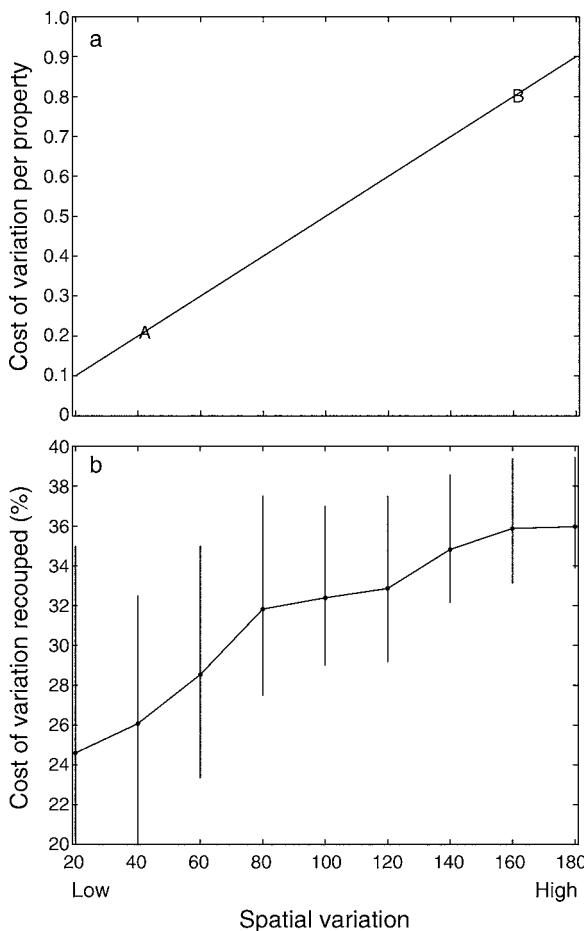


FIG. 1. The relationship between spatial variation and (a) the cost of variation and (b) the percentage of the cost of variation recouped through agistment. The cost is per generation and relates to the model’s payoff matrix (Table 1); the cost per pastoralist in the agistment market (either supply or demand) is $-R$, which is completely recouped if two pastoralists cooperate wholly in an agistment interaction. The vertical lines in Fig. 1b show the 25–75 percentile ranges; in these simulations we do not consider spatial covariation (spatial covariation, $v_C = 1$). Points A and B in panel (a) emphasize levels of low and high spatial variation, respectively.

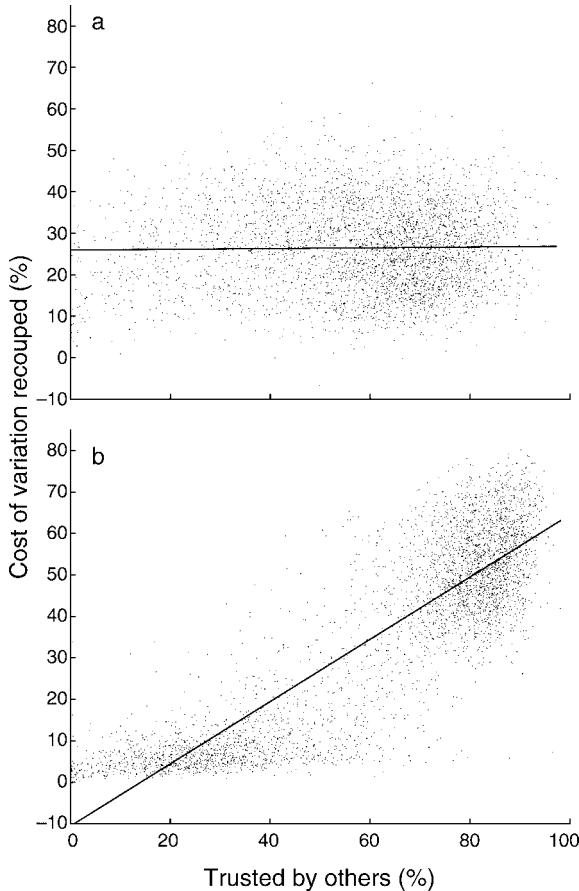


FIG. 2. Relationship between the percentage of the cost of variation recouped by agistment and the degree to which an individual is trusted by others, with (a) low spatial variation (corresponding to point A on Fig. 1a) and (b) high spatial variation (corresponding to point B on Fig. 1a). The vertical axis shows the percentage of the potential cost of variation a pastoralist recoups through agistment. The horizontal axis shows how much trust, on average, is placed in others in an individual's network. For an individual, trust is measured as the mean degree to which one is trusted by others at the end of the game, weighted by the total number of times an opponent was encountered.

In order to more intimately consider the role of spatial variation, we examined the relationship between how trusted an individual is by others and the percentage of the cost of variation recouped by agistment. We compared two cases: low spatial variation (Fig. 2a) (corresponding to point A on Fig. 1a) and high spatial variation (Fig. 2b) (corresponding to point B on Fig. 1a). In both cases, the relationship was positive: generally the more trusted an individual, the greater the payoff from agistment. However, the difference between the two cases is clear. When spatial variation is low, the benefit of being trusted is only marginal, but when spatial variation is high, the benefits are much more apparent.

Using the same two cases (high and low spatial variation), we then examined the relationship between

the degree of trust placed in others and the percentage of the cost of variation recouped by agistment. When spatial variation was low, the relationship between trust placed in others and the cost of variation recouped was concave, with the best outcomes achieved when an intermediate degree of trust was placed in others; too little and too much trust in others afforded less favorable outcomes for individuals (Fig. 3a). When spatial variation was high, while the relationship was also concave, our results showed that the best outcomes were achieved by individuals exhibiting a much higher degree of trust in others (relative to the low-variation case).

Finally, we combined the role of spatial covariation into our analysis and found that the relationship between spatial covariation and the percentage of the cost of variation recouped by agistment was positive

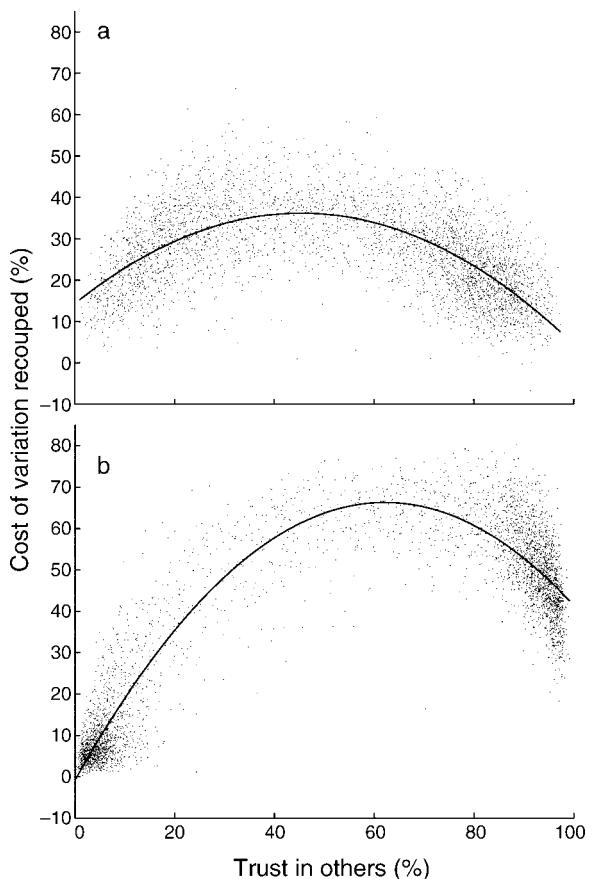


FIG. 3. Relationship between the percentage of the cost of variation recouped by agistment and the trust placed in others, with (a) low spatial variation (corresponding to point A on Fig. 1a) and (b) high spatial variation (corresponding to point B on Fig. 1a). The vertical axis shows the percentage of the cost of variation a pastoralist recovers through agistment. The horizontal axis shows how much, on average, an individual trusts others in his network. Trust is measured as the mean trust placed in others at the end of the game, weighted by the total number of times an opponent was encountered.

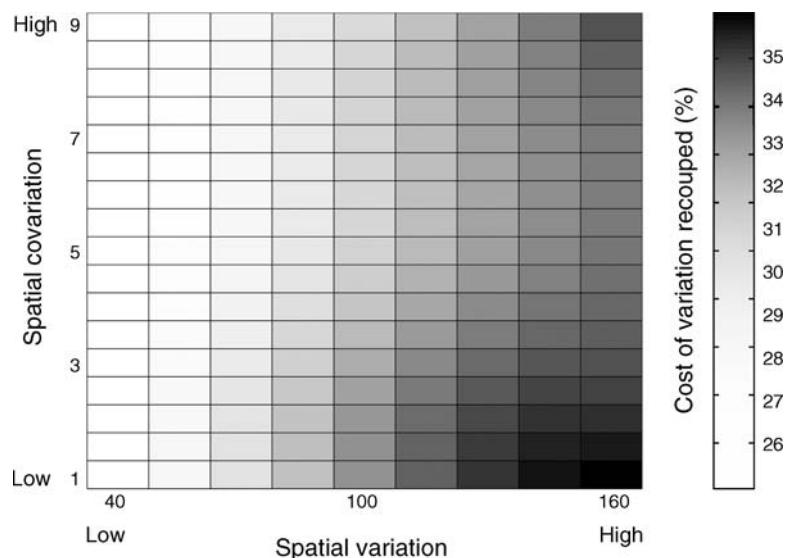


FIG. 4. Percentage of the cost of variation recouped through agistment, under different combinations of biophysical spatial variation and covariation. This is a graphical version of Table 3, with Matlabs interp2function used to interpolate.

(Fig. 4). However, it would appear that the role of spatial variation is more important than covariation, and that the positive relationship between spatial covariation and the percentage of the “cost of variation” recouped by agistment was more significant when combined with high spatial variation (Table 3). The percentage of the cost of variation recouped by agistment is linked to how much trust develops with each combination of variation (Table 3).

DISCUSSION

In rangelands, spatiotemporal variation in forage quality and quantity is high and dictates animal population dynamics (Illius et al. 1998). Livestock productivity (often measured by mortality and reproduction), in the absence of human intervention is restricted by forage availability in the most improver-

ished part of its spatiotemporal distribution (Illius and O'Connor 1999). Spatial connectivity allows livestock to cushion spatial distribution (no such luck with temporal distribution). But where livestock movement is bound by either social controls or infrastructure, at a scale that is smaller than the scale of resource variability, then any increase in the degree of resource variation induces a cost in productivity. In this paper, we are concerned primarily with the link between the characteristics of biophysical variation in the forage resource and the effectiveness of agistment networks. We developed a model to test the hypothesis that such a link could exist, and we found that agistment networks are more effective where spatial variation in resource availability is high, and generally more effective when spatial covariation is low.

TABLE 3. Value of trust under different combinations of biophysical spatial variation and covariation: recoup indicates the percentage of the cost of variation recouped, while trust indicates, on average, how much individuals are trusted (using the same definition of trust as employed in Fig. 2; see Fig. 2 legend).

Spatial covariation	Spatial variation		
	Low ($v_S = 40$)	Mid ($v_S = 100$)	High ($v_S = 160$)
High ($v_C = 9$)			
Recoup	25.0 (24.6–25.4)	30.5 (30.1–31.0)	34.5 (34.0–35.1)
Trust	56.9 (56.5–57.4)	57.6 (57.0–58.2)	61.2 (60.7–61.8)
Mid ($v_C = 5$)			
Recoup	25.1 (24.7–25.4)	30.9 (31.3–30.4)	33.8 (33.1–34.4)
Trust	57.0 (56.6–57.4)	59.1 (58.2–59.7)	60.9 (60.2–61.6)
Low ($v_C = 1$)			
Recoup	26.8 (26.5–27.1)	33.1 (32.4–33.8)	35.9 (35.2–36.7)
Trust	58.6 (58.0–59.1)	61.4 (60.6–62.1)	62.7 (62.0–63.4)

Notes: Recoup indicates the percentage of the cost of variation recouped, while trust indicates, on average, how much individuals are trusted (using the same definition of trust as employed in Fig. 2; see Fig. 2 legend). Values are means with 95% CI in parentheses.

In societies that tend towards formal institutions and private property regimes, spatial connectivity is lost when fences restrict movements (Boone and Hobbs 2004; Hobbs et al., *in press*), and artificial watering (dams, bores, wells etc.) makes this restriction physiologically possible. Although infrastructure can remove spatial connectivity, agistment networks have the ability to reconnect them (see Fig. 3. in Janssen et al. 2006). Agistment does not fully overcome the costs induced by variation, but rather allows pastoralists to recoup some of the losses, both through maintaining stock and condition in poor times, and by cashing in on good times (Sandford 1983). In our model, if all agistment interactions were mutually cooperative, then agistment would alleviate the total costs induced by variation. But human behavior generally prohibits this outcome, even though from an individual–pastoral perspective, being trusted has an economic value (Dwyer et al. 1987, Doney and Cannon 1997). We found that generally in agistment interactions, the more one is trusted, the better one's outcome. This result is consistent with expectations based on previous work on reciprocal altruism. Experimental games showed that individuals tended to trust altruistic individuals more than they did nonaltruistic individuals, and to contribute more to others in their group when they expected to play a two-part trust game afterwards (Barclay 2004). Furthermore, reciprocal altruism is commonly observed behavior, not just in human societies (Kaplan and Hill 1985, Niamir-Fuller 1998, Gurven 2004), but in those of primates (Seyfarth and Cheney 1984, Boesch 1994, de Waal 1997, Hauser et al. 2003) and other animals (Wilkinson 1988, Hart and Hart 1992). Our results are notable in documenting how in pastoral communities the development of reciprocated trust (hence a successful agistment outcome) varies both with spatial covariation and spatial variation, where the mechanism for variation's impact on agistment interactions is through its impact on network structure.

The link between biophysical variation and the success of agistment activity is via variation's impact on the structure of the agistment network. Biophysical variation dictates which pastoralists can interact and when, and how many alternative pastoralists are in the agistment market at a given time. These characteristics determine how frequently a pastoralist will encounter the same individuals, which in turn determines the ability of pastoralists to build on mutually cooperative behavior, and likewise to accurately avoid noncooperators (i.e., poor managers and cattle thieves).

To explore the link between biophysical variation and the success of agistment networks, we have to consider what variation actually means in the context of a rangeland landscape. With very high levels of spatial variation, the whole landscape may be filled with pastoralists who are in the agistment market. The alternative is that only a few pastoralists at a given time are in the market, and in this latter case, regardless of

the level of spatial covariation, supplying and demanding pastoralists are more likely to be geographically dispersed. Also, in a system with low spatial variation, having less pastoralists in the market for agistment means that an individual will have a lower chance of finding any counterpart they trust. This is more important than it may seem, because having a lower chance of finding someone they trust means they may also have to travel considerable distances to find agistment interactions. As a result, they will be in unfamiliar territory and less likely to accurately estimate trust. When spatial covariation is high, pastoralists in the agistment market need to travel further afield to find a pastoralist in the opposite climatic condition. This is because, when spatial covariation is high, nearby properties are likely to be in the same condition hence not suitable for an agistment arrangement. By traveling farther, and in an unspecified direction, the number of pastoralists dealt with over successive seasons is much greater than when there is no need to travel so far; in a grid of square properties, a pastoralist has eight neighbors, the next layer of properties includes double that number.

In summary, both higher spatial covariation and lower spatial variation limit options for agistment interactions between pastoralists within close geographic proximity. This increases the number of pastoralists an individual needs to deal with over time but decreases the average number of times each individual pastoralist is dealt with and hence generally weakens the strength of ties within the network. There is a paradox of spatial variation. While as a percentage, the cost of variation recouped through agistment increases as spatial variation increases, it is this variation that is the source of the cost in the first place. However, despite improved efficiency in the agistment network, overall costs always increase with variation: uncertainty in rainfall is always a cost (Walker and Janssen 2002).

Variation's impact on the structure of the agistment network is the link between variation and the success of agistment activity, but this link is not a simple linear relationship. Individuals build relationships, but the sum of individual relationships has important system-wide implications. An environment or atmosphere can be formed that either stifles or encourages trust and, depending on the characteristics of variation, the transition between the two alternative states may be defined by a threshold. In a system with few mutually cooperative agistment interactions between non-strangers, individuals tend to be less trusting of strangers too; and this behavior can be self-reinforcing. We can see this in our results. Individuals can trust too much: individuals who trust others at a level above some threshold have worse outcomes from agistment. When the system is characterized by less cooperative behavior, the level that defines "too much" is lower.

The informal institutions that facilitate resource reciprocity are well established in various common-

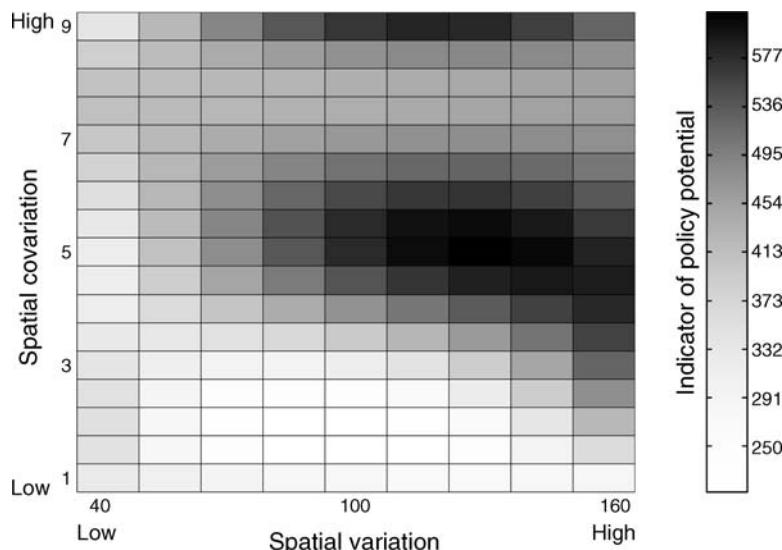


FIG. 5. The potential for policy to increase the amount of the cost of variation recouped through agistment, under different combinations of biophysical spatial variation and covariation (expressed as the amount of the cost of variation recouped less the corresponding amount recouped from data presented in Fig. 4).

property African pastoral systems (Perevolotsky 1987, Scoones 1992, Niamir-Fuller 1999), if not disrupted by periodic attempts to privatize the rangelands (Niamir-Fuller 1999), or to make common-property arrangements too exclusive (Goodhue and McCarthy 2000). The policy relevance of networks and stock movement in response to spatiotemporal biophysical variation has been discussed (Behnke and Scoones 1993, Bayer and Waters-Bayer 1995, Niamir-Fuller 1999, Agrawal 2002). Corresponding discussions have not taken place for rangelands societies like those in Australia, where institutions tend to be more formal and where private property regimes dominate. Our focus is on these latter systems. While our aim was to establish the link between biophysical variation and agistment network structure, and hence agistment outcomes, we briefly discuss policy. Specifically, we consider the potential benefits to pastoralists when policy is designed to work with the “grain” of informal pastoral networks. The structure of pastoral networks, whether in private or common-property systems, needs to be taken into account in the establishment or modification of stock routes and holding grounds, public water points, publicly funded marketing arrangements, and disease-control policies (Sandford 1994). Examples of working against the grain are the subsidization of drought feed and post-drought restocking. These ease the short term, and in some individual cases the terminal, effects of drought, but in the long-term they are likely to reduce the incentive for individuals to invest in the maintenance of networks, so that dependence on drought relief grows at society’s expense (Hazell 2000).

One example of a policy to support agistment or other networks is through investing in information flow.

Making good agistment decisions depends on the system rewarding cooperation and punishing noncooperation. The success of this process depends on the information available and how much of this information can be possessed. Making the network smaller may allow more information to be processed per individual in the network, but for agistment, large networks are required in order to link climatically diverse environments. But what if modern technology could be used to complement the existing pastoral networks? E-bay, for example, facilitates trading between strangers using recommendations to gauge the trustworthiness of trading partners (Luo 2002). What if modern internet technology, available to most pastoralists in developed countries, were used to increase the availability and reliability of information in agistment networks? We can test this policy in our model by making the symbols more accurately represent individual behavioral preferences. We simply converted half of the symbols to the binary representation of an individual’s aversion to exploiting others α_i , and the other half, an individual’s degree of altruism β_i . The potential for improved agistment outcomes differs depending on the characteristics of variation (Fig. 5). It seems that the greatest potential in this regard is in rangelands with moderate levels of variation. In systems with low levels of variation, the low cost of variation means that there is little potential for improving agistment outcomes. In systems with high biophysical variation, the networks are already working effectively. With moderate variation, there are moderate costs associated with existing variation and the networks are ineffective enough such that they respond well to the improved accuracy of information.

Our research was limited by a lack of detailed empirical information. We therefore made assumptions and drew inferences that may be modified in light of new information. Meanwhile, in this paper, we have demonstrated two important things. First, policy designed to work within existing informal pastoral institutions has great potential even in private property regimes. Second, how the system responds to any policy depends on social relationships, which do not exist independently from the biophysical characteristics of the system. Mehta et al. (1999) said that institutions embedded in social relations span spatiotemporal scales and can work to embrace, moderate, or exacerbate uncertainty. An agistment network is an institution which “embraces” uncertainty in biophysical resource variation. Further, we show how biophysical uncertainty can shape the network.

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