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Evolution of a Social-ecological System: Adaptation and Resilience in the New South Wales Rangelands 1850 to 2020

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Abstract

We analyse historical changes in the pastoral system of western New South Wales. As this social-ecological system evolved from its establishment in the mid 19th century it has been subjected to environmental, social and economic disturbances, and the threats and new opportunities these bring. Humans have adapted to these disturbances at local, regional, State and national scales. The adaptations have affected the resilience of the pastoral system - its ability to persist through future disturbances. We apply theory from range ecology and political economy to analyse the system from the perspectives of pastoralists, governments, Aboriginal peoples and conservationists. After exploring the evolution of the system we derive principles for enhancing resilience through institutional change, and speculate about its future.

Introduction

This paper analyses the evolution of a pastoral system in the rangelands of the State of New South Wales (NSW) in the federation of Australia (Figure 1). As this social-ecological system (SES) evolved from its establishment in the mid 19th century it has been subjected to environmental, social and economic disturbances, and the threats and new opportunities these bring. Humans have adapted to these disturbances at local, regional, State and national scales. Their adaptations have mainly been about securing their current or future interests. The adaptations have affected the resilience of the pastoral system, that is, its ability to experience disturbance yet retain its essential functions and controls (Holling and Gundersen 2001; Abel, this issue). More resilient systems are likely to persist longer than less resilient ones for a given disturbance regime. We try to understand how adaptation at one scale may affect system resilience at the same or another scale. An adaptation may enhance system resilience, or reduce it. It seems that in general human adaptations have favoured short term aims but reduced system resilience (Blaikie and Brookfield 1987; Tainter 1988).

Understanding relationships between adaptation and resilience is important because climate, global population, diseases, technology, commodity prices and global institutions are all set to change and consequently impose a new regime of disturbances. Humans and biota will adapt to the new regimes, and their adaptations will affect the resilience of the SES. The purpose of this paper is to gain an understanding of relationships between adaptation and resilience in the past, and use it to develop measures to enhance adaptive capacities in readiness for impending changes. These measures must take account of political-economic and ecosystem behaviours, and they should enhance system resilience, not compromise it.

The paper first describes the region and its stakeholders, and sets boundaries on the system. Next we outline theories and methods, landscape function and political economy in particular, before applying the theories to a history of the region. The historical narrative deals with occupation and pastoral development, pastoral political power, drought and economic depression, pastoral collapse and re-organisation, policies and policy reversal, and pastoral adaptations to policies, prices and ecological perturbations. We then review the impacts of past use on landscape function, animal production and biodiversity, and describe the policy and institutional tangle that now enmeshes the social-ecological system. We end by exploring a future in which principles of resilience are built into the social-ecological system.

The Region, the Stakeholders and the System Boundaries

The region occupies 325,000 km^2. Mean annual rainfall varies from 150 to 450 mm/y from West to East. Rainfall variability in time and space is very high. Relatively wet phases are interrupted by droughts brought about by the El Nino–Southern Oscillation phenomenon (Bureau of Meteorology 1993/4). There are 251 land systems, each representing a different pattern of topography, soils and vegetation, each with internal variation in soils, vegetation, and resilience to grazing and drought (Walker 1991). Soils are infertile. The region contains around 52,000 people, around 6 million sheep and as many kangaroos. Animal numbers fluctuate widely. Minerals, crops, wool and sheep sales are the main primary contributors to gross regional product (NIEIR 1999).

Figure 1. Australia, New South Wales and the Region

Stakeholders include Aboriginal peoples, farmers, pastoralists, the minerals industry and conservationists. Although the minerals industry and arable farming are fundamental to the structure and functioning of the regional economy, they occupy little land. Pastoralists, on the other hand, hold around 93% of the area under perpetual lease, 3.5% is reserved for biodiversity conservation and 0.5% is Aboriginal land. Pastoralists' decisions are therefore fundamental to the resilience of the rangelands. For most of the paper we therefore focus on pastoralism, ignoring the 60 millennium-long history of Aboriginal use (Chappell *et al* 1996; Roberts *et al* 1994), and we refer to the other stakeholders mainly in terms of their interactions with pastoral interests. In the optimistic scenario at the end of the paper we bring other stakeholders fully into the discussion as we envisage a socially diverse SES persisting despite economic and climatic disturbances.

The spatial boundary of our SES is the region. Its political-economic boundaries span scales from household and firm to regional, State, federal and international scales, depending on the issues. The timescale of our analysis runs from the establishment of pastoralism from the mid 19^{th} century to the present. Our assessment of its resilience is necessarily limited to this timescale.

Theories and Methods

One set of approaches to understanding responses of systems to stress comprises reductionist studies of system components. For example, variations in the output of wool from a rangeland could be related to changes in independent variables (Duncan 1972). However,

while selected explanatory variables of complex adaptive systems (CASs) are amenable to reductionist analysis and falsification, the broader system is not (Pahl-Wostl 1995), because variables are not orthogonal and because emergent properties are lost in the reduction. One of these emergent properties is resilience. Ideally one should combine reduction with systems analysis, but resource constraints obliged us to choose, and holism was the higher priority. Since falsification is not feasible in a systems approach (Chalmers 1982), we accept an explanation, at least for the time being, if it is coherent and convincing (Quinn 1995). We expect to be wrong in some ways, but we see learning and adaptation in rangeland systems as part of a continuous process to which our work is a contribution.

Quantitative modelling is currently the most favoured approach to systems analysis (e.g. Janssen *et al*. 2000). While modelling yields important insights into systems dynamics, it has limitations that are well understood by good modellers, but not always by others. They do not cope well with the attributes of CASs. These include lagged responses, non-linearity, path dependency, adaptation of components, system evolution, hierarchy and cross-scale interactions (Abel, this issue). We therefore see modelling as a useful tool in analysing and understanding system dynamics, emergent properties and for revealing and explaining counter-intuitive results, but it should be supported by scholarship with deeper foundations. We used historical narrative – explaining the causes of change in a system as it evolves over time (Abel and Blaikie 1986, Blaike and Brookfield 1987, Pickard 1991; Tainter 1988). Historical narrative can cope with the attributes of CASs. Historical narrative explains why the system, with its contradictions became the way we find it (Dovers 1994a; Wasson 1994; Wasson and Galloway 1986,). There are excellent historical studies of human-environment interactions in Australia (Dovers 1994b; Quinn 1995). None has used a CAS framework, though Dovers does address scale, and non-linearity is routinely addressed in historical studies.

Complex adaptive systems (CAS) theory is the framework for our narratives (Abel, this issue). It integrates theories from the bio-physical and social sciences (Abel *et al.* 2000). Theories of landscape function, economic development and political economy are discussed next.

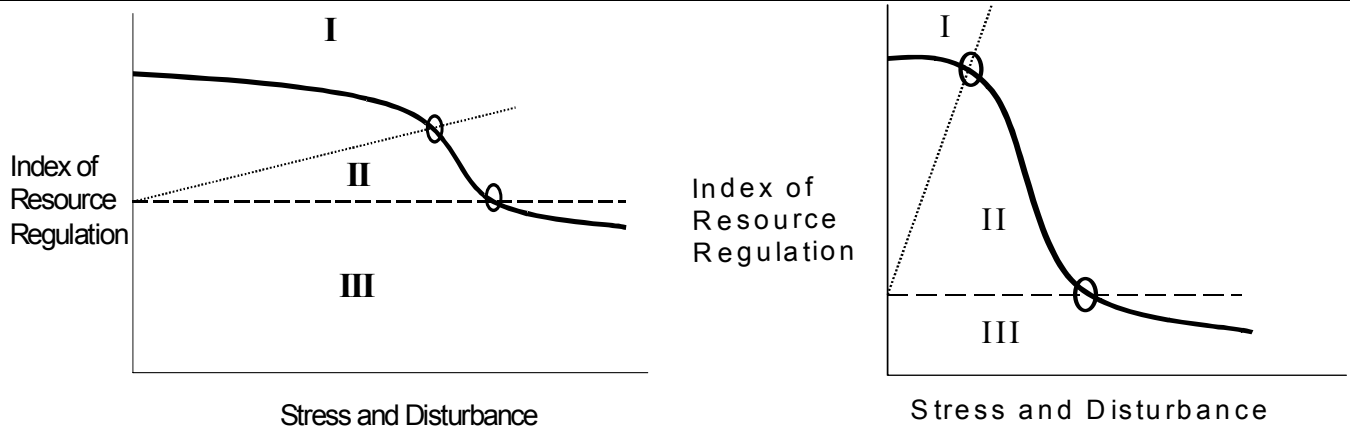
Landscape Function

The range ecology theory we use follows Ludwig and Tongway (1997). In their model rainfall is topographically distributed. As it is transferred across the landscape it collects mineral and organic materials and transports them to depositional sites. These may be topographic sinks, the bases of growing plants, logs or rocks. Wind flows also transport and deposit materials, which therefore become locally concentrated. Locally enriched sites support plant growth, and plants increase infiltration at these sites through the deposition of litter and root growth. Such sites support a soil fauna and flora that also improves infiltration. The enriched sites store nutrients and soil moisture at levels much higher than the landscape average. The landscape thus comprises run off sites that are relatively bare of vegetation, acting as resource catchments for depositional sites where plant growth and soil biota are concentrated.

A functional range landscape is one supporting patches of vegetation that capture and store water and nutrients effectively. Grazing and drought can reduce functionality by causing the death of perennial plants (Hodgkinson 1995) and limiting subsequent perennial grass recruitment (Anderson et al. 1996), so reducing control over water and nutrients. These resources will be captured elsewhere in the landscape, but at a broader scale. This will change the pattern of primary productivity, but depending on the land use and the scale, it does not necessarily constitute degradation (section on Review of the Impacts of Past Use on

Landscape Function, Production and Biodiversity). We shall see that dust storms have carried soils from Western New South Wales to coastal cities and beyond, definitely a net loss to our region. The effects of finer scale redistributions are less clear, but the efficiency of capture and use of scarce water and nutrients is higher on a well functioning landscape than a dysfunctional one. Production of forage, wool or meat per mm of rainfall can be a proxy for landscape function, as can number of animals carried per mm, but the efficiency of rain use in secondary production is strongly affected by stocking rate decisions which may confound conclusions. Efficiency of rain use in livestock production can also be reduced by encroachment of woody vegetation that competes with forage production, or by changes in species composition from palatable to unpalatable species.

Tongway and Hindley (2000) have described changes in these landscapes in terms of three states, two thresholds and hysteresis (Figure 2).



2a. A "Robust' Landscape

2b. A 'Fragile' Landscape

Figure 2. Landscape Function, Stress and Disturbance

A line running from the lower point of maximum curvature to the y-axis represents a functional threshold below which an ecosystem will not recover spontaneously within a timescale relevant to pastoralists (functional state III) even if all stresses are removed. A line running from the intersection of the first line with the y-axis to the point of upper maximum curvature defines two other functional states. In state I the system is self-regulating with respect to control of resources. State II is "meta-stable", where control over resources has been lost, but may recover if stress and disturbance is lowered sufficiently. The upper line is defined as the "horizon of resource regulation sufficiency". State II has two management options: remove stress/disturbance until the ecosystem crosses the horizon of resource regulation sufficiency, or provide a means or mechanism to improve resource capture and retention. Tongway and Hindley distinguish in Figure 2 between 'robust' and 'fragile' landscapes, thus combining concepts of resilience and resistance.

The landscape function concept links to Holling and Gundersen's (2001) use of the terms ecosystem function and controls in their definition of resilience. A resilient landscape for pastoralism is therefore one that is able to retain or recover sufficient function to support fodder production, despite disturbances. But it is crucial to specify the scale at which resilience is being considered. A decline in functionality can translate to a decline in the productivity of sheep at the scale of experimental enclosures on a particular land system (Freudenberger *et al.* 1999). However, in our Review of the Impacts of Past Use on

Production and Biodiversity we give several explanations of why this does not translate into a decline in regional productivity of sheep.

The Political-economic System

The patterns of production and distribution in a capitalist society are set through markets and institutions. By institution we mean the rules governing social transactions and human-environmental relationships, and the organisational arrangements for implementing those rules. The rules range from formal and more durable ones, such as laws, to more ephemeral policies, regulations and plans. They affect the capacity and propensity of humans to adapt to economic or ecological change. For example, a policy that quarantines animals for disease control may limit the capacity of pastoralists to adapt to drought by preventing stock movements. Institutions guide investments in research-and-development, education, infrastructure, services and subsidies. These affect knowledge, costs of production and distribution, thus patterns of resource use in time and space. Institutions affect tax rates, thus the absolute and relative levels of public and private investments. Institutions guide rates of trade-off between local and global resources through their effects on imports and exports through tariffs and exchange rates.

Institutions affect intergenerational equity through their effects on current rates of consumption and patterns of investment. Perennial institutions (statute laws, constitutions) are major sources of memory in an SES, and they may lock the system in a late monopoly phase (Abel, this issue). On the other hand perennial institutions may provide measures such as post-drought relief that provide the continuity that enables an SES to return to a desired state after release and re-organisation (Abel, this issue). Changes in institutions are thus crucial to the evolution of an SES, and its resilience during that evolution.

Magee *et al.* (1989), and Godden (1997) use modified public choice theory to explain how political processes affect institutions and ultimately land use and management in a pluralistic society such as ours. We shall develop the explanation through the paper that global prices and regional rainfall are the fast variables driving the SES, but strong mediation by political economic processes and biophysical responses (such as landscape function) guide the course of its evolution and its resilience.

Godden treats a democratic political system as an imperfect market in which participants attempt to maximise their utility. Institutional change plays the same role in political processes as prices in the economy (Magee *et al.* 1989). These authors distinguish between economic efficiency – the optimal allocation of resources to production of optimal levels and mixes of outputs – and political efficiency. The latter is the allocation of resources to secure political influence, thus the ability to appropriate resources from elsewhere in the economy and increase utility. There is often a trade off between these efficiencies: an increase in economic efficiency produces a higher value of output per dollar of input, whereas much political behaviour about the distribution of that output.

Participants in this political-economic process are voters, political parties, bureaucracies and stakeholder groups, including industries, firms, the media, and groups of citizens pursuing a particular interest – pastoralists, Aboriginal peoples, and conservationists, for example. Politicians aim to be elected or re-elected. Political parties offer competing sets of investments and institutional changes to voters. These changes purport to increase the welfare of targeted groups of voters. The design of the sets is based on the expected net return to the party in terms of political support. The sets are designed to win elections. However, political parties need campaign resources, so institutional changes must also earn these. Campaign resources are supplied by stakeholder groups (usually industries). They calculate the likely

returns to their members in terms of favourable institutions and investments, and subscribe accordingly (Magee *et al.* 1989). The set of existing institutions and resource use patterns established by similar processes in the past constrain the behaviour of all current participants in the process. Examples include legislation governing party funding, constituency boundaries and the rules of voting – e.g. whether or not votes are transferable between candidate (Woodward *et al.* 1997). All these factors strongly affect institutional changes emerging from the process. We predict these institutional changes affect patterns of resource use and management. Figure 3 summarises some of these relationships.

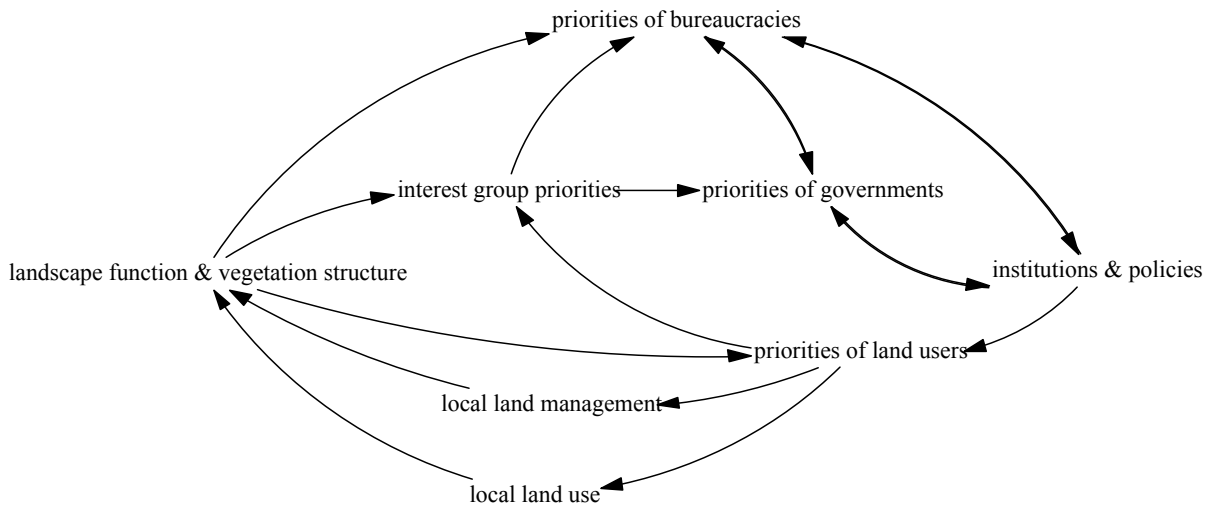


Figure 3. The Political-economic Process, Land Use, Land Management and Landscape Function

Future generations are weakly represented in the political-economic process. Voters' priorities reflect their understandable pre-occupations with employment, incomes, health and crime (Mackay 1993). Politicians necessarily work within an electoral time-frame, and are obliged to respond to voters' priorities. Competition among firms in our capitalist economy reinforces this bias. Investment decisions are strongly influenced by the opportunity cost of capital, which sets the rate at which future benefits and costs are discounted to present values. Thus a $1000 cost falling due in 50 years is reduced to a present value of $9 when discounted at 10%. Potential party funders are mainly driven by short-term commercial goals. Political and economic processes thus mutually reinforce focus on the short term. The weak influence of "green" parties reflects this (Walker 1994).

A state or federal government has strong influence over the determination of priorities through its control over the political agenda (Pritchard and Sanderson 2001). It selects which stakeholder groups it will consult. Groups that are not "mainstream" find it difficult to get on the agenda (Doyle and Kellow 1995), thus Aboriginal interests have not been effectively expressed for most of the last two centuries. Conservationists have been disadvantaged by promoting values that conflicted with developmentalism (next section). The ability of pastoralists to get on the agenda may be slipping as the ratio of rural to urban voters declines (Table 1). Magee *et al.* (1989) point out that institutional arrangements that benefit large numbers of people are likely to be more efficient economically than those that benefit only special interests, so there are win-win opportunities in making inclusive institutional changes.

Table 1 Changing Political Influences of Stakeholders

Stakeholder Group	Relative Strength Now	Postulated Reasons for Relative Strength	Estimated 20 Year Trend	Reason for Trend
Conservationists	Moderate	• Conservationist paradigm clashes with dominant developmental one • Perceived as anti-growth, so anti-jobs (limits their influence)	Growing	• Concerns about sustainability of resource use • Species losses • Support from urban middle class • Support from scientists
Pastoral Industry	Strong	• National icon status - the self sufficient pioneers • Economic importance in the past • Uniformity of rural voting • Voting systems and electoral boundaries	Weakening	• Perceived as damaging the land by urban people • Perceived as subsidised • Low and diminishing economic importance • Decline in ratio of rural/urban voters
Aboriginal Peoples	Weak	• Loss of land and culture • "Protection" policies in the past • Low numbers	Growing	• Political activism • Growth in numbers • International support • Some urban middle class support

Federation adds complexity to the political-economic process. The Colonies became a federation in 1901. Each state and territory has its own constitution and legislation, and substantial autonomy over natural resource management. Federal government has often been obliged to trade off votes and internal funding support to satisfy powerful overseas governments and international business interests. Multinational companies (such as mining companies), with their gigantic economic power, are able to import or export money and technology, create or remove jobs, influence the media and dictate political agendas. Global currency markets must also be taken into account when forming policy – heavy expenditure of public funds is punished by a fall in the exchange rate with consequent rise in the cost of imports and the rate of inflation.

In addition to their statutory functions, state and federal bureaucracies have their own values and agendas, which commonly include expansion of their own power and resources. One federal department, Agriculture, Forestry and Fisheries Australia follows a mainly developmentalist paradigm. Another, Environment Australia, subscribed for a time at least to an environmentalist paradigm. It is claimed that industries can "capture" agencies established to regulate them. The identities of industry and agency merge and policies converge until the agency promotes the interests of the industry rather than society (Magee *et al.* 1989). Agency staffs are not elected but they nevertheless have a strong influence on policies and legislation through their advisory roles. They play a particularly important role in providing continuity (system "memory" – Abel, this issue) when governments change.

The influence of a stakeholder group in setting political priorities at any time depends on the perceived state of the environment, economy, jobs or society (Pritchard and Sanderson 2001). The media play a crucial role in feeding the perceptions of political players. Thus newspapers

have fuelled fears over Aboriginal native title claims. The media have also brought the degradation of land and water to the attention of voters, as we shall see in our history of the region. Journalists have their own perceptions, and other groups, pastoralists for example, attempt to change them. Politicians use the media as information conduits to potential supporters. However the media have substantial control over what is published, so issues important to groups that are not influential may not get discussed or acted upon, and such groups may be unable to expand their influence. The media need financial security, so are under pressure to confirm the values of their customers, thus tend collectively towards conservatism.

Godden (1997) calls the influence of landholders on institutional change "farming the government". The impacts of institutional change on pastoralism at local scales occur through the response of household economies to changes in infrastructure and services, costs and prices. Households are predicted to react by reallocating labour, capital and land, or changing land management, thus affecting landscape function (Figure 3). We shall meet examples of these reactions, such as changing stocking densities or type of animal, or to wildlife harvesting, planting a crop, getting off-farm work, or buying or selling land.

Government-Stakeholder Interactions in the Evolution of the Pastoral System

Occupation and Development

The British imported a resource use system when they colonised New South Wales in 1788. The institutional framework that subsequently evolved was much influenced by British models; had the Dutch or French been the colonisers, as they nearly were, this framework would have been different – an example of initial conditions and path-dependency. The British imported a capitalist economic development paradigm. "Developmentalism" is the use of social and economic capital to extract value from natural capital. By social capital we mean knowledge, memory, skills, organisations, networks and institutions. Economic capital is the physical means of production and distribution. Natural capital is the more-or-less self-maintaining ecosystems that provide humans with inputs to production, waste absorption and life support services, stabilising services (e.g. erosion control) and psychological satisfaction. Some of the value extracted is used to meet current needs, some is reinvested in social and economic capital for the further extraction of value from natural capital. The previous section describes how political economic processes determine the pattern of investment, resource use, production and distribution. The new economy was based on private ownership of the means of production. This paradigm had evolved under a predictable climate with high soil fertility. We shall show that it was ill-suited to conditions in the region. The colonists subsequently imported technologies which enabled people to over-ride ecological feedbacks. This new social-ecological system became ever more tightly linked across scales to the world social-ecological system. We review the effects of these arrangements on landscape function and resilience later in the paper.

Like its Aboriginal predecessor, the evolutionary path of this SES has been driven by variable rainfall (Flannery 1994). Unlike the Aboriginal system, it has also been driven by commodity price fluctuations and trends. On the one hand this adds to the vulnerability of the SES. On the other, technology, communications, infrastructure and political influence give landholders access to external resources and underground water that have enabled them to cope with droughts, floods and price collapses. The evolutionary path was thus influenced strongly by two interacting types of human political-economic adaptation. One is investment by a resource user to increase or maintain the value of economic output (e.g. drilling bores to tap groundwater for stock). The second is appropriation of benefits generated elsewhere in the economy (Magee *et al.* 1989; and the political economy section).

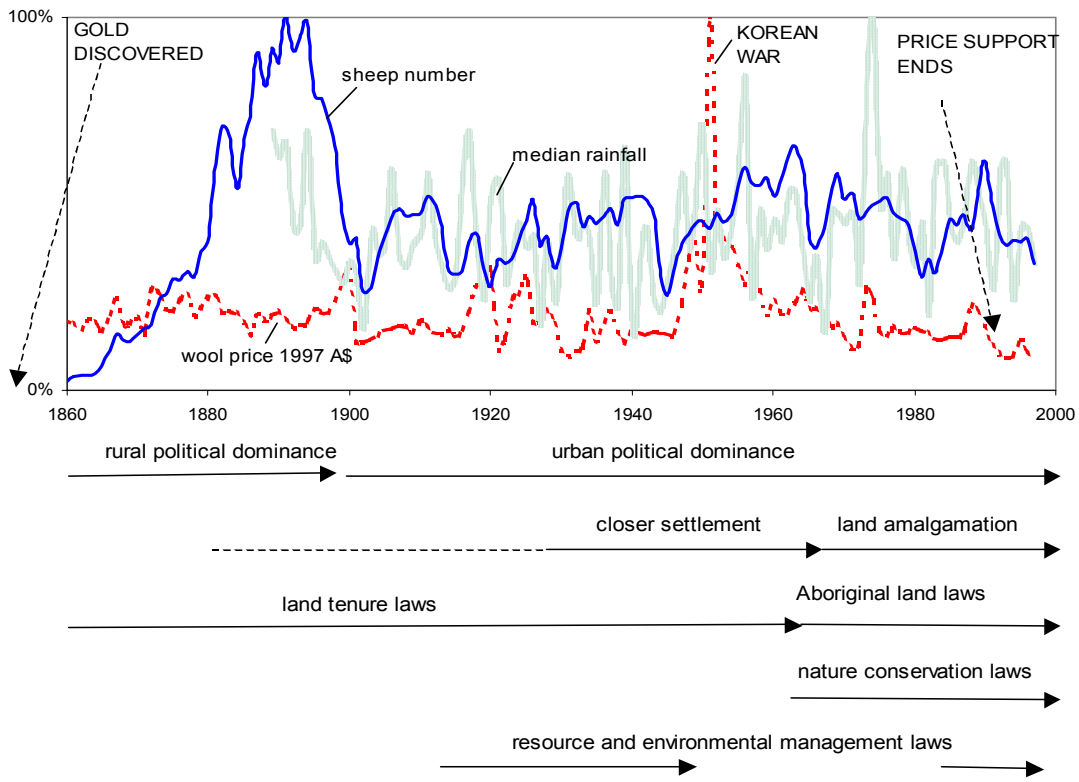


Figure 4. Sheep Numbers, Wool price and Rainfall (Sources: 1860-1902 - Barnard 1962; 1903 – 1979 – Western Lands Commissioner, 1980; 1980-1997 – ABARE 2000)

Notes: 100% is the maximum value recorded during the period; other values are proportional to this maximum. From 1980 the boundary for recording sheep numbers changed slightly.

Pastoralists occupied the NSW rangelands after the 1830s, and initiated a growth stage (Figure 4). Misled by a long period of unusually good rainfall, and lacking system memory (Abel, this issue) there was "a wild orgy of business speculation and a fictitious prosperity" (King 1957, p16). Immense tracts were occupied by (initially) illegal pastoral 'squatters'. Drivers in this growth stage (Abel, this issue) were two broad-scale variables. One was Australian demand for meat, fuelled by the gold rush in Victoria and the consequent increase in the population of Australia (quadrupled in a decade). International demand caused wool price to usurp meat price as a driver by the 1880s. The other driver was rainfall, and it remains so today. River and camel transport, later publicly-funded roads and railways made it possible to respond to these drivers by taking wool and meat out of the hinterland (Hardy 1969).

The Power of the Pastoralists

Between 1880 and 1891 wool accounted for two thirds of the export income of NSW. Economic power gave squatters political influence at State scale (Cain 1962). In 1856 44% of members of the Legislative Assembly were squatters. The squatters wanted to maintain large holdings. Their methods were suited to the spatial and temporal variability in the land, for they often controlled a set of satellite runs which enabled them to be semi-nomadic. Stock was moved to exploit good pastures, so grazing pressure was probably light and episodic. The colonial government wished to sub-divide the large holdings, establish rural settlements,

infrastructure and services. Squatters had attempted to frame the State constitution in 1853 as a measure to protect their holdings against this 'closer settlement policy' (Cain 1962). City interests prevented it, for pastoral power was countered by the development of the minerals industry and towns that developed around it. Trade unions, the Shearers' Union among them, were very influential (Condon 2000a; Hardy 1969). Following a NSW election won on the need to make more land available to more claimants, legislation in the 1860s opened large holdings to claims by would-be pastoralists (Condon 2000a).

The foundations of political influence laid by the squatters were built upon by subsequent generations of farmers and pastoralists. Only a national minority of these resided within our region, but they benefited from the collective political pressures on State and federal governments from farmers and pastoralists. The investments and institutional changes they secured from their lobbying and voting patterns during the 19th and 20th centuries have included: land tenure in perpetuity; provision of infrastructure and communications; support for agricultural research and extension; pest control; tariffs to exclude competitors; tax relief; tax averaging to ameliorate market and climatic impacts; drought and flood relief; loan subsidies; direct income subsidy; subsidisation of inputs; price support; currency devaluation to increase revenue to farmers; subsidised withdrawal from the industry for farmers with low incomes (Davidson 1992).

These policies have affected resource use patterns and management practices profoundly. Many were designed to buffer external shocks. Resilience theory (Abel, this issue) predicts that buffering will enable a system to persist in the monopoly stage. By excluding disturbances, though, adaptations that enhance resilience are discouraged. This is because resilience mechanisms require resources to make them work, and in the absence of disturbances the investment is not worthwhile.

A Big Collapse and Reorganisation

The primary disturbances affecting pastoralism have been cross scale interactions among droughts, pests and international business cycles (Figure 4 shows wool price fluctuations). Rabbits, released in ignorance, irrupted towards the end of the 19th century to add to grazing pressure (Rolls 1984). Kangaroos increased as artificial water points gave them greater access to grazing (Figure 7). From the 1880s awareness of the decline of forage plants in the NSW rangelands was growing (Quinn 1995). Pastoralists also had to adapt to the spread of "scrub" (woody vegetation that reduces pastoral production). In pre-pastoral times, low grazing pressure away from natural permanent water allowed build up of fuel sufficient to support periodic fires lit by Aboriginal peoples to manage vegetation (Noble 1997). With the advent of livestock and establishment of water points fuel loads declined. Aboriginal peoples were evicted, and with them the traditions and skills of management with fire. Noble (1997) speculates that the extinction of browsing meso-marsupials, e.g. *Bettongia lesueur,* may have reduced controls on scrub. First reports of scrub increase were made in the 1870s (Noble 1997). Scrub can reduce grazing capacity by suppressing herbaceous growth, and increase the costs of mustering. Gardiner *et al.* (1998) suggest that many range types have not reached their potential woody cover: scrub will continue to increase on susceptible soils until density is in dynamic equilibrium with soil moisture.

During the 1890s extended drought and the spread of rabbits devastated the NSW rangelands. Sheep numbers crashed (Figure 4). It is widely believed that much of the degradation (irreversible change) in the NSW rangelands occurred during this time (Noble and Tongway 1986). The lack of surface water would have concentrated degradation around permanent water, mainly perennial rivers and natural springs, and a few wells, tanks and bores (Figures 6 and 7). Feedback on the condition of local landscapes was carried to cities and beyond by

dust-storms. City newspapers reported events. Pastoral lobby groups were active. The pressure resulted in a Royal Commission in 1900. The Commission's recommendations brought in new legislation and administration of pastoral land, lower lease rentals and longer leases for the NSW rangelands (Quinn 1995). The understanding of interactions among stock, rabbits, soil erosion, drought, scrub growth, wool prices and debt conveyed in the Commission's report are sound, so the periodic recurrence of the same syndrome over the next century needs explanation. We attempt to supply it later.

The pastoral system did collapse at this time, but it was quickly reorganised and launched into a new growth phase using resources imported from State level. Politicians cannot usually afford to do otherwise. We propose that large-scale collapse and release can happen in local-scale human-ecological systems that lack access to outside resources (Pritchard *et al.* 1998), but not in one that has political influence at State scale. The subsequent history of the region supports this view, for while collapses did occur, social and economic capital were not released and reallocated at a local scale because the system was supported from State and later from Federal scales. After the Big Collapse a series of smaller ones occurred, but external resources enabled the SES to "ratchet" towards the late monopoly stage where it now exists.

Closer Settlement, and Pastoral Learning and Adaptation

Pastoralists learned much from droughts and wool price fluctuations. Duncan (1972) identified particular periods when labour productivity in pastoralism increased, and hypothesised that learning was rapid during these phases. Both periods of productivity increase coincided with relatively higher rainfall following severe drought. Pastoralists adapted to local scale ecological change mainly by building artificial water points to extend the area grazed (figure 7). Fencing to separate flocks was crucial in this process (Pickard 1992). Some pastoralists pushed over edible shrubs, grew a crop, or switched in and out of cattle production if their land and fencing was suitable (Quinn 1995). Having access to a mix of soil textures and topographies buffers variations in fodder production, and moving animals within or outside the region further reduces risks (Stafford Smith and McKeon 1998). At regional scale, networks of publicly-funded water points and stock routes enabled animals to be driven towards markets and rainfall. The use of the 'long paddock' – grazing along roadsides and stock routes – during droughts is a long-established tradition. Drought-adapted, fly-resistant sheep have been bred that produce more (Figure 5) and better quality wool. Pastoralists have also adapted by forming sub-regional networks of reciprocal obligations that became part of the pastoral culture. These are comparable to pre-invasion arrangements among Aboriginal clans and tribes (Lourandos 1997)

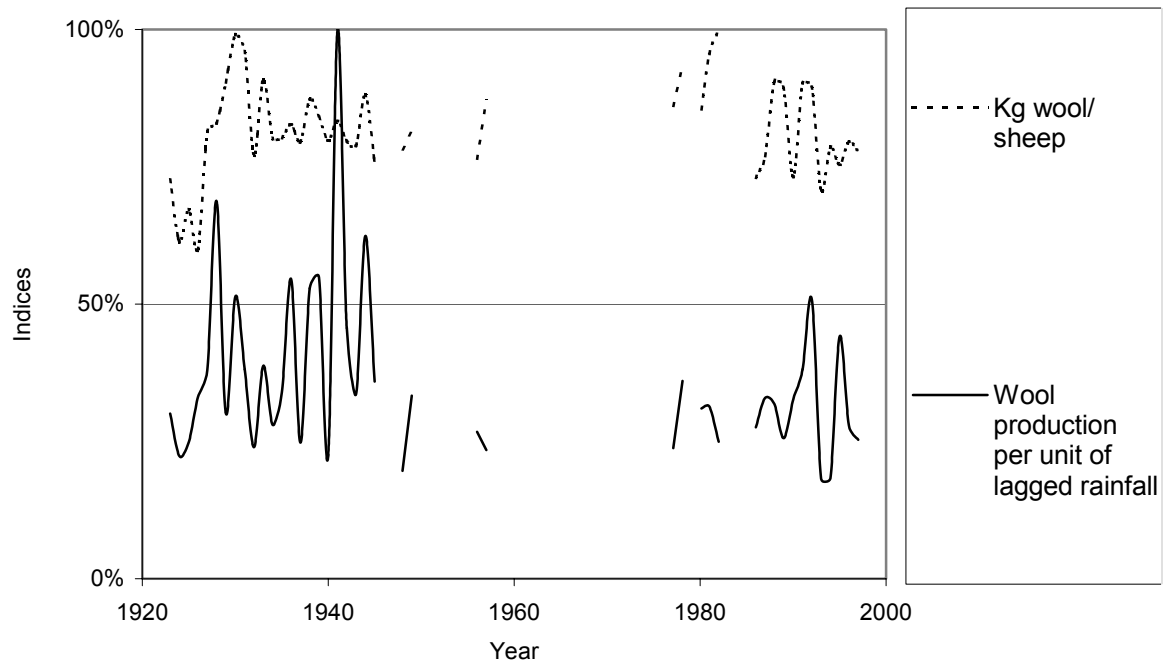


Figure 5. Indices of wool production per sheep, and per unit of rainfall, in the Western Division of New South Wales, Australia (Source: Barnard 1962, ABS Yearbook; ABS 1995).

Notes: 100% is the maximum value recorded during the period; other values are proportional to this maximum; maximum clip of wool per sheep was 5.8 kg (1964); maximum yield of wool was 1.1 kg/100 ha/mm (1941); median rainfall is lagged by one year; missing values reflect lack of data.

Property size is a key determinant of adaptive capacity. Although disturbances have been buffered by State and Federal institutions secured through the political process, the ability of pastoralists to adapt has been hampered, especially for the last half of the 20th century, by a "closer settlement" policy that broke up large holdings to settle new land holders. Reduction in the size of properties is associated with: lower diversity of soils and vegetation, therefore increased variation in production; loss of economies of scale; and increased risk-taking by leaseholders as they attempt to raise their incomes (Hassalls and Associates 1982).

Urban pressure to sub-divide large properties to release land for new settlers continued. There was also support for measures, like lease extension, to increase opportunities for borrowing to improve land and make it more "drought proof", despite the fact that the Royal Commission had identified debt as a fundamental cause of poor financial viability.

The new pastoral lands administration put pressure on banks to forgive pastoral debts. Together with rent reductions it had the effect of raising the market value of leases, their value as collateral, thus the level of debt that could be accumulated, thus potentially reducing resilience at property scale (i.e. the ability of the pastoral enterprise to persist). The longest fence in the world, shooting and poisoning almost eliminated predation by dingoes on sheep, and incidentally on kangaroos whose numbers increased (Caughley 1987) to put further pressure on landscape function and pastoral incomes.

With closer settlement policy well established, the next stage in the evolution of the pastoral system matches the monopoly stage (Abel, this issue). One maverick continued to flout policy. Sydney Kidman, a surviving squatter, controlled a pastoral company that held leases from northern to South Australia and through the NSW rangelands. He ran cattle and horses, which are less susceptible to dingo predation than are sheep. His NSW holdings were seen by wool-growers as "dingo-incubators", and by proponents of closer settlement as offering few jobs (wool production is relatively labour intensive). He managed variation in time and space by moving cattle among his satellite holdings to follow forage and prices (Quinn 1995; GRAETZ ??). The broad spatial scale for his type of operation was determined by temporal variation of rainfall. Like other holders of large leases he was offered extension of lease period in exchange for reduction in size. He was one of very few who declined to trade space for time - his strategy depended on large areas. His death in 1935 was followed by the departure of his company from the NSW rangelands (Condon 2000a; Hardy 1969).

A Small Collapse, a Small Re-organisation

Drought, low wool prices and wider economic depression coincided in the 1930s (figure 4). Smaller properties were especially badly affected. The Sydney Morning Herald spread the bad news statewide and hastened the policy response. Pastoralists lobbied State government. Another Royal Commission was called. The understanding shown in 1901 about over-stocking, debt and bankruptcy resurfaced. Yet the pastoral lands administration was criticised for the slow rate of implementation of the closer settlement policy. Public support for closer settlement was still strong. It is unlikely the State government could have afforded to go against it despite the negative consequences. New legislation extended the duration of leases to compensate for forfeiture of a part of the lease for closer settlement, thus trading space for time. Eventually all leases were held "in perpetuity".

Soil erosion emerged as a major policy issue in the 1930s. A broadening of the scale of concern led to sharing of ideas with the USA, which was experiencing its "Dustbowl", and southern Africa, where closer settlement of Africans to make way for white farmers was also causing soil erosion (Abel 1993). The NSW Soil Conservation Service was established, and legislation introduced to control erosion (Quinn 1995). Tensions were heightened between pastoralists, who wanted to clear native vegetation and crop, and regulators concerned with soil erosion.

Although some individuals went bankrupt, the crisis of the 1930s did not cause a collapse of the pastoral system at regional scale. The limited reorganisation of the 1930s was resourced by the State. The area of land grazed continued to increase as new water points were added in country previously grazed only episodically. Figures 6 and 7 show the intensity of grazing on this newly opened land dropped rapidly from the end of the 19th Century. Figure 4 shows there was no increase in regional sheep number as a result of closer settlement, and for the one initially large property for which data are available, sub-division resulted in a decrease in the stocking density (Pickard 1990). Thus the closer settlement policy imposed major financial hardships on the pastoralists, but they adapted by increasing the area grazed and reducing the intensity of grazing.

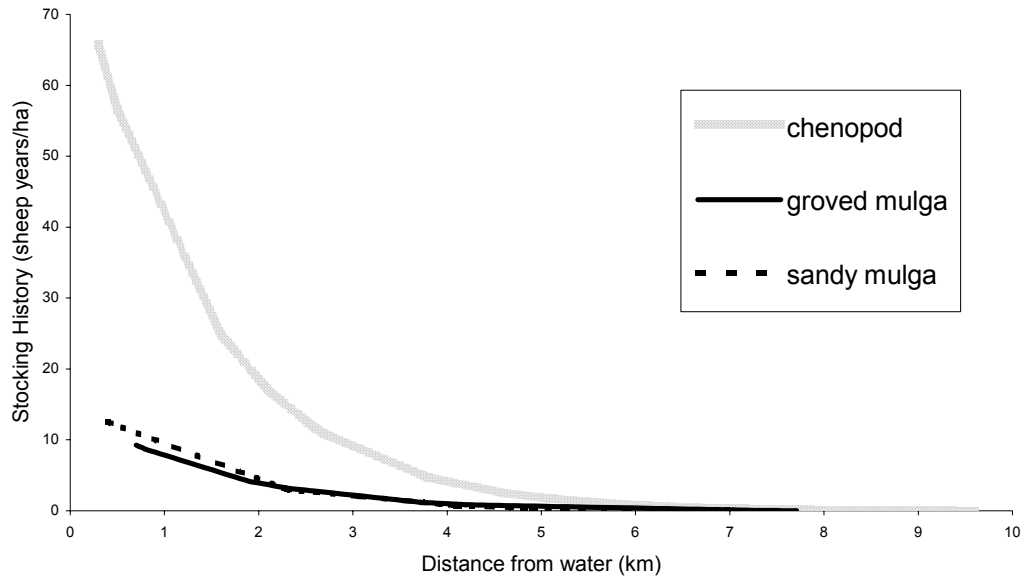


Figure 6. Estimated Stocking History and Distance from Water (Source: Pringle 2000)

Closer and Ever Closer Settlement

After World War II returning servicemen were settled on the land. Access and services were increased at sub-regional scale by the establishment of local government over 75% of the region in 1955. Together with mass-produced vehicles, this made settlement more attractive, especially as establishment of new settlers was subsidised through State and Federal funding. Local government also brought a much improved road network that made possible the motorized, rapid and cheap movement of stock during droughts, and reducing stock mortality (Hassall and Associates 1982).

The NSW government was strongly interventionist. It regulated the sale price of leases, and made the inheritance of leases subject to ministerial approval, to prevent accumulation of excessive areas. Pastoral inspectors were appointed to monitor the implementation of lease conditions, including soil conservation. Property surveys were begun during the droughts of the 1960s to establish safe stocking rates (Condon 2000a). Federal scale intervention led to the development and release of the *Myxoma* virus in 1950s, after which rabbit populations crashed (Noble 1997).

It was events at international scale that made closer settlement viable in the short term. The Korean War, like the Boer War and World War I before it, (Figure 4) increased demand for wool for military clothing. The wool price soared (it had been controlled by Federal government during World War II). Pastoralists were briefly and spectacularly prosperous (Condon 2000a). Crawler tractors became available along with the money to buy or hire them. There was a surge in the rate of construction of stock dams (Condon pers. com.), thus extending grazing further (Figure 7).

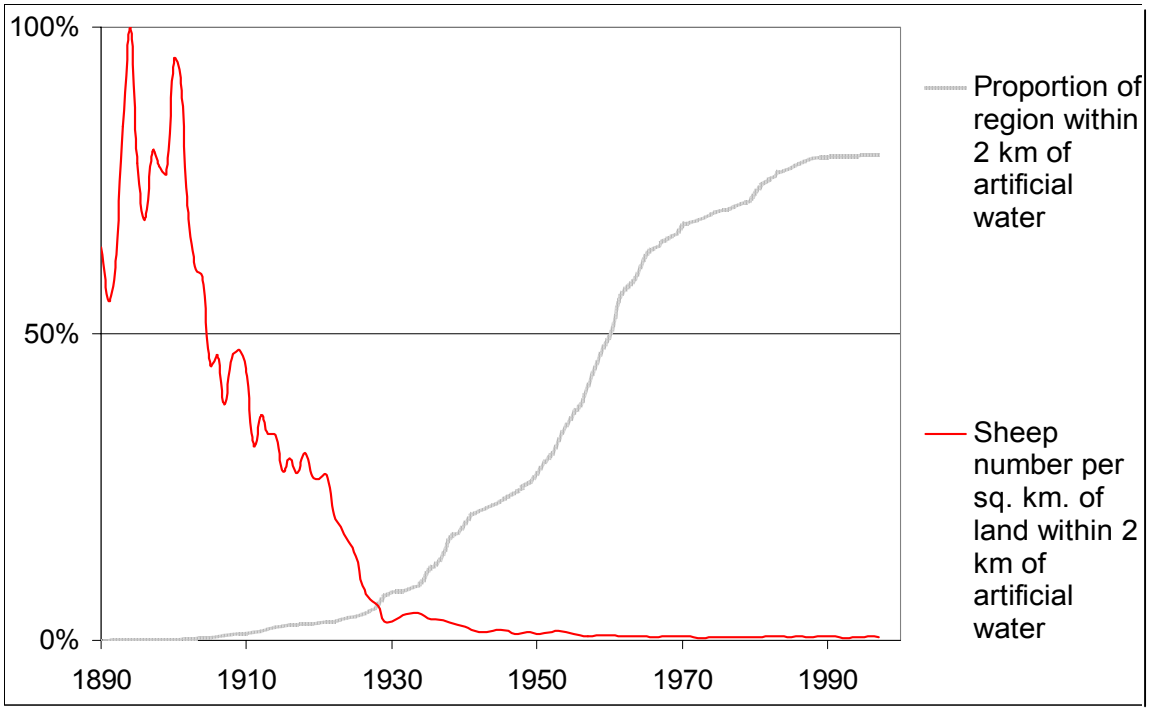


Figure 7. Effect of artificial water points on intensity and distribution of grazing in the Western Division of New South Wales, Australia. (Sources – Habermahl etc).

Notes: bore data existed for the whole period. Tanks (stock dams) were mapped in the 1970s, but there are no time series data. We assumed the rate of establishment of tanks was the same as that for bores, and used the 1970s ratio of tanks to bores to estimate the curves.

100% is the maximum value recorded during the period; other values are proportional to this maximum; calculations are based on these formulae

$a = 100.(\Pi r^2.W)/325{,}000$

$d = S/(\Pi r^2.W)$

where the region is 325,000 km^2

and for any year

a is the proportion of the region within 2km of water, %;

r is the radius of the area around one water point, i.e. 2 km, based on figure 6. Since radii of water points will overlap when they are less than 4 km apart, which many are, 'a' will be over-estimated. This bias is countered by the increasing use of plastic pipe to distribute water to livestock, a practice not captured in the statistics.

W is the estimated number of artificial water points in the region

d is the number of sheep per km^2 of land within 2km of artificial water;

S is the number of sheep in the region in each year

By the 1950s the closely administered pastoral system was well consolidated in the monopoly stage. In 1911 243,000 km^2 were held in properties of over 40,000 ha. By 1956 this had fallen to 87,000 km^2 (Spinks and Gruen 1958). The end of the Korean War marked the start of a 50-year downward trend in wool prices (figure 4). The wool price trend was converging on an upward trend in production costs (Macleod 1990). Wheat, saviour of many a pastoral family, was similarly affected. When price and rainfall troughs coincided in the 1960s the pastoral system was again in trouble (Figure 4). The system did not collapse and release resources in the Holling sense – it was not politically feasible to allow it to do so. As in the crises of the 1890s and 1930s, resources were supplied from a broader scale to support the system. But the crisis did result in a major policy reversal, a renewal stage of the adaptive cycle (Abel, this issue).

Policy U-turn - Property Amalgamation

In 1968 the closer settlement policy was at last reversed in favour of property amalgamation. The positive relationship between property size and financial viability had been recognized in the pastoral crisis of the 1930s (Quinn 1995). The pastoral lands administration had been told after the 1940s drought that holdings for returned servicemen were too small (Condon 2000a). The understanding has been substantially confirmed since then. Hassals and Associates reported to the Western Lands Commission in 1982 on the adverse effects of small property size on land, debt, income and investment, but the Commissioner himself had noted it earlier (Condon 1978). Young (1985a) showed the negative relationship between vegetation condition and property size in South Australia, as did Passmore and Brown (1992) for Queensland. Macleod demonstrated that in 1990 most properties in the NSW rangelands were still too small to be financially viable. Why was the apparently logical solution of increasing property size ignored for so long?

It was the droughts and low prices of the 1960s that triggered the reversal. Dust storms and newspapers again spread alarm about the condition of the rangelands to cities, fostering political support for policy changes (a key cross-scale interaction). It is interesting to speculate whether the policy response would have been different if the prevailing wind had been easterly, transporting the evidence of pastoral crisis away from cities. Storms in the 1940s had probably been at least as severe (Condon 2000a), but Australia had been distracted by war. Policy reversal had never been prevented by legislation: it began when under 1901 legislation the Minister allowed lessees to purchase additional leases.

Persistence of the policy in the face of evidence of its harmful effects can be explained in ideological terms. Closer settlement was a policy in all states and the Northern Territory, although in the rangelands it has only been applied in New South Wales and Queensland (Young 1985b). Williams (1975) shows there were multiple and contradictory motives behind closer settlement. We discuss just one that operates at national scale. Australia was legally defined as empty land, because it was not cultivated, before the British seized it. Ever since there has been awareness among Australians of the threat that the densely populated countries to the north pose to this seemingly lightly populated continent. Closer settlement seemed to validate our possession of it. The adverse consequences were either accepted as a necessary cost of validating territorial possession, or were denied. Perhaps it was not a coincidence that the reversal of closer settlement policy in New South Wales coincided with willingness by non-Aboriginal Australians to accept the citizenship of Aboriginal people in 1967? Both may have been an expression of the growing confidence of the European newcomers in their right to be here. This would have weakened the need for closer settlement as a demonstration of valid occupation, and allowed the policy reversal to occur.

Pastoral Adaptation After the End of Closer Settlement

The pastoral system adjusted under the new land amalgamation policy, with land purchases a high priority. Over the 24 years after the policy reversal the number of properties declined by 36% (Condon 2000a), but many are still too small to be viable because falling wool price has continued to press down towards rising costs of production. Sydney Kidman's nomadic approach remains a tantalizing example of how to maintain pastoral resilience. For pastoralists constrained by property boundaries water point establishment continued to spread grazing pressure. Figure 7 shows a declining rate of establishment of bores, and does not account for the establishment of new water points supplied by cheap plastic pipe available from the 1980s. Improvements in roads and trucks have lowered transport costs, making agistment more attractive, so that stock can be moved quickly to follow rainfall, following the traditions of Kidman. Feral and farmed goats have become an important complementary income source. Strategic buying and selling of stock are major sources of local scale resilience (Stafford Smith and McKeon 1999). Many properties are viable only because a family member has an off-farm job. Others have invested income from good years in shares. Smart buying and selling strategies based on accurate perceptions of landscape function and markets enable skillful pastoralists to avoid bankruptcy.

The adaptive capacity of a pastoral household is influenced by its stage in the household cycle. A newly-established young couple tends to lack capital and will attempt to accumulate it, often with off farm work. The birth of children reduces adaptive capacity in the short term because they compete with income-earning opportunities. As children grow they increase the supply of labour and enhance adaptive capacity. However, when they reach secondary school age distances dictate that they are often sent away to boarding schools. So adaptive capacity is reduced again as the household is hit simultaneously by large school fees and a reduction in labour supply. There are many anecdotes about deliberate overstocking as a short-term means of paying school fees. When schooling is over higher education may require more financial support from the household. When education is finished children may return to the property and contribute to its adaptive capacity through on- or off-farm earnings. The trend is, however, to leave agriculture for better-paid and less arduous jobs in the cities.

Governments have added to the adaptive capacity of pastoralists since the reversal of closer settlement policy. They invested in climate forecasting that pastoralists are beginning to use in buying and selling decisions (Stafford Smith and McKeon 1996). *Myxoma* virus continues to limit rabbit densities, and was supplemented by viral haemorrhagic disease in the 1990s. Both were developed with federal funding. Lobbying has maintained some State and Federal support for research, infrastructure, services, property amalgamation and fuel subsidies. A federally funded 'Landcare' movement has spread to the rangelands from agricultural regions, and fostered the growth of local groups of pastoralists sharing knowledge and labour for better range management.

A Federal reserve price scheme with stockpile was established in 1970 to buffer producers against price fluctuations that might drive many out of business. At times of low prices the scheme bought wool that failed to meet a floor price, thus guaranteeing minimum revenue to producers. It was stockpiled, then sold strategically to influence prices and recoup costs (Committee of Review into The Wool Industry 1991). Supply was driven by rainfall variation and producers' decisions, so in practice it proved difficult to buffer the price without over-filling or emptying the stockpile. Producers and traders managed their private stockpiles, so adding uncertainty to the price and to the management of the federal stockpile. Meanwhile pressure from producers changed the purpose of the scheme from maintaining a minimum price to achieving the maximum sustainable price – the target moved from the floor to the mezzanine (J. Ive pers. comm.). In 1989-90 China and the USSR had economic problems, and rising exchange rates strengthened the value of the Australian dollar, reducing demand.

Good seasons increased supply. The price fell and the stockpile grew bigger than the annual national wool clip. Federal Government demolished the scheme in 1991. The Committee of Review into the Wool Industry (1991) believed that on balance there were small net benefits from the Scheme until the crisis. Some producers favour the reintroduction of a modified scheme, arguing that it was a chance sequence of events, misjudgments and perversion of the intent of the scheme that led to the crisis (Moylan 1991).

Review of the Impacts of Past Use on Landscape Function, Production and Biodiversity

Landscape Function

Prior to pastoral use grazing pressure varied in time and space with the distribution and fluctuations of populations of kangaroos and wallabies. These were affected by rainfall, scarce surface water, fire, available pasture and predation (Caughley *et al.* 1987; Newsome *et al* 2001). Grazing pressure spread ever more evenly in time and space across the landscape because artificial waterpoints allowed continuous grazing of wildlife and domestic stock in areas that would have previously been periodically inaccessible. Persistence of grazers in the landscape during periods of drought, in part due to the influence of drought relief policies, has caused changes that it vary markedly between range types (Baker *et al.* 1999). The model summarised in Figure 3 attempts to show how landscape function and political processes interacted as the SES evolved to produce the effects summarised in Table 2.

Table 2 Summary of the Impact of Pastoralism on the Rangeland Types
(adapted from Baker *et al.* 1999)

Rangeland Type	% of region	Loss of desirable plant species that provide function*	Increase of undesirable plant species	Active soil erosion	Condition **
Belah and Bluebush	16	Some	Some	Little	Resilient
Bimble box–pine	7	Some	Some	Some	Some irreversible changes
Downs Country	12	Extreme	Extreme	Large	Irreversible changes
Gidgee and Brigalow	2	Extreme	Potentially extreme	Some	Resilient
Mallee	9	Extreme	Extreme	Extreme	Irreversible changes
Mitchell Grass Plains	1	Little	Little	Some	Resilient
Mulga	32	Large	Extreme (scrub)	Large	At risk of losing resilience
Northern Floodplains	13	Extreme	Some (exotics)	Some	At risk of losing resilience
Saltbush Plains	4	Extreme	Extreme (scrub)	Some	Some irreversible changes
Southern Grasslands	1	Some	Some (exotics)	Little	Resilient
Southern Riverine Woodlands	3	Extreme	Some (exotics)	Little	Resilient

*Desirable plant species may include perennial woody plants that provide soil stability, protection for annual grasses and forbs, drought fodder and diversity to cope with drought (ie, function).
** Condition is used here to assess the status of the rangeland after adverse impacts caused by pastoralism based on a landscape function viewpoint.

Table 2 shows a variety of responses from the various range types. Tongway and Hindley (2000) account for these differences in terms of "robustness" (resilience) of landscape function under stress and disturbance (Figure 2, and the Landscape Function section). They distinguished two thresholds and three states of landscape function. "Fragile" landscapes require higher management inputs if recovery is to be achieved. Tongway and Ludwig (1996) and Ludwig and Tongway (1996) experimentally restored resource regulation into a landscape judged to be in state II (Landscape Function section). Whilst maintaining a high level of grazing, branch mounds were laid on the contour. Within 18 months, perennial grasses had established and soil and litter were accumulating. After 3 years, soil N and C levels and microbial respiration had increased by 50% and water infiltration was an order of magnitude greater than controls. Ten years after establishment, including 4 years of drought, the treatment was still effective (Ludwig and Tongway pers. comm.). Although this experiment was conducted on one particular land type, it goes some way to explain the pastoralists' perception that the region is generally resilient to grazing, and will recover if a series of good rainfall years occurs.

Freudenberger *et al.* (1999) further examined the pastoralists' rationale for heavy stocking despite its known effects in lowering landscape function (temporarily or irreversibly). They tested the effects of stocking rates ranging from 0.3 to 0.8 sheep/ha on landscape function and sheep productivity over seven years. Wool production per ha increased linearly with stocking rate, with no evidence of a secular decline in productivity per ha even though perennial grasses and landscape function declined. Live-weight gain per animal and per ha did decline over the course of the experiment. During drought the higher stocking rates could not support sheep for either wool or meat production, and stock were removed from the enclosures. The capacity to support stock decreased over the course of the experiment as landscape function declined.

These results help explain the rationale of heavy stocking – wool output increases but becomes more variable as stocking rate increases. However, production is never restricted to the fine scale of the experimental enclosures used by Freudenberger *et al*. Increasing variability of forage production at landscape scale is probably countered by moving animals to exploit landscape heterogeneity (Ash and Stafford Smith 1996). Most pastoralists today believe that the establishment of water points (Figures 6 and 7) has halted any past downward trend in forage production (Condon 2000a). Duncan (1972) claimed to show that the productivity of land for wool production had not declined over time in the region. He did not include in his analysis the area grazed – that is, the area close to permanent water. Most sheep grazing occurs within 2 km from water. Figures 6 and 7 show that the density of sheep within that distance has fallen sharply, and with it the productivity per ha of wool production from land where most of the grazing occurs. This could reflect a change in state and a loss of resilience, in stocking strategy, or both.

Duncan (1972) rightly pointed out that sheep numbers and wool production are rainfall driven, and that declines in all three are correlated. A decrease in sheep numbers need not necessarily imply a loss of landscape function because sheep numbers are affected by stocking rate decisions unrelated to the condition of the land. Rainfall was high prior to the droughts and the sheep population crash of the 1890s, and was higher in the period 1940 to the present than in the previous 40 years (Figure 4). It is useful therefore to examine the rain use efficiency of the region as a proxy for landscape function. In New South Wales as a whole there was a linear increase in wool production from 1 kg/sheep/year in the 1870s to 4.5 kg by 1920. There is a suggestion in Figure 5 that the production of wool per unit of rainfall increased until the 1920s, pulled upward by the increased yield per sheep, and then declined, but the data are incomplete. A decline in rain use efficiency may be due to the encroachment

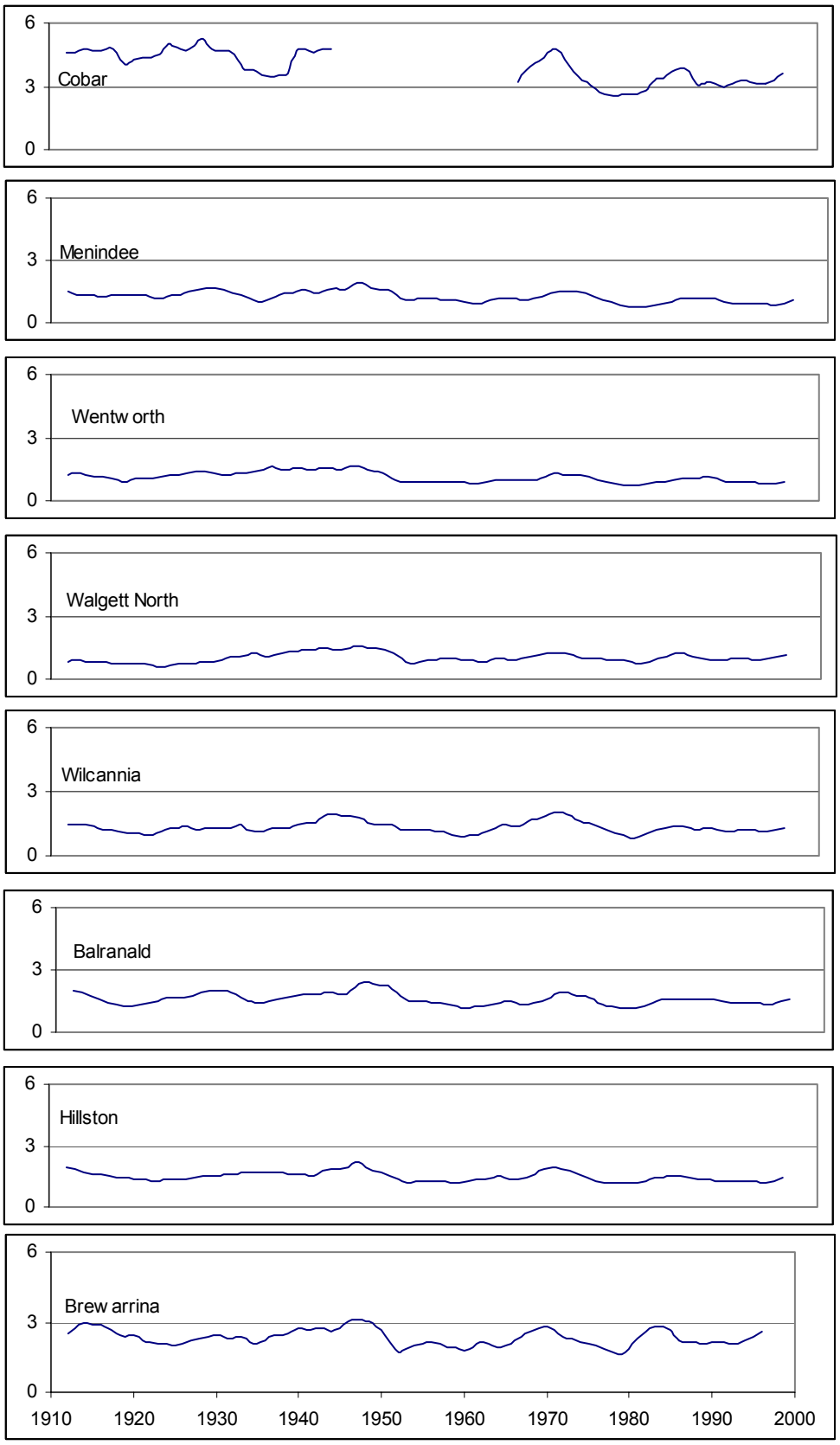


Figure 8. Rain use efficiency in Rural Lands Protection Board districts

Notes: Reliable data were not available before 1906; Three Districts omitted because of missing data or because they lay mainly outside the region; Lagged rainfall was the total of the two preceding years.

of scrub that competes with fodder grasses, and does not necessarily mean the landscape has lost its ability to retain resources. Figure 8 shows no secular trend in rain use efficiency in seven out eight sub-regions. Scrub encroachment has been widespread in one of the sub-regions (discussed next).

The spread of water points would be expected to increase rain use efficiency by making more land available for grazing, but this did not occur (Figure 8), perhaps because landscape function was deteriorating at regional scale as water points spread, or because pastoralists were stocking water points more lightly, or both. The downward trend in wool prices since the 1950s is not matched by a decline in the total number of sheep in the region. Forrester (pers. comm.) found that while water points and lagged rainfall accounted for 70% of the variation in sheep numbers in our data set, wool price accounted for very little. This conclusion is not surprising, as sheep remained the least unattractive enterprise option over much of the region for most of the period.

Scrub Encroachment

Scrub continues to encroach (Gardiner *et al.* 1998), and will continue to do so until densities approach equilibrium with soil moisture. Cobar and Bourke Rural Lands Protection Board districts (RLPBs) are regarded as the sub-regions worst affected by scrub encroachment (Condon 2000b). Figure 8 compares the number of stock carried per unit of lagged rainfall in RLPB districts from 1908. Earlier data were unreliable or missing, and most of the Bourke data were unavailable. Cobar data support the hypothesis that there has been a decline in rain use efficiency, with the reservation that data are missing from this series too. This suggests that scrub is competing with grass in this sub-region. Hassalls and Associates (1982) attribute part of the spatial variation in pastoral profitability to scrub encroachment. However, the currently favourable price of goat meat is promoting a change towards these animals. They browse selectively when grazing is scarce (Harrington 1979). This provides a new opportunity for pastoralism in the medium term, subject to goat prices. In the longer term it is likely that selective browsing will favour the spread of unpalatable scrub.

Loss of Biodiversity

Concurrent with the growth and persistence of pastoralism there has been a loss of native species (Lunney *et al. 19*94; Pringle 2001). Mammal species loss (Table 3) seems to have occurred in two waves. The first was before 1857, coinciding with the spread of pastoralism along the floodplains. The second was after 1890, when a series of good rainfall years and rapid increase in sheep numbers ended in an extended drought, crashing sheep numbers (Figure 4) and much soil erosion. Extinctions have been variously attributed to feral cats, foxes, rabbits, sheep, vegetation clearing, habitat fragmentation, change in the fire regime, soil change and hunting . (Dickman *et al.* 1993, Smith and Smith 1994, Sadleir 1994). Sixty four species of vascular plants are listed as endangered in the NSW rangelands and fifteen are presumed extinct.

Table 3. Changes to the Status of Central and Western Division Vertebrates

Numbers of species:	Mammals (losses are mainly smaller marsupials and rodents)	Birds	Reptiles	Amphibians
Recorded since 1788	88	329	117	28
Regionally extinct by early 1990s (nationally extinct)	27 (7)	6(0)	0(0)	0(0)
Under threat in early 1990s	27	60	48	8

Sources: Dickman (1994), Sadlier (1994) and Smith and Smith (1994).

Landscape function is certainly affected by the species composition of the vegetation (Hodgkinson and Freudenberger 1997). It does not follow that resilience declines directly with decreasing biodiversity, because key functions (nutrient cycling, for example) are usually controlled by only a subset of its species – the 'drivers'. The others are 'co-drivers' and 'passengers' under present conditions. Co-drivers duplicate functions performed by drivers. If conditions arise that cause a driver to decline, and there is a co-driver species that can thrive in the new conditions, then the function persists (adapted from Walker *et al.* 1999). Biodiversity is thus a source of adaptive capacity – 'resilience-in-waiting'. It corresponds with the environmental economics concept 'option values' (Pearce and Turner 1990). It is also valued by Aboriginal peoples for medicinal and cultural purposes, while conservationists acknowledge its intrinsic as well as its actual or potential functional roles.

Artificial water points are the key to conservation of native species in the region. Using distance from artificial water as a proxy for grazing pressure, Landsberg *et al.* (1997) found in a sample survey of national rangelands that 15-38% of species from a range of plant and animal taxa decline under grazing. Between 10% and 33% appeared to increase under grazing. The rest were apparently unaffected by grazing. Figure 7 shows the estimated trend in the area subjected to continuous grazing. While this area has increased, the number of sheep has remained fairly constant so the intensity of grazing has declined. We infer nevertheless from Landsberg *et al.* (1997) that most decreaser species are threatened over most of the region. Parks and conservation reserves now cover 3.5% of the region. This tiny area is unable to contain representative and persistent sets of the biodiversity of the region, so that intrinsic values, Aboriginal cultural values and adaptive capacity for non-pastoral land uses are all compromised.

Conclusions about Pastoral Development and Landscape Change

On the evidence available the landscapes as a whole have so far been resilient for the production of wool. Rain use efficiency has not increased as water points have spread. This may be because pastoralists have preferred to stock water points more lightly, or it may be that the increase in the area grazed intensively is just keeping pace with regional loss of landscape function. According to landscape function theory, different landscape types will be on different parts of their various landscape function/stress-and-disturbance curves (Figure 2 and Table 2). Some landscapes would be in state I (Figure 2), showing easily reversible losses in landscape function. Those in state II would recover with lighter stocking, which follows from the addition of water points. Those in state III have lost resilience and changed state irreversibly for management purposes. If sufficient landscapes moved into state III in the future a regional decline in wool output and sheep number per mm of rainfall would occur. Meanwhile, there has not been an ecological collapse as Holling *et al* envisage (2001). Even the impacts of the extraordinarily high stocking rate at the time of the severe drought of the 1890s were limited in their distribution by the lack of water points and dependency of domestic animals upon them (Figures 6 and 7).

Much of the adaptive capacity of the system resides in its biodiversity. Species may exist with the ability to perform key functions under conditions not previously experienced. That potential has been reduced by pastoral use, and it cannot be maintained in the 3.5% now allocated to conservation. However, as the species that have been lost are those sensitive to grazing, it is unlikely that adaptive capacity for pastoralism has been lost.

The inconclusiveness of the ecological evidence is characteristic of management and policy making for an SES, and must be taken into account in the design and adaptation of institutions.

A Rangeland Enmeshed

If pastoralism is still sustainable after a century and a half, it is because of the adaptability of pastoralists and the resilience of the landscapes. Aboriginal peoples, conservationists, the minerals and more lately the tourism industries are now competing strongly with pastoralists as they attempt to influence the evolution of the system in favour of the interests of their group (Table 1). No one group or institution is "in charge" of the whole (Magee *et al.* 1989), and the system is strongly self-organising. Politicians have been unable to make institutional changes that are in the state or national interest unless the interests of the competing groups are sufficiently aligned.

Despite these limitations State government has played a part in maintaining options for future generations. Before 1967 there were no laws protecting native flora and fauna for their intrinsic values, no environmental laws, no Aboriginal land rights legislation, and there were just five Acts regulating natural resource use. Since then seven nature conservation, three environmental protection, seven Aboriginal and seven natural resource use Acts have been passed at State and federal levels. This was mainly because of pressure from urban voters. Because of soil conservation (1938) and later native vegetation legislation the area of vegetation cleared and cropped is substantially less than it would have been without controls. State government has also established a system of conservation reserves and National parks, inadequate though it is. On the other hand the closer settlement policy (ten Acts passed before 1960, none since), first dismantled then prevented the re-emergence of a pastoral system adapted to the temporal and spatial patterns of rainfall in and beyond the region. Now, as the growing pace of social and climatic changes require flexibility and rapid responses, the adaptive capacity of pastoralists, other stakeholders and bureaucracies is threatened by the complexity of the institutional arrangements that enmesh social transactions. How did this complexity arise?

Institutions are a response to both uncertainty (Pritchard *et al.* 1998) and clashes of values (Stafford Smith pers. comm.). Thus perceived environmental and social crises have resulted in the elaboration of laws. The legislation affecting the NSW rangelands is now:

> ….a complex mixture of ancient and modern, which has seen layer built upon layer, with no attempt to conduct any fundamental re-evaluation. The approach of government in recent years has been to deal with specific problems relating to the older legislation as and when they have arisen by *ad hoc* amendments, rather than carrying out a fundamental reform. For the most part, the new breed of holistic "environmental law" has been simply superimposed on outdated sectoral and segmented natural resources law. (Abel *et al.* 1999, p. 71).

None of the crises in the NSW rangelands has been followed by major collapse and release of resources for re-organisation, as Holling *et al.*, (2001) predict. Complexity of organisations and policies has grown with the accumulation of problems. Each agency operates under specific legislation, and the various laws are themselves in conflict in some areas. Separate community committees have been established for catchment management, river management, regional vegetation management, pastoral matters and Aboriginal affairs. Their spatial boundaries do not match, nor do they match with local government boundaries that are used for environmental protection legislation and plans. State Aboriginal sub-regions do not match the federal classification. There are various departmental sub-regions. Their boundaries do not match each other, nor do they coincide with the boundaries of the community committees or local government. The multiplicity of strategic plans over-laid on conflicting boundaries and administered under laws that both overlap and conflict makes transaction costs very high. That the system function at all is a credit to the public servants, who are aware of its ludicrous over-complexity. They are themselves, though, enmeshed and find it difficult to initiate change.

Societies tend to address problems through elaboration of institutions rather than simplification or change of functions. This is because of the opposition of individuals and organisations to perceived losses in resources or status. Tainter (1988) argues that, because of this tendency to grow without compensating decline, societies have in the past collapsed under the burden of their own administrative costs. Interestingly, Janssen *et al*. (2000) modelled the evolution of pastoral strategies under 'free market', 'conservation' and 'stability policy regimes, and found that the free market regime produced in the long run the best adapted population of pastoralists. Fitness was assessed in terms of their abilities to cope with fluctuating rainfall and prices, and manage scrub encroachment by burning. We are not, however, arguing for free-markets in rangelands. Casualties of the evolutionary process included pastoralists who were removed by bankruptcy, and poor management of vegetation before selection and learning improved management. We accept that maintaining or enhancing resilience in social-ecological systems does require substantial resources. We are not arguing for reduced investment, but institutional simplification, and re-allocation of resources to the building of adaptive capacities.

What Next for Pastoralism?

Producers in the NSW rangelands now face falling demand for wool as long term overseas household spending patterns change, and synthetic fibres compete. Demand for fine wool may persist, but this niche market is better supplied from higher rainfall areas where returns are more favourable. The terms of trade between wool revenue and input costs have meanwhile been worsening in the long term (Beare 1995; Hassalls and Associates 1982). Debt levels are high and growing (? 9). While cattle prices hold some pastoralists have moved into beef production in those limited areas where land is suitable. Harvesting feral goats has kept many household economies viable. Goat prices have been high this decade. They fare better than sheep and cattle where scrub has encroached, so a weed and a pest have combined to become a resource, for the time being at least. Some producers have left the land, encouraged by Federal exit payments. The resulting increase in property size increases potential viability, but costs have continued to rise and wool price to fall so pastoralism has remained under threat (Figures 4 and 9, and Beare 1995). Federal and State governments invested fairly heavily in the development of rural regions until the 1980s. Since then they have switched to a more regulatory role, and rural services and infrastructure have suffered. Rural stakeholder groups have been lobbying and voting to maintain support for the rural regions, often successfully, but the ratio of rural to urban voters is declining, and with it rural power (Table 1). The region lacks adaptive capacity as it faces climatic, economic and social changes.

Because no government can manage the SES as a whole, the challenge for those attempting to influence the sustainability of land use is to learn when, where, at what scale and how to intervene to enhance the resilience of the system to impending global changes, while accommodating the diverse needs of the various stakeholder groups. We offer examples in the next section. Being unable to predict the evolution of the SES, we offer instead a scenario of how it might develop.

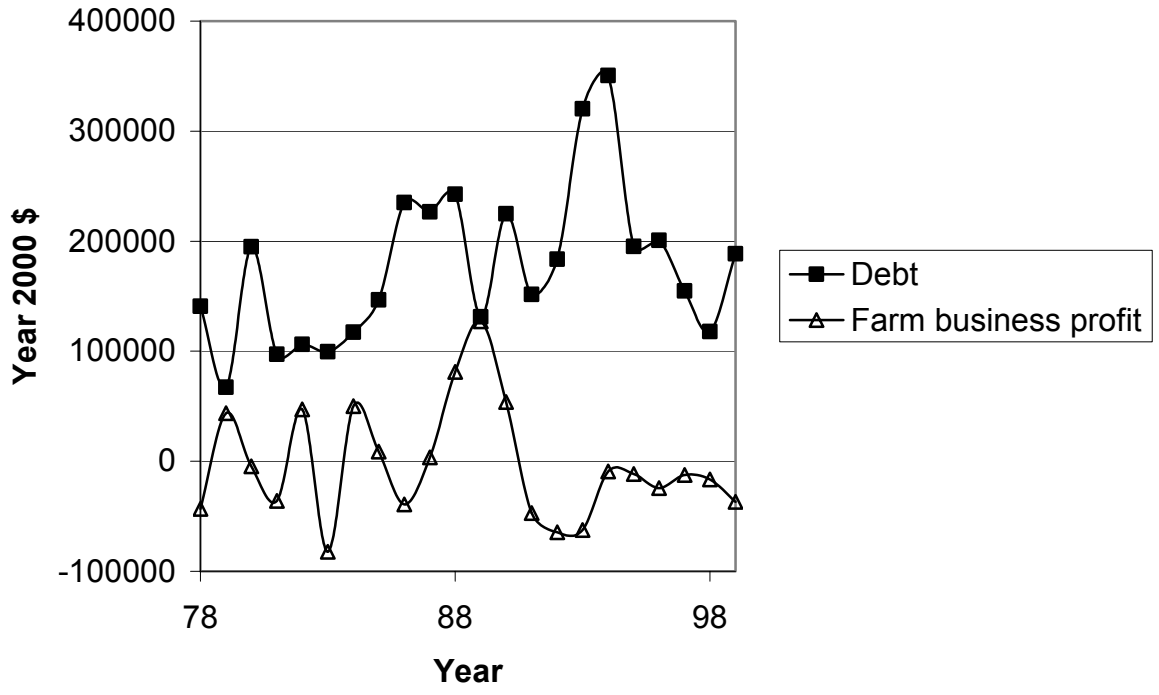


Figure 9. Pastoral Financial Trends Source: ABARE 2000

Looking Back from 2020

Looking back from the year 2020 we see how much has been learned about regional resilience. It is clear in retrospect that policy-makers and pastoralists had placed too much emphasis upon fast variables (rainfall and prices in particular). Around the turn of the 20th Century focus shifted to slow variables as it was these that set the thresholds of resilience, even though a change in a fast variable (such as price) may actually trigger a collapse (Carpenter *et al.* 2001). Key slow variables at broad scale have been:

- climatic change - as rainfall becomes more variable financial risk and risk to landscape function and biodiversity increase (Timmermann *et al.* 1999);
- demand for wool – international tastes changed, and shrinking profit per hectare dictated land use changes;
- the ratios of rural to urban, and Aboriginal to non-Aboriginal voters – both fell, and with it the ability of the agro-pastoral industry to influence policies;
- the developmentalist ideology – it was displaced at State and national scales by an eco-centric one that promoted long term use of natural capital.

Major slow variables at local scale have been:

- landscape function;
- scrub increase – it made sheep unprofitable, favouring goats and other browsers, and it suppressed native grassland biota;
- debt – the security of their leases allowed pastoralists to accumulate debts that could not be repaid as costs rose and prices fell;

- capital – investment in fences and water points enabled pastoralists to take advantage of landscape heterogeneity;
- land tenure –property sizes have continued to increase, and changes in lease conditions enabled multiple land use.

System memory is a form of slow variable. At national and State scales it resided in constitutions and laws, as well as in widely shared ideologies and values. While these have provided continuity, persistent system memory can be harmful. The pre-occupation of governments with closer settlement of the rangelands as a way of emphasising colonists' rights to possession of the continent had some geopolitical and psychological rationale following from the ousting of Aboriginal peoples from their lands, and the potential for territorial threats from our Asian neighbours. However, the policy forced pastoralists to operate at a scale that was too fine for the patterns of rainfall and landscapes in time and space. The ideology of private ownership reinforced this inappropriate scale of use. Early in the 21st Century a paradigm shift spread through the rangelands, heralding changes in land tenure. New land tenure law favoured multiple land use and producer cooperatives, thus increasing adaptive capacity through the diversity of new opportunities created, and allowing producers to realise economies of scope and scale.

The rangelands have been challenged by fluctuating commodity prices, livestock disease outbreaks, introduced weeds, and are now locked into drought. The system still survives – so far – thanks to the institution-building promoted around the turn of the century by State and Federal governments, non-governmental organisations, industries and local communities. Markets were established for carbon accumulation, and for biodiversity, which subsequently became important uses of rangelands.

Change in the rangelands was facilitated by the Western Lands Review (Kerin 2000), and the "Sustainable Use of Rangelands in the 21st Century" project (www.cse.csiro.au/nsw_rangelands). Both processes based their recommendations on the concept of resilience. Between them they advocated: simplification of laws; organisational mergers; re-alignment of administrative boundaries; integration of stakeholders in planning processes; conflict resolution processes including the promotion of access agreements between leaseholders and Aboriginal people; land tenure changes to support multiple land uses; and learning through adaptive and collaborative policy making and management (Mobbs 2000; Westley 2001).

The principles of institutional change advocated by the Western Lands Review and the Sustainable Rangelands project incorporated these considerations of resilience (Berkes and Folke 1998):

- institutions should give just sufficient external support to prevent a system crash, but without discouraging internal adaptive capacity;
- institutional memory should be maintained to guide the region through recovery following disturbance;
- the capacity to learn from past disturbances should be enhanced in order to increase the ability to anticipate and adapt to future disturbances;
- innovation and diversity in society and land uses should be fostered so as to provide a wide range of options if the economy or climate change;
- some redundancy in infrastructure, technology and institutions should be accepted so that if part fails there are back-ups.

The process of centralisation of power and control epitomized by the closer settlement policy has been reversed. Since the turn of the century the emphasis of governments has been upon building adaptive capacities at local and regional scales. Implicit in the changes that followed was recognition that institutional arrangements that bring benefits to large numbers of people are usually economically efficient, whereas those that benefit only special interest groups tend to be inefficient (Magee *et al.* 1989). With widespread voter support, the State Premier challenged the competitive territorial behaviour among the land and water resource, environmental planning and biodiversity conservation agencies and local governments. Agencies and local governments began to form new organisations with regional communities under new legislation. The agencies initiated the process in 2003 by closing their regional offices and reallocating the resources. They devolved their staff and responsibilities to community-based organisations at sub-regional scale. These organisations included elected stakeholder representatives, and technical staff from the agencies. Local governments amalgamated with these new organisations. The roles of the new organisations were to: carry out adaptive regional planning; coordinate sub-regional and sectoral plans (agro-pastoral, minerals, tourism, infrastructure and services); assess and approve development applications; and monitor the implementation of plans and their consequences.

A conservation reserve system was established on representative land types on what were then pastoral leases. An array of approaches was and is still being tried. In one, leaseholders removed stock, closed artificial water points, controlled feral animals, established a burning regime and received stewardship payments through a publicly-funded incentive scheme. The stewardship payments were 10% higher than the gross margin of the best alternative land use. The financial cost of establishing and managing the reserve system was significantly less than doing so under the conservation agency, and there was substantial public support for the arrangement. The proximity of the leaseholder to the land assisted monitoring and hastened management responses. Some conservation reserves became tourist attractions, and the extra expenditure by tourists benefited the economies of rural towns. Mining companies bought pastoral leases to get access to groundwater. Taking advantage of tax laws, most of the lease was managed for conservation of biodiversity. The work was sub-contracted to whichever Aboriginal group had established native title.

Initially the needs of Aboriginal peoples for access to land began to be addressed through formal agreements with leaseholders under 1990s native title legislation. Slow and expensive court battles were thus avoided. A major institutional breakthrough was the establishment of a new land tenure system that recognized spatial and temporal variability and cultural diversity. A State statute supported the voluntary process. The spatial framework was the lands of surviving Aboriginal tribes, and the "dreaming tracks" that connected sites of mythological significance. Leases within these tribal boundaries were voluntarily amalgamated after very lengthy negotiations among pastoralists and Aboriginal peoples. Pastoralists and Aboriginal peoples became co-users of these sub regions. Livestock was privately owned, but land was held in common by the co-users under a single title. The title specified the resource use rights of the group. They included all the above ground resources, subject to soil conservation, water resource, nature conservation and heritage laws, and subject also to the limitation that 25% of each land system should be ungrazed by stock and managed for the conservation of native biota. Minerals remained under public ownership and subject to licensing. The group drew up a constitution, adapted to local circumstances from a general model. It described the goals of land and water use, group and individual rights and duties, the terms under which a member could dispose of rights, organisational structure, conflict resolution mechanisms, and a monitoring system. Three schemes are now working well, and another three are under negotiation.

The future of the region is of course still uncertain as changes in global climate, human populations, their values and economies bring new threats and opportunities. The social-ecological systems of the region increase their chances of persisting by adhering to principles drawn from resilience theory (Pritchard *et al.* 1998; Folke *et al.* 1998). Society is now seen as co-evolving with, rather than 'managing' the non-human elements of the system. Diversity of species, ecological communities, land uses, cultures and ideas are seen as necessary for resilience, rather than as threats to economic growth, or to the stability of society. It is understood that some economic and climatic disturbances must be expected, and that local adaptations must be fostered to cope with them. And society has long since recognised that complex, dynamic social-ecological systems cannot be managed by detailed, proscriptive and static laws, and prescriptive policies. Such thinking neglects a particular implication of the adaptive cycle – that the behaviour of a system changes according to the stage of the adaptive cycle it has reached. The emphasis is therefore upon monitoring, and learning from the feedback, instead of relying on technical advice from agencies, backed by legal sanctions. Laws are still used as ultimate sanctions, but they also specify the outcomes desired, set out the social processes required in seeking them, and offer non-litigious solutions to resource use conflicts.

As a consequence of the emphasis upon knowledge instead of regulations, the level of ecological understanding among land users has increased several-fold this century. In a parallel change, cumbersome, centralised organisations have been replaced by decentralised decision making dispersed hierarchically at scales suited to the heterogeneity of the land (Ostrom 1990). As a consequence, human responsibility matches the scale of the biophysical phenomena (Briggs 2001; Lee 1993; Pritchard *et al.* 1998; Wilson et al. 1999). There is overlap, so that a degree of coordination is maintained across scales. Organisation at the broad scale does not disappear, for the extensive view is needed, but budgets and power are devolved.

In attempting to match the scale of decision making to the scale of ecological processes (Pritchard *et al.* 1998), it is proposed to connect the new group landholdings described above into spatially separated sets of satellite holdings. In a re-enactment of Aboriginal and early pastoral adaptations, these would extend across State boundaries and across rainfall gradients. Property rights and property obligations would also be allocated at scales that take account of the scales of ecological processes.

Obligations to future generations are now taken into account by appointing advocates to represent their interests in law and policy making processes that might affect resource availability in the future. Also in the interests of future generations, it is recognised that the social-ecological system must avoid the tendency of such systems to become locked in a monopoly stage with loss of diversity, over-elaborate and rigid institutions, and a propensity to collapse into an unwanted state.

Researchers and policy makers have learned much over the last 20 years. CAS theory has simplified and structured their thinking about complex systems. It has provided a framework for the arrangement of disciplinary theories, models and analytical methods at appropriate scales and temporal resolutions. Analyses of cross-scale interactions are now routine, though still not easy. Non-linearity remains analytically difficult, but most researchers see that the problem lies in reality rather than their minds.

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References

ABARE 2000. ASPIRE Database. Australian Bureau of Agricultural and Resource Economics, Canberra.

Abel, N. and Blaikie, P.M. 1986. Elephants, people parks and development: the case of the Luangwa Valley, Zambia. Environmental Management 10, 6: 735-751

Abel, N., Farrier, D., Tatnell, B. & Mooney, C. (1999) A rangeland enmeshed: the legal and administrative framework of the Western Division of New South Wales. Report to the Western Lands Review.

Abel, N., Ive, J., Langston, A., Tatnell, B., Tongway, D., Walker, B. and Walker, P. (2000). Resilience of NSW rangelands: A framework for analysing a complex adaptive system. Pp 59-71 P.Hale, A.Petrie, D.Moloney and P.Sattler (eds.). Management for Sustainable Ecosystems. The Centre for Conservation Biology, Brisbane.

ABS 1978. The Official Yearbook of New South Wales. Australian Bureau of Statistics, Canberra.

ABS 1995. Integrated Regional Database. CD ROM. Australian Bureau of Statistics, Canberra.

Anderson, V.J., Hodgkinson, K.C., and Grice, A.C., 1996. The influence of r4ecent grazing pressure and landscape position on grass recruitment in a semi-arid woodland of eastern Australia. Rangeland Journal 18(1): 3-9

Ash, A.J. and D.M. Stafford Smith. 1996. Evaluating stocking rate impacts in rangelands: animals don't practice what we preach. Rangeland Journal 18:216-243.

Baker, B., Barnett, G., Doherty, M., Gordon, A., Kearns, A., Mazzer T., Sarre, A., and Tatnell, B., 1999. Biophysical status and trends of the land and water systems of the Western Division. Final Report to the Western Lands Review. New South Wales Department of Land and Water Conservation, Sydney.

Barnard A. 1962. The simple fleece. Cambridge University Press, London.

Beare, S, 1995. Agriculture in the rangelands: a study of economic viability. Australian Commodities, 2 (4): 499-510

Berkes, F., and Folke, C., 1998. Linking social and ecological systems for resilience and sustainability. Pages 1-26 in Folke, C, Berkes, F, and Colding, J, (eds.). Linking social and ecological systems. Cambridge University Press, Cambridge.

Blaikie, P.M. and Brookfield, H., (eds.) 1987. Land degradation and society. Methuen, London.

Briggs, S.V., 2001. Linking ecological scales and institutional frameworks for landscape rehabilitation. Ecological management and restoration 2(1): 28-35

Bureau of Meteorology 1993/1994. Australia's Climate and Weather. Pages 46-58 in National Farmers' Federation,. Australian Agriculture. Morescope, Camberwell.

Cain, N. and Com, B., 1962. Companies and squatting in the Western Division of New South Wales, 1896-1905. In: The Simple Fleece, (ed.) Barnard, A., pp. 435-456.

Carpenter, S.R., Brock, W.A., Ludwig, D., 2001. Collapse, Learning, and Renewal. Chapter 7 in Gunderson, L. and Holling, C.S. (eds.). Panarchy: Understanding Transformations in Human and Natural Systems. Island Press.

Caughley, G, 1987. Ecological relationships. Pages 159-187 in Caughley, G, Shepherd, N, and Short, J. (eds.). Kangaroos: their Ecology and Management in the Sheep Rangelands of Australia. Cambridge University Press, Cambridge.

Caughley, G, Shepherd, N, and Short, J. (eds) 1987. Kangaroos: their Ecology and Management in the Sheep Rangelands of Australia. Cambridge University Press, Cambridge.

Chalmers, A F, (1982). What is This Thing Called Science? University of Queensland Press, St. Lucia.

Chappell, J.M.A., Head, J.M. and Magee, J.W. (1996). Beyond the radiocarbon limit in Australian archaeology and Quaternary research. Antiquity 70: 543-52.

Committee of Review into the Wool Industry, 1991. The Australian Wool Industry: Recommendations for the Future. Report to the Minister for Primary Industries and Energy. Commonwealth of Australia, Canberra. 115 pages.

Condon, 1978. Land tenure and desertification in Australia's arid lands, with particular reference to Western New South Wales. Search 9, 7:261-264.

Condon, 2000a. Historical perspectives on land settlement in the Western Division of New South Wales. In 'Out of the West'. Lower Murray Darling Catchment Management Committee, Department of Land and Water Conservation, Buronga, and the Western Catchment Management Committee, Department of Land and Water Conservation, Cobar

Condon, 2000b. Historical perspectives on the pastoral industry in the Western Division of New South Wales. In 'Out of the West'. Lower Murray Darling Catchment Management Committee, Department of Land and Water Conservation, Buronga, and the Western Catchment Management Committee, Department of Land and Water Conservation, Cobar

Davidson B. R. 1992. Rum Corps to IXL: services to pastoralists and farmers in New South Wales. Review of Marketing and Agricultural Economics 60, 3: 313-332.

Dickman, C. R. (1994) Native mammals of western New South Wales : past neglect, future rehabilitation? In Lunney, D., Hand, S., Reed, P. and Butcher, D. (1994) (eds). Future of the Fauna in Western New South Wales. Royal Zoological Society of NSW, Mosman.

Dovers, S., (ed) 1994a. Australian environmental history: essays and cases. Oxford University Press, Oxford.

Dovers, S. 1994b. The history of natural resource use in rural Australia: practicalities and ideologies. Pages 1-20 in Dovers, S., (ed) 1994. Australian environmental history: essays and cases. Oxford University Press, Oxford.

Doyle T. & Kellow A. (1995) Environmental Politics and Policy Making in Australia. Macmillan, Melbourne.

Duncan R.C. 1972. Technological change in the arid zone of New South Wales. The Australian Journal of Agricultural Economics, 16,1: 22-30

Flannery, T F, 1994. The Future Eaters. Reed Books, Chatswood.

Folke, C, Berkes, F, and Colding, J, 1998. Ecological practices, and social mechanisms for building resilience and sustainability. Pp 414-434 in Berkes, F, Folke, C, and Colding, J. Linking social and ecological systems. Cambridge University Press, Cambridge.

Freudenberger, D., A. Wilson and R. Palmer. 1999. The effects of perennial grasses, stocking rate and rainfall on sheep production in a semi-arid woodland of eastern Australia. The Rangeland Journal 21:199-219.

Gardiner D.B., Tupper G.J. & Dundeon G.S. (1998) A quantitative appraisal of woody shrub encroachment in western New South Wales. Rangeland Journal. 20, pp 26-40.

Godden, D.P., 1997 Agricultural and resource policy : principles and practice. Melbourne, Oxford University Press.

Gunderson, L. and Holling, C.S. (2001). Panarchy: Understanding Transformations in Human and Natural Systems. Island Press.

Hardy, B. 1969. West of the Darling. Jacaranda, Milton.

Harrington, G.N., 1979. The effects of feral goats and sheep on shrub populations in a semi-arid woodland. Australian Rangeland Journal 1: 334-345

Hassalls and Associates 1982. An economic study of the Western Division of New South Wales. Report commission by the NSW Western Lands Commission, Sydney.

Hodgkinson, K.C., 1995. A model for perennial grass mortality under grazing. In N.E. West (Ed) Rangelands in a Sustainable Biosphere, Proceedings Vth International Rangeland Congress. Vol. I.. Denver, Society for Range Management. pp. 240-241.

Hodgkinson, K. and Freudenberger, D., 1997. Production pulses and flow-ons in rangeland landscapes. Pages 23-34 in Ludwig, J., Tongway, D., Freudenberg, D., Noble, J. and Hodgkinson, K. (Eds). 1997. Landscape ecology, function and management: Principles from Australia's rangelands. CSIRO Publishing, Collingwood.

Holling, C. S., L. H. Gunderson 2001. Resilience and Adaptive Cycles. Chapter 2 in Gunderson, L. and Holling, C.S. (eds.). Panarchy: Understanding Transformations in Human and Natural Systems. Island Press.

Holling, C.S., L.H. Gunderson, G.D. Peterson, 2001. Sustainability and Panarchies. Chapter 3 in Gunderson, L. and Holling, C.S. (eds.). Panarchy: Understanding Transformations in Human and Natural Systems. Island Press.

Janssen, M.A., B. Walker, J. Langridge and N. Abel (2000), An adaptive agent model for analysing co-evolution of management and policies in a complex rangeland system. Ecological Modelling, Vol. 131 (2/3), 249-268.

Joint Select Committee 1983. First Report from the Joint Select Committee of the Legislative Coucil and Legislative Assembly to Enquire into the Western Division of New South Wales. Parliament of New South Wales, Sydney.

Kerin, J. (2000). Western Lands Review - Final Report. NSW Land and Water Conservation, Sydney.

King, C.J. 1957. An Outline of Closer Settlement in NSW. Part 1. The sequence of the Land Laws 1988-1956. "Review of Marketing and Agricult6ural Economics" Division of Marketing and Agricultural Economics, Department of Agriculture, New South Wales.

Landsberg, J, James, C, Morton, S, Hobbs, T, Stol, J, Drew, A, and Tongway, H, 1997. Effects of artificial sources of water on rangeland biodiversity. Final report to the Biodiversity Convention and Strategy Section of the Biodiversity Group, Environment Australia. CSIRO Wildlife and Ecology, Lyneham.

Lee, K.N. 1993. Greed, scale mismatch and learning. Ecological Applications 3: 560-564.

Lourandos, H, 1997. Continent of Hunter-gatherers: New perspectives on Australian Pre-history. Cambridge University Press, Cambridge.

Ludwig, J. and Tongway, D. 1997. A landscape approach to rangeland ecology. Pages 1-12 in Ludwig, J., Tongway, D., Freudenberg, D., Noble, J. and Hodgkinson, K. (Eds). 1997. Landscape ecology, function and management: Principles from Australia's rangelands. CSIRO Publishing, Collingwood, Victoria

Ludwig, J., Tongway, D., Freudenberg, D., Noble, J. and Hodgkinson, K. (Eds). 1997. Landscape ecology, function and management: Principles from Australia's rangelands. CSIRO Publishing, Collingwood, Victoria

Ludwig, J.A. and Tongway, D.J. (1996) Rehabilitation of semi-arid landscapes in Australia. II. Restoring vegetation patches. Restoration Ecology 4, 398-406.

Lunney, D., Hand, S., Reed, P. and Butcher, D. (1994) (Eds) Future of the Fauna in Western New South Wales. Royal Zoological Society of NSW, Mosman.

Mackay, H., 1993. Reinventing Australia: the mind and mood of Australia in the 90s. Angus and Robertson, Sydney.

MacLeod, N.D. (1990). Issues of size and viability of pastoral holdings in the Western Division of New South Wales. Australian Rangeland Journal. 12(2):67-78.

Magee, S P, Brock, W. A., and Young, L, 1989 "Black Hole Tariffs, and Endogenous Policy Theory. Cambridge University Press.

Mobbs, C., 2000. Regional planning for sustainability: towards adaptive and collaborative perspectives. PhD. Thesis, Australian National University, Canberra.

Moylan, F, 1991. U-turn for Wool: a Radical Solution to the Problems of the Wool Industry. New Street Books, Melbourne.

Newsome, A., Catling, P.C., Cooke, B.D., and Smyth, R. 2001. Two ecological universes separated by the dingo barrier fence in semi-arid Australia: interactions between landscapes, herbivory and carnivory, with and without dingoes. Rangeland Journal 23(1): 71-98

NIEIR (1999). The Western Division of New South Wales: its human geography and economic prospects. Report to the Western Lands Review and the CSIRO/DLWC/LWRRDC Project Sustainable Use of Rangelands in the 21st Century. National Institute of Economic and Industry Research, Melbourne.

Noble, J.C. 1997. The delicate and noxious scrub: CSIRO studies on native tree and shrub proliferation in the semi-arid woodlands of Eastern Australia. National Rangelands Program, Commonwealth Scientific and Industrial Research Organisation, Canberra.

Noble J.C., and Tongway, D., 1986. Pastoral settlement in arid and semi-arid rangelands. Pages 217-242 in Russell, J.S. and Isbell, R.F. (eds). Australian soils: the human impact. University of Queensland Press, Brisbane.

Ostrom, L., 1990. Governing the Commons: the Evolution of Institutions for Collective Action. Cambridge University Press, Cambridge.

Pahl-Wostl, C, 1995. The dynamic nature of ecosystems: chaos and order entwined. John Wiley and Sons, Chichester.

Passmore, J.G.I., and C.G.Brown, 1992. Property size and rangeland degradation in the Queensland Mulga rangelands. Rangeland Journal 14 (1): 9-25.

Pearce, D W, and Turner, R K, 1990. Economics of Natural Resources and the Environment. Harvester Wheatsheat, New York.

Pickard, J., 1991. Land management in semi-arid environments of New South Wales. Vegetatio 91: 191-208

Pickard J., 1992. Technological change in fences and European pastoral heritage in semi-arid New South Wales. Rangeland Journal 14(2): 190-204.

Pickard, J., 1990. Analysis of stocking records from 1884 to 1988 during the sub-division of Momba, the largest property in semi-arid New South Wales. Proceedings of the Ecological Society of Australia 16:245-253

Pringle H.J., 2001. Grazing Impacts in Rangelands. PhD. Thesis, Australian National University, Canberra.

Pritchard, L.Jr., Sanderson, S.E. 2001. The Dynamics of Political Discourse in Seeking Sustainability. Chapter 6 in Gunderson, L. and Holling, C.S. (eds.). Panarchy: Understanding Transformations in Human and Natural Systems. Island Press.

Pritchard, L., J. Colding, F. Berkes, U. Svedin, C. Folke, 1998. The problem of fit between ecosystems and institutions. IHDP Working Paper No. 2, 50 pages. International Human Dimensions Programme on Global Environmental Change, Bonn.

Quinn, M.J. 1995. Posessing the West: the public management of the Western Division of New South Wales, 1880s to 1930s. Ph.D Thesis, Australian National University

Roberts, R.G., Jones, R., Spooner, N.A., Murray, A.S. and Smith, M.A. (1994). The human colonization of Australia: optical dates of 53,000 and 60,000 years bracket human arrival at Deaf Adder Gorge, Northern Territory. Quat. Geochron. Q. Sci. Rev. 13: 575-83.

Rolls, E.C., 1984. They All Ran Wild: the Animals and Plants that Plague Australia. Angus and Robertson, Sydney.

Sadlier, R. A. (1994) Conservation Status of the Reptiles and Amphibians in the Western Division of New South Wales - An Overview. In : Lunney, D., Hand, S., Reed, P. and Butcher, D. (1994) (Eds) Future of the Fauna in Western New South Wales. Royal Zoological Society of NSW, Mosman.

Smith, P. and J. Smith (1994) Historical Change in the Bird Fauna of Western New South Wales - Ecological Patterns and Conservation Implications. In : Lunney, D., Hand, S., Reed, P. and Butcher, D. (1994) (Eds) Future of the Fauna in Western New South Wales. Royal Zoological Society of NSW, Mosman.

Spinks, G.R. and Gruen, F.H., 1958. Post–war trends in farm size in New South Wales. Review of Marketing and Agricultural Economics 28, 3: 167-184

Stafford Smith, M., and McKeon, G. M. 1998. Assessing the historical frequency of drought events on grazing properties in Australian rangelands. Agricultural Systems 57:3:271-299

Tainter, J. A., 1988. The Collapse of Complex Societies. Cambridge University Press, Cambridge.

Timmermann, A., Oberhuber, J., Bacher, A., Esch, M., Latif, M. and Roeckner, E. (1999). Increased El Niño frequency in a climate model forced by future greenhouse warming. Nature 398:694-697.

Tongway, D., and Hindley, N., 2000. Assessing and monitoring desertification with soil indicators. Pp 89-98 in Arnalds, O., and Archer, S. (eds.). Rangeland Desertification. Advances in Vegetation Science 19. Kluwer, Dordrecht.

Tongway, D.J. and Ludwig, J.A. (1996) Rehabilitation of semi-arid landscapes in Australia. I. Restoring productive soil patches. Restoration Ecology 4.

Walker,K.J. (1994). The Political Economy of Environmental Policy: an Australian Introduction. University of New South Wales Press, Kensington.

Walker, B., Kinzig, A. and Langridge, J. 1999. Plant attribute diversity, resilience and ecosystem function: the nature and significance of dominant and minor species. Ecosystems 2: 95-113

Walker, P., 1991. Land systems of Western New South Wales. Technical Report Number 25. Soil Conservation Service of New South Wales, Sydney.

Wasson R.J., 1994. Living with the past: uses of history for understanding landscape change and degradation. Land Degradation and Rehabilitation, 5: 79-87.

Wasson, R.J. and Galloway R.J. 1986. Sediment yield in the Barrier Range before and after European settlement. Australian Rangeland Journal 8: 79-90

Western Lands Commissioner 1980. Annual Report. NSW Government, Sydney.

Westley, F., 2001. The devil in the dynamics: adaptive management in the front lines. Chapter 13 in Gunderson, L. and Holling, C.S. (eds.). Panarchy: Understanding Transformations in Human and Natural Systems. Island Press.

Wilson, J., Low, B., Costanza, R., and Ostrom, E., 1999. Scale misperceptions and the dynamics of a social-ecological system. Ecological economics 31: 243-257

Williams, M., 1975. More and smaller is better: Australian rural settlement 1788-1914. Pages 61-103 in Powell, J.M., and Williams, M. Australian Space and Time: Geographical Perspectives in Australia 1788-1914. Oxford University Press, Melbourne

Woodward, D., Parkin, A., and Summers, J., 1997. Government, politics, power and policy in Australia. Sixth Edition. Longman, Melbourne.

Young, M.D., 1985a. The influence of farm size on vegetation condition in an arid area. Journal of Environmental Management 21: 193 – 203.

Young M.D., 1985b. Precis of land tenure and administration. Pages 3-30 in Johnson, R.F. Pastoral land tenure and administration in Queensland, New South Wales, South Australia, Northern Territory and Western Australia. Pastoral Board of Western Australia, Perth.