KinModel: An Agent-Based Model of Rangeland Kinship Networks

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EXTENDED ABSTRACT

What role does kinship and family structure have in the adaptive capacity of Australian rangelands? We have been considering this question as part of the CSIRO's Complex Systems Science funded project "Social Adaptation and Ecological Uncertainty" and in this paper we present our concept on how to treat the problem as an agent-based model.

Human-based networks disseminate information, help enforce social norms, facilitate trade, and so forth. An additional role of networks in many rural settings is linking otherwise fragmented ecological nodes (Janssen et al. in press). In rangelands, ecological units which have been fragmented and disconnected through conversion to pastoral land are linked through human networks (McAllister et al. in press). This is significant because rangeland resources are highly variable in time and space, and some networks that allow the movement of stock around the landscape have the potential to reconnect fragmentation units of land and hence buffer the effects of resource variation. Kinship based networks may help in this buffering role, and these networks are the focus of this paper.

Here we present 'KinModel', an agent-based model exploring kinship networks in rangeland landscapes. The model is constructed using the agent-based modelling platform *RePast* (version 3, Java). We devote this paper to outlining our concept, preliminary implementation, and data sources for a case-study rangeland system, the Dalrymple Shire.

The key elements of the model are:

- a rangeland landscape, with variation of resources in time and space (Figure 1); and
- pastoralists, who can marry, produce offspring and bequest their properties.

While our methods are still developmental, details are starting to emerge. One hypothesis we wish to consider is that because labour was initially in short supply in many Australian rangeland systems, long surviving families should be associated with families with many sons. Our model shows this argument could be flawed in two ways. First, brides were is shorter supply than labour, so daughters had a much greater chance of marring into successful pastoral families and building a larger kin-based network. Second, if we assume that all sons (and daughters for that matter) shared inherited land (i.e. not just the eldest son), then large families could ultimately split the enterprise into parcels too small to individually make a living. Small enterprises are limited in their capacity to buffer resource variation. Even if a small enterprise returns enough profit on average to support itself, it is at risk of collapsing economically in poor years if its networks are not strong enough to help in the buffering process.

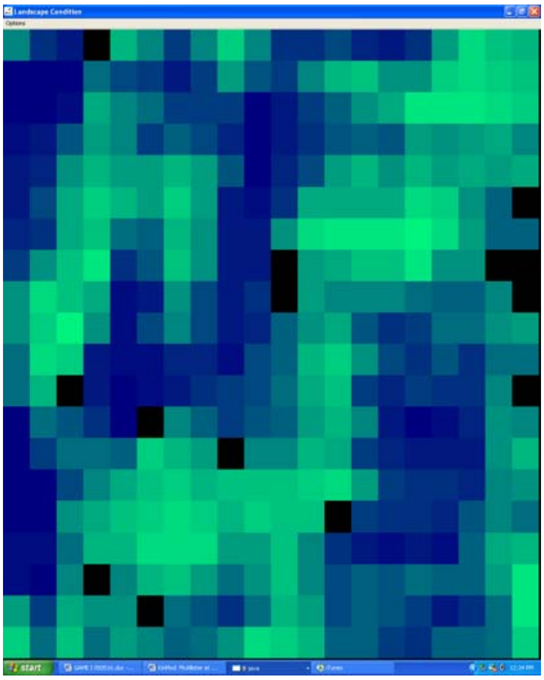


Figure 1. Landscape display. Blue and green (dark/light) represent low and high levels of resource abundance respectively.

1. INTRODUCTION

What role does kinship and family structure have in the adaptive capacity of Australian rangelands? We have been considering this question as part of the CSIRO's Complex Systems Science funded project "Social Adaptation and Ecological Uncertainty" and in this paper we present our concept on how to treat the problem as an agent-based model, and show model outputs as a means of method demonstration.

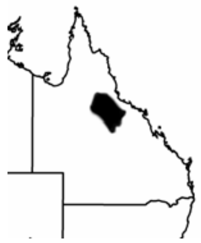
Human-based networks disseminate information, help enforce social norms, facilitate trade, and so forth. An additional role of networks in many rural settings is linking otherwise fragmented ecological nodes (Janssen et al. in press). In rangelands, ecological units which have been fragmented and disconnected through conversion to pastoral land are linked through human networks (McAllister et al. in press). This is significant because rangeland resources are highly variable in time and space, and some networks that allow the movement of stock around the landscape have the potential to reconnect fragmentation units of land and hence buffer the effects of resource variation. Over the past 30 years, transport and communication technologies have helped to foster trust-based, networks which facilitate the movement of stock in search of patchy resources (McAllister et al., 2005a). Kin based networks based on the links between family members may also play a buffering role, and these networks are the focus of this paper.

We assert that kin-based networks were particularly important in the initial phase of pastoral development. At that time, kin-based networks were pre-established, while networks based on other relationships between pastoralists were still to develop. Case studies exist of kin-based networks embedded in the rangelands of developing countries (e.g. Scoones, 1992, Borgerhoff Mulder, 1998, Borgerhoff Mulder, 2000). Swedish researchers have analysed how clan communities or kinship have impacted on their socio-ecological systems over long periods of time (Low, 1994). However, no such work has focused on Australian rangeland networks.

We take a complex systems science view point, which builds on a small but growing body of literature treating Australian rangelands explicitly as linked social-ecological landscapes (Anderies et al., 2002, Walker and Janssen, 2002, Gross and McAllister, 2003, Janssen et al., 2004, Gross et al. in press, McAllister et al., 2005b). This new direction is driven by the recognition of the importance of non-linearities and uncertainty in ecosystem functioning. Accordingly management philosophies are changing from control and stability (Holling and Meffe, 1996) to the maintenance of 'resilience': the system's capacity to absorb shocks (Walker and Abel, 2002, Folke et al., 2002). Resilience is fundamental in building adaptive capacity in rangelands.

Our model is an agent-based model, constructed using the agent-based modelling platform *RePast* (version 3, Java). We devote this paper to outlining our concept and preliminary implementation, and our data sources for a case-study rangeland system, the Dalrymple Shire.

2. CASE STUDY: DALRYMPLE 1859-1930



Given the relatively short history of pastoral activity in Australia, we are very well placed to pioneer an understanding of the role of kinship in system resilience in rangelands. However, data collection is painstakingly slow, so we limit our research to the Dalrymple Shire in the period 1862-1930.

The Dalrymple Shire covers 66,709 km^2 of rangelands in the upper Burdekin River catchment, northern Queensland. The area is dominated by cattle grazing and European pastoralists began displacing indigenous populations in 1859 (Stokes et al. in press). In our model key actions of our human agents (marriage, death, birth etc., see below) are generated probalistically, with these probablities estiamted using data from the case-study region. By understanding the past, we hope to develop theories that will help us understand the role of kinship, and networks more generally, in maintaining healthy funcitoning rangelands today.

We aspire to collect and match family tree (births, deaths and marriages) to land ownership data. With this type of information we could, for example, crudely proxy how much of a pioneering family's DNA remains in the rangeland system today relative it's to family structure, allowing us to consider what types of families tend to be more persistent. Meticulous record keeping by the Queensland Government Treasury has meant that leasees of each block in the region can be traced between our period of interest, 1859 to 1930. Sufficent time has ellaspsed for births, deaths and marriges data to become publicly avalable for the pre-1920s, We have also been talking to pastoralists about their families as well as talking to local family historians. While our 'family tree' data in particular are incomplete and imperfect, we are able the build a picture from which to frame our model. Further, we plan to survey present-day pastoralists in order to collect post-1920s data and also to fill in any pre-1920s data gaps .

The data collection task is omious, however some insights are already being developed. It seems that family structures and communities have played an important role in pastoral enterprises in Dalrymple, but the nature of the relationship is still unclear; some families have been in the region since pastoral enterprises began, and evidence suggests that informal networks based on kinship have helped some pastoral families survive. Alternatively, financial pressure seemed to be higher on newcomers (i.e. mid 1900s), which sometimes meant that despite fewer networking opportunities, these newcomers adopted improved land management practices while more established enterprises did not, suggesting that networks bred conservatism. Hence the strength of kin-based networks do not necessarily improve resilience of pastoralists and their land.

3. THE MODEL

'KinModel' is an agent-based model of kinship networks in rangelands. The key elements of the model are:

- a rangeland landscape, with variation of resources in time and space; and
- pastoralists, who can marry, produce offspring and bequest their properties.

We implemented our model in *RePast*, which offers some attractive features in terms of the ease of displaying networks (see below). Like other platforms for agent-based modelling (e.g. Cormas, Swarm, etc.) *RePast* allows the use of standard features for the control (scheduling) of the model and gathering user-defined parameters (Figure 1).

In presenting our model, we discuss design concepts, and where appropriate, we show the *RePast* graphical display that conveys the data to the user.

3.1. Pastoral agents

As discussed above, key actions of our human agents are generated probabilistically, with these probabilities estimated using data from our case-study region. For example, from historical records we have a good idea about how many people married and how many children couples had (and how many of these died young). As a result, we can apply observed probabilities to our model: a single male had an observed probability of getting married, etc.

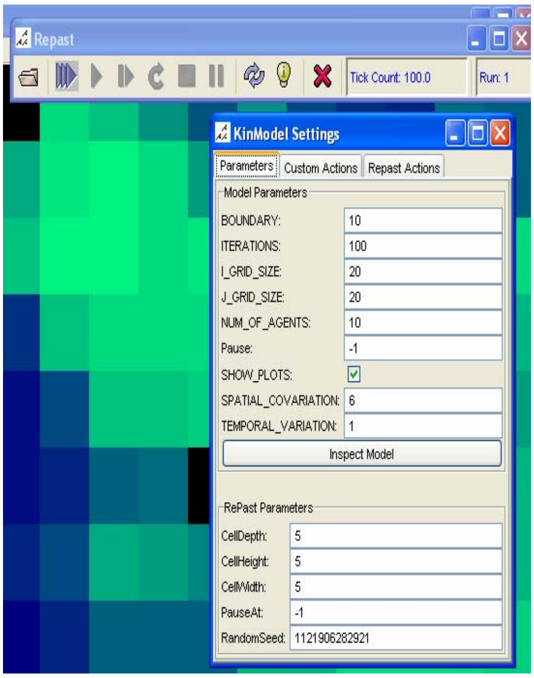


Figure 1. KinModel's *RePast* graphical user interface.

As we are interested in how kinship networks form between pastoralists in rangelands, this requires us to treat people in our system as individual agents. These individuals have basic characteristics:

- sex;
- parents;
- age; and
- land ownership.

And they have actions. They:

- marry;
- grow old;
- have children;
- die; and
- bequest land.

Real pastoralists have heterogenous mental models (Abel, 1998), and it is important that we capture this when it affects their kin based relationships.

We introduce heterogeneity by randomly parameterising key variables and allowing the control of the setting of important rules:

- Individuals may or may not own land;
- If an individual does own land, then we can specify rules for inheritance; and

- Longevity varies for individuals (latest age of death).

Heterogeneity is also introduced through stochasticity. In other words, individual characteristics differ because individuals change in a probabilistic fashion:

- They may not find a partner to marry (and this may be related to wealth);
- They may die prematurely; and
- They may have any number of children, with any combination of sexes.

3.2. Kinship Networks

Representing large complex kin-based networks poses the question of how to present this parsimoniously. We employ the approach adopted by White and Jorion (1996). A pastoralist (and his/her partner) constitutes a node, while a child constitutes a link. Note that by defining a node as a pastoralist, we are effectively truncating the network to exclude family members who do not own at least one block of land. This simplifies what would otherwise be a tremendously complex set of connections.

Examples of our truncated family tree are shown in Figure 2. The circles are nodes and the nodes are linked by children. Example (1) is where a pioneer dies without passing on his/her land. This may mean that he/she never had children, or it may mean that the children never inherited the parents' land and never owned other land. If there were indeed children involved, all that matters to our analysis is that the children left the land and therefore did not form a link in a network which associates pastoral properties. In example (2) the pioneering couple had one child who went on to own land. Pre-1930 land was generally passed down from parent to child, but our network would look the same even if the land owned by the child was not inherited but instead sourced elsewhere. The second generation pastoralist also had a one child who went on to own land.

The first two network examples in Fig. 2 may be quite common in practice, but there are more complex situations. In example (3), we show two pioneers who both produced one child who stayed on the land. Further, the second generation pastoralists had children who stayed on the land, with one second generation pastoralists having two children on the land, one of which married the child of the other second generation pastoralist. Here we can see how kinship networks form over time –marriages can link pastoral families and

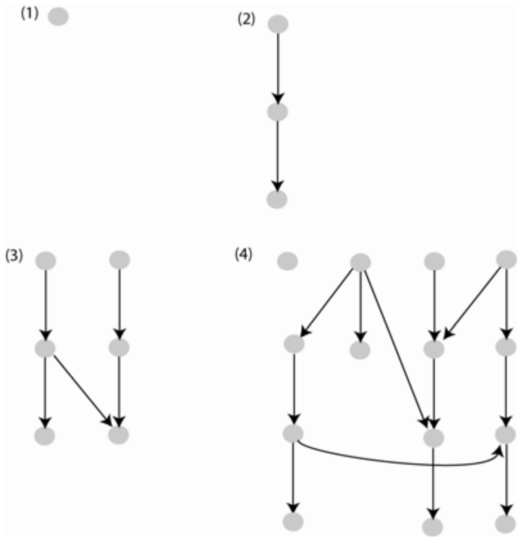


Figure 2. Representing kinship networks

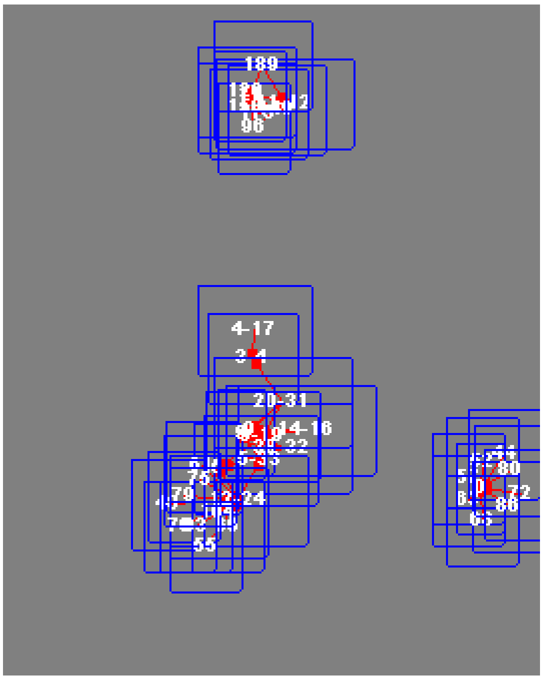
their lands. Example (4) shows a more complex example, and our research shows that there are several complex networks such as this within the Dalrymple Shire.

In our implementation of the model we use *RePast*'s ***`FruchGraphLayout`*** class in order to display the networks which are formed during simulations, as depicted in Figure 3. This display is graphical only, and network statistics are also needed as model outputs for analytical purposes (these are yet to be implemented.) The outcome depicted in Figure 3 points to a common result: that several independent networks form, where the boxes represent nodes and the numbers in the nodes are the codes of the relevant pastoralists (less thousand for presentation).

3.3. Landscape

Our landscape reflects the variation of rangeland resources in time and space. The characteristics of variation (temporal and spatial) are user defined. We use the approach developed by McAllister et al. (in press). Essentially, we treat our landscape as a grid, where in each period of time each cell both dries and hydrates. Drying occurs uniformly across the landscape. Hydration occurs through randomly dispersed rain events. In each period (assumed to be one year in length), the amount of water lost through evaporation is equal to the amount introduced through rain. The degree of spatial variation and spatial co-variation in the landscape is user defined such that we can test the importance of kinship networks under different regimes of resource variation. This can be used to test the hypothesis that such networks are more important when variation is high. Here, *Repast*'s

Value2DDisplay class is used to graphically represent the landscape over time (Figure 4).



Figire 3. Kinship network display.

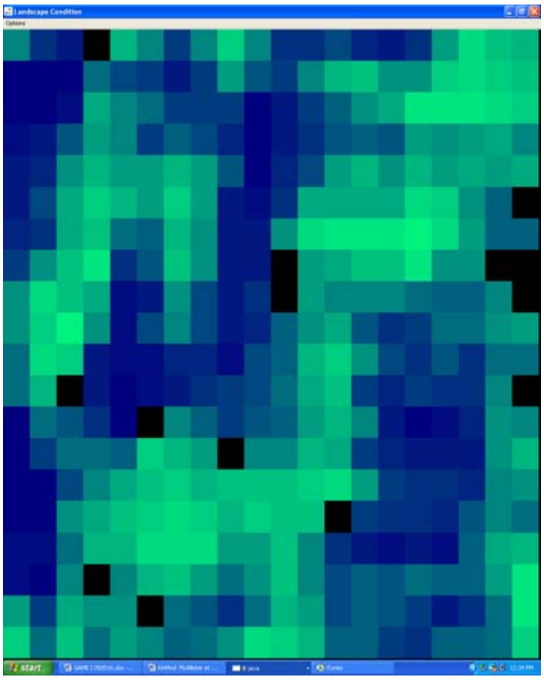


Figure 4. Landscape display. Blue and green (dark/light) represent low and high levels of resource abundance respectively.

3.4. Land ownership

We know that the sizes of pastoral blocks when pastoralism began where small enough such that many blocks were needed in order to support a single family or even person. Legislation also set a maximum number of blocks ownable by a single person. This seemed in part to drive the success of enterprises operated as a family based network (well-known local families included: Hann;, Annings; Allingham; Firth. see Allingham, 1977.) In our model we assume all colonizing pastoralists are allocated a set number of blocks (user defined) that tend to be joined geographically.

Changes in land ownership are critical dynamics in the model because the spatial layout out of properties owned by an individual determines the potential to buffer spatial variation in resources (see below). In other words, the pattern of land ownership provides a link between the environment and human agents.

We use RePast's ***Network2DGridDisplay*** class to graphically represent changes in ownership over time (Figure 5), with each block of land labelled with either the owner code or 'uo' to show that the block is not owned.

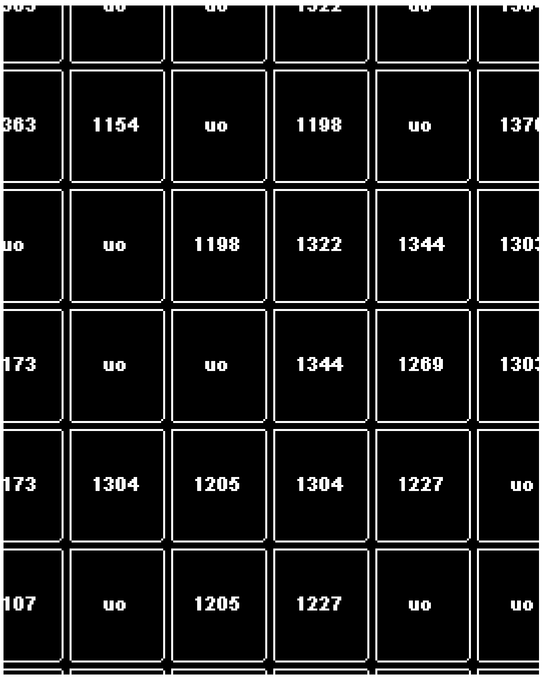


Figure 5. Ownership Display.

3.5. Returns form land ownership

Individuals generate economic returns from each block of land they own. We assume the return from each block is however related to the resources available on their most resource-abundant block in each period of time (which varies in time and scape). This generally means that the more blocks an individual owns the greater their return per block, simply because with more blocks the chances of a higher resourced block is greater. However, it also means that the spatial pattern of land ownership is also important. An individual with 10 blocks in an area with fairly homogenous resources is likely to be worse off than a individual with 10 blocks that are distributed across an area with asynchronous variation in recourses (Stokes et al., in review).

3.6. How kinship effects returns

Above we discussed how our model pastoralists generate returns based on the resources in their most abundant block of land. We also assume that pastoralists, in a probabilistic manner, can access the lands of their kin. If their kin with the greatest level of resource abundance has greater resource abundance than themselves, we assume that returns are generated as though they too had access to their kin's land: with

- 75% certainly (based on a uniform random number generator) if the kin are mother father (included in-laws);
- 50% certainly if the kin are brother or sister (included in-laws);
- 25% certainly if the kin are cousins;
- 10% certainly if the kin are more distant;

3.7. Changes in land ownership

In this preliminary implementation of our model land only changes hands when people die and bequest land to their children. In this case, the rules for inheritance determine who then owns the land. However, based on our observations in the Dalrymple Shire, the ratio of men to women was heavily biased towards men, and because of this many male pastoralists died without heirs. In this case, blocks where allocated to other land owners in the system.

We assumed every individual had a target number of blocks in which they demanded (user defined). Only if they had less then this number did they seek additional blocks. If multiple individuals demand land at the same time, blocks were allocated to the individuals who have accumulated the greatest returns from their pastoral enterprises in the past.

4. SUMMARY

While our methods are preliminary some interesting details are starting to emerge. One hypothesis we wish to consider is that because labour was initially in short supply in the many Australian rangeland systems, long surviving families should be associated with families with many sons. Our model shows this argument could be flawed in two ways. First, brides were is shorter supply than labour, so daughters had a much greater chance of marring into a successful pastoral families and building a larger pastoral network. Second, if we assume that all sons (and daughters for that matter) shared inherited land (i.e. not just the eldest son), than large families could ultimately split the enterprise into parcels too small to individually make a living. Small enterprises are limited in their capacity to buffer resource variation. So even if a small enterprise returns enough profit on average to support itself, it is at risk of collapsing economically in poor years if its networks are not strong enough to help in the buffering process.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

Abel N. (1998), Mental models in rangeland research, communication and management, *The Rangeland Journal*, 20(1), 77-91.

Allingham A. (1977), *Taming the Wilderness*. James Cook University, Townsville.

Anderies J.M., M.A. Janssen, and B.H. Walker (2002), Grazing management, resilience, and the dynamics of a fire-driven rangeland system, *Ecosystems*, 5(1), 23-44.

Borgerhoff Mulder M. (2000), Optimizing offspring: the quantity-quality tradeoff in agropastoral Kipsigis, *Evolution and Human Behavior*, 21(6), 391-410.

Borgerhoff Mulder M. (1998), Brothers and sisters: how sibling interactions affect optimal parental allocations, *Human Nature*, 9(2), 119-162.

Folke, C. and others (2002), Resilience and sustainable development: Building adaptive capacity in a world of transformations. Background paper for The World Summit on Sustainable Development on behalf of the Environmental Advisory Council to the Swedish Government.

Gross, J.E., and R.R.J. McAllister (2003), Modelling rangelands as complex adaptive social-ecological systems, *African Journal of Range and Forage Science*, 20(2), 204 (abstract).

Gross J.E., R.R.J. McAllister, N. Abel, D.M. Stafford Smith, and Y. Maru (in press), Australian rangelands as complex adaptive systems: A conceptual model and preliminary results, *Environmental Modelling and Software*.

Holling C.S., and G.K. Meffe (1996), Command and control and the pathology of natural resource management, *Conservation Biology*, 10(2), 328-337.

Janssen M.A., Ö. Bodin, J.M. Anderies, T. Elmqvist, H. Ernstson, R.R.J. McAllister, P. Olsson, and P. Ryan (in press), Towards a network perspective of the study of resilience in social-ecological systems, *Ecology and Society*

Janssen M.A., J.M. Anderies, and B.H. Walker (2004), Robust strategies for managing rangelands with multiple stable attractors, *Journal of Environmental Economics and Management*, 47(1), 140-162.

Low B.S. (1994), Men in the demographic transition, *Human Nature*, 5(3), 223-253.

McAllister R.R.J., I.J. Gordon, M.A. Janssen, and N. Abel (in press), Pastoralists' responses to variation of rangeland resources in time and space, *Ecological Applications*.

McAllister, R. R. J., I. J. Gordon, and M. A. Janssen, (2005a), Trust and cooperation in natural resource management: The case of agistment in rangelands, *Proceedings of the International Congress on Modelling and Simulation*.

McAllister, R. R. J., J. E. Gross, and C. J. Stokes, (2005b), Rangeland consolidation patterns in Australia: An agent-based modelling approach,CABM-HEMA-SMAGET, Bourg-Saint-Maurice.

Scoones I. (1992), Coping with drought: responses of herders and livestock in contrasting savanna environments in southern Zimbabwe, *Human Ecology*, 20(3), 293-314.

Stokes C.J., R.R.J. McAllister, and A.J. Ash (in review), Fragmentation of Australian rangelands: risks and trade-Offs for intensified pastoral production, *The Rangeland Journal*,

Stokes C.J., R.R.J. McAllister, A.J. Ash, and J.E. Gross (in press), Changing patterns of land use and tenure in the Dalrymple Shire, Australia, in: (Eds.), Galvin, K.A., Reid, R., Behnke, R.H., Hobbs, N.T., *Fragmentation in Semi-Arid and Arid Landscapes: Consequences for Human and Natural Systems*, Kluwer.

Walker B.H., and N. Abel (2002), Resilient rangelands - adaptation in complex systems, in: (Eds.), Gunderson, L.H. Holling, C.S., *Panarchy: Understanding Transformations in Human and Natural Systems*, Island Press, Washington, pp. 293-313.

Walker B.H., and M.A. Janssen (2002), Rangelands, pastoralists and governments: Interlinked systems of people and nature, *Philosophical Transactions of the Royal Society of London B*, 357, 719-725.

White D.R., and P. Jorion (1996), Kinship networks and discrete structure theory: applications and implications, *Social Networks*, 18, 267-314.