Appendix A: Theory

Complex Adaptive Systems

Complex adaptive system (CAS) theory provides a framework for the integration of theories from the social and bio-physical sciences (Abel and others 2000). It is therefore a useful framework for understanding change and sustainability in a region such as the Western Division of New South Wales. CAS theory also takes account of system behaviours that tend to be neglected in the social and bio-physical sciences. Thus CAS theory takes account of hierarchical structure of systems, interactions across scale, non-linear processes, fast and slow processes, and lagged responses. It also treats a CAS as an evolving, self organising system, drawing on theories of biological evolution and social history. It is therefore concerned with system 'memory', path dependency and initial conditions.

CAS theory requires a holistic approach, but it simplifies complexity by recognising that interactions occur within a structure. Groups of components and processes occur at particular spatial and social scales in a hierarchy (Holling and others 2001; O'Neill and others 1986). Behaviour of a sub-system at one scale is qualitatively different from that of a sub-system at another scale (e.g. a farm compared with a region), and there is a degree of autonomy between the scales. However, the sub-systems are nested, finer within broader scale, so there are linkages across scales. A change in a broadscale sub-system can cascade to a fine scale to affect local resource use (Holling and others 2001). The Korean War caused a demand for wool that raised the price and encouraged establishment of artificial waterpoints in previously ungrazed country in the region. Likewise, disturbance within a fine-scale sub-system can spread through the hierarchy and affect broader scale sub-systems. An example is objection of rural people to a policy that disfavours them, and the resulting ousting of the government in the next election. Behaviour of the finer scale sub-systems is generally controlled by influences of the broader scale ones, but that change at the broad scale can be initiated by 'revolt' – a local disturbance that transforms the regional system (Holling and others 2001).

Some processes in complex systems are non-linear (major technological or institutional change, for example), and the multiplicity of interactions enhance the likelihood of non-linear responses to disturbances. Ecology (Pahl Wostl 1995) and economics (Brock chapter) tend to ignore such behaviour because it is analytically intractable. However, humans continue to face and adapt to non-linear change, perhaps at an increasing rate as the pace of climatic, ecological and social change increases, so theories must take account such changes. CAS theory attempts to do so using history and modelling (Janssen and others, in press).

CAS theory takes account of variation in the rates at which processes occur. What ecology and economics treat as parameters (e.g. soil structure; institutions), CAS theory sees as slow variables. It also takes account of lags between cause and effect. For example, the displacement Aboriginal peoples from their tribal lands in the 19th Century has caused conflicts among Aboriginal peoples around the turn of the 20th Century because of uncertainty about tribal "boundaries".

Complex adaptive biological systems are self-organising. Disturbances select for fitness of individuals, species adapt, and the system reorganises to accommodate the change. The evolutionary path of the system is the outcome of these adaptations. Humans do influence the behaviour and evolutionary path of social-ecological systems, but long term attempts to control them through hierarchical 'command and control' have generally failed (Gunderson and others

1995). This is because multiplicity of local processes, and their ecological and social heterogeneity, is not amenable to centralised control. Thus social-ecological systems are facing a future in which powerful climatic and economic drivers are likely to disturb them with unforeseen consequences for sustainability, yet top-down directives are ineffective. Thus CAS theory points towards changes in the decision-making environment of resource users as a means of achieving a sustainable evolutionary path. In other words, changes to institutions (Ostrom 1990, Hanna and Munasinghe 1995).

CASs have been disrupted in the past. Some were transformed to other configurations, others maintained their current configuration because of their resilience. Holling and others (2001) define resilience as the capacity of a system to experience disturbance and maintain its functions and controls (more formally, to remain in the same stability domain). Resilience is in their view measured by the magnitude of disturbance the system can experience and still persist. They contrast this definition with that of Pimm, for whom the appropriate measure is the ability of the system to resist disturbance, and the rate at which it returns to equilibrium following disturbance (Pimm 1984; Tilman and Downing 1994). The distinction has been useful in encouraging managers of naturally variable systems (e.g. rangelands), to think about persistence of such systems and break with their traditional preoccupation with management for (unachievable) stability. It has had the unfortunate effect of diverting research attention away from those systems that are particularly persistent because they are intrinsically resistant – they absorb high levels of disturbance, change little, and nevertheless persist (e.g. self-mulching clay soils; rice production from volcanic streams in Java). We agree with Holling and others that the key criterion of resilience is persistence. Unlike them, we class any system, stable or unstable, as resilient so long as it is also persistent (figure 1).

We attempt to explain why resilience has increased and decreased during the evolution of the Western Division. This understanding leads to the identification of ways of increasing resilience through institutional change, and through investment in learning.

It is likely from the work of Holling and others (2001) that interventions to influence the resilience and guide the evolutionary path of complex systems should take account of the particular stage the system is in. They recognise four stages:

1. growth - as in the establishment and rapid growth of colonising species on bare ground after disturbance, or colonisation of new land by humans. A system in this stage is characterised by weak feedback loops, so its behaviour is prone to high variation, and the evolutionary path it follows is undetermined (Holling and others call this the ‘exploitation stage’);
2. monopoly - for example, the self-consolidating behaviour of a climax plant community through monopolisation of resources; or the domination of a market by a few collaborating companies. A system in this stage is characterised by strong feedback loops that tend to maintain stability, in the short term at least (Holling and others call this the ‘conservation stage’);
3. release of resources following a disturbance which breaks feedback loops and causes the system to collapse;
4. reorganisation to direct the flows of those resources through the establishment or re-establishment of interactions, including feedback loops, among components.

Holling and others (2001) envisage these stages as occurring within each of the nested sub-systems in a CAS hierarchy, each sub-system out of phase with the others. Stages need not occur in the sequence listed. The history of "Western" development has been about the establishment of a growth stage in newly colonised lands, and evolution to a monopoly stage. Humans have subsequently invested much capital and labour in attempts to prevent passage to the release and reorganisation stages. Perhaps this is an attempt to postpone the inevitable, and delay of the release may make collapse more catastrophic when it does come, as in a social revolution.

It is apparent that different interventions would be appropriate at different stages. Towards the end of a monopoly stage, a dominant paradigm (Kuhn 1970) might be brought to an end by a few publications that spread ideas contagiously through minds that are ready for change (Abel and others 1998); the same information delivered at an earlier stage might have been ignored. During the release and reorganisation stages the system has weak feedback controls and is therefore susceptible to loss of resources from the system (soil erosion, species, human and financial capital), that potentially make it impossible for the system to return to a preferred configuration. Measures to conserve capital would be appropriate in these circumstances. During release and reorganisation feedback loops are weak, and the system is susceptible to change to an unwanted configuration. Guidance is needed. Influential ideas – such as the constitutions of the new Australian colonies during settlement – can become entrained and guide subsequent evolution of the system. Once entrained, they become incorporated into the dominant ideology (collective mental model) of the subsequent monopoly stage, with long lasting effects, therefore acting as system 'memory'.

System memory is any mechanism that maintains continuity. Another example is topography in a landscape. It provides a 'template' for re-organisation. Given sufficient time between bouts of clearing for agriculture, a consistent natural vegetation structure can reappear. Memory can thus maintain resilience by guiding recovery of a system towards a preferred configuration after disturbance. An example is the role of a constitution in easing the transition from one government to another after an election. Memory can also, if it prevents adaptation, make a system more vulnerable to disturbance - laws that hamper creativity during a monopoly stage, for example.

The memory concept is linked to those of path dependency and initial conditions. At any point in its evolution a system is limited in the range of feasible configurations it can enter by earlier adaptations of its components to previous disturbances. Adaptations and disturbances form a series of forks in the evolutionary path, and the route followed at a particular junction cannot be retraced and re-routed. Thus the nature of Australia's landscape, soils and vegetation, its climatic history and its isolation are consequences of the path and pace of movement of its tectonic plate. The attributes and dynamics of its ecological communities were shaped by this irreversible history (Flannery 1994). They and the properties of landscape and climate will in turn limit future possibilities. Understanding conditions at particular points in the evolutionary path is thus necessary for explaining the path that was subsequently followed. It may also suggest what conditions in the present might serve to guide the future path, therefore the responsibility of present generations to those in the future.

These concepts – sub-systems in a nested hierarchy, cross-scale interactions, non-linearity, fast and slow processes, lagged responses, 'memory', evolution, self-organisation, initial conditions and path dependency – were employed as we explored the growth and decline of resilience in the region. Three bodies of disciplinary theory have helped us understand the evolution of the system – social psychology, landscape ecology and political economy. We outline them next

Psychology

Kelly (1955) believed people use experiences to build mental "templates", or "constructs", which enable them to understand the world, predict what will happen, and react. The individual compares new experiences with existing constructs. If they fit, the constructs are not changed. Otherwise they may be modified, but people tend to accept information that confirms their constructs, and shed the rest. They may rearrange the information to fit the constructs.

Constructs are organised hierarchically into systems and sub-systems (Kelly 1955). Together with the tendency to ignore or modify challenging information, hierarchy imposes some stability on the model, for a minor construct cannot necessarily be changed without re-arranging other constructs so they are sufficiently compatible (the ability of individuals to live with some cognitive dissonance is well known). Because of innate stability, it requires direct experiences to challenge a person to change their constructs (Mackay 1994) – "telling" is not usually enough. This is a partial explanation of the inability of humans to be proactive about environmental change. There is a striking parallel between mental model and CAS behaviours: dominant constructs tend to control subordinate constructs most of the time – analagous to the monopoly stage of a CAS. However, an experience can bring about change in a subordinate construct which makes 'release' of constructs and (self) reorganisation of the hierarchy necessary. A subsequent growth stage can be envisaged. Other analogies are apparent – constructs are modified in the light of 'disturbances' (experiences), change in an individual's mental model tends to be path-dependent and evolutionary, and is non-linear, memory provides continuity, and there are lagged responses.

Structuring and simplification of highly complex 'reality' is the primary function of a mental model. Without this capacity floods of information would swamp our minds. A mental model is not as complex as the system is represents, though to be useful it must represent the main processes (Rouse and Morris 1986; Johnson-Laird 1983). But simplification carries a cost.

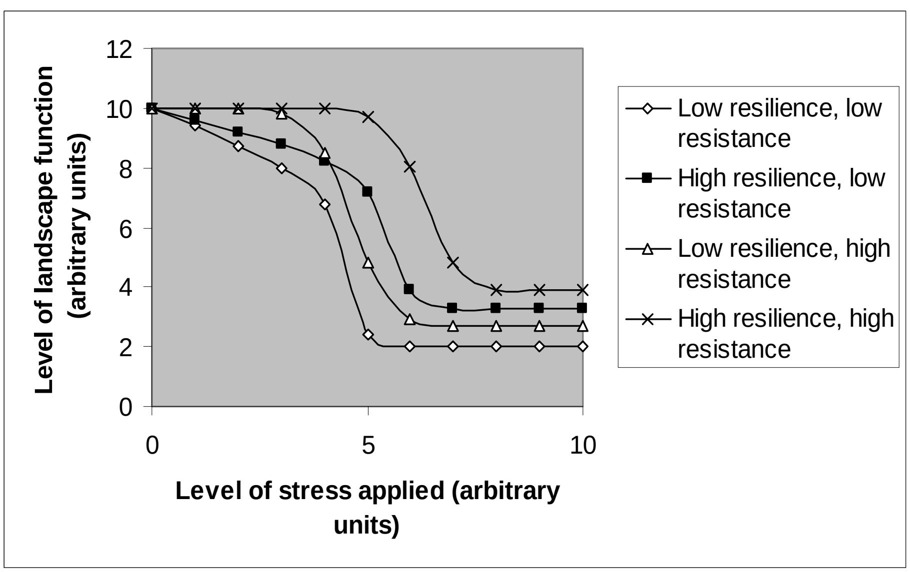
Abel and others (1998) wrote: "When people simplify reality they abstract selectively. Because individuals have different experiences, they select difference parts of "reality" to produce models that differ in structure and content from those of other individuals. Personal construct systems therefore differ in their focus and range of concerns (Kelly 1955). This can hamper communication. Kelly argues that for two people to communicate, one need not adopt the other's construct system. However, at least one must understand the construct system of the other. This is made easier when there is overlap between construct systems. In many cases there is insufficient commonality between people's construct systems to support communication. However, construct systems are moulded through experience, and incompatible systems exposed to common experiences can approach commonality." The theory of communication implicit in mental model theory is the reason we based the design of this project upon participative research as a means of providing experiences of the system in which the project participants are potential agents of change and conflict resolution.

Landscape Ecology and Population Ecology

In a grassland producing beef, graze-sensitive native grasses might be irreversibly replaced by more tolerant exotic species without a measurable change in level or variability of output. The exotic system might have a high resilience as a producer of beef, able to recover from droughts and fires indefinitely, without changing to another new configuration. If, though, the system is evaluated for the conservation of intrinsic value, then the loss of native species marks a collapse of resilience. Identification of the relevant processes, those that must persist if a configuration is to be maintained, depends on purpose. Loss of integrity of those processes denotes loss of resilience, so identification of change in resilience depends on prior framing of purpose (Ludwig and Tongway 1997).

The concept of landscape function is common to most potential rangeland uses because a well-functioning landscape could be used for a broad range of purposes. As function declines, that range decreases. In a well-functioning landscape infiltration, runoff and soil erosion are controlled by vegetation. Soil organic matter contributes to soil structure and cation exchange capacity. Loss of vegetation can breaks controls and propagules, water, nutrients, organic matter and sediments are exported with run-off and wind and redeposited at a broader scale. Dysfunctional landscapes typically have significantly lowered levels of seeds, stored nitrogen and organic carbon in the topsoil, infiltration rates and herbaceous productivity (Tongway and Ludwig 1997). Some landscape types are able to tolerate more stress than others without loss of function – they are more resilient (Tongway and Hindley 1999). Loss is not necessarily irreversible – vegetation can become re-established, soil organic matter re-accumulate, and function can thus return even where mineral soils have been lost. The return path is probably hysteretical, and slower than the degradation (Ludwig and Tongway 1997). Recovery is an attribute of a resilient landscape. We depart from Holling and others' (2001) view of resilience by using the level of stress applied as the measure off resilience, rather than the degree of change undergone. A resistant system is one that changes little under stress. The relationship between resistance and resilience is expressed in figure 1.

Figure 1. Landscape Function, Resistance and Resilience (adapted from Tongway and Hindley 1999).



Landscape function depends on perennial plants to control resource flows. Perennial grasses are especially important, but are susceptible to grazing pressure (Hodgkinson 1995). Walker and others (1999) have shown that dominant species in a community have analogues among the minor species on terms of the functional roles they perform. The species differ in their responses to disturbances. If a dominant species declines following disturbance, a minor species may be available to fulfil its functional role. Thus redundancy may enable landscape function and biota depending on it to persist. Redundancy can decline under grazing pressure, and grazing pressure is affected by policies and institutions that affect hunting pressure, livestock densities and investment in water points

Caughley and others (1987) describe feedbacks that may prevent red and grey kangaroos from becoming so numerous that they destroy their food supply, and damage landscape function, or so scarce that they cannot recover after drought. Pasture growth is driven by rainfall, but the rate declines as biomass accumulates. The rate of forage consumption is an asymptotic function of forage biomass, and below a threshold intake falls below maintenance need. The exponential rate of increase of kangaroos likewise increases asymptotically with forage biomass, and becomes negative at a threshold. This ‘centripetal’ system varies widely, because it is driven by erratic rainfall, but the feedback mechanisms enable it to persist. The relationship between forage biomass and intake in sheep rate are similar. Their mortality and fecundity rates are also related to intake, but in drought pastoralists reduce mortality by moving them elsewhere, buying feed, or pushing edible shrubs over with a tractor. This breaks the feedback loops and threatens landscape function.

Vegetation structure varies in time and space, and affects landscape function. In the absence of herbivores the density of trees and shrubs at a site is determined by available soil moisture (Noble 1998). This depends on rainfall, topography, soil texture and structure. Density of woody plants will increase until equilibrium with soil moisture is reached. If the landscape is burned when fuel load is high, woody cover will decline. Burning is influenced by laws, including those of liability when fires escape, and pastoralists are reluctant to burn in NSW. Browsing herbivores will tend to reduce woody plant density too, and high prices for feral goats can result in heavy harvesting and consequent reduction in browsing pressure. In the absence of browsers, grazing will encourage woody regrowth to occur in a landscape previously opened by fire, because it removes fuel and reduces competition between woody seedlings and herbaceous plants. One functional role of shrubs is maintenance of soil stability. A dominant but palatable shrub may be replaced by an unpalatable one under browsing pressure. This is another example of functional redundancy contributing to resilience.

These aspects of landscape ecology were linked to changes in the land in the course of the history of the region.

Political Economy

New South Wales was established as a British colony in 1788. The institutional framework that subsequently evolved was much influenced by British models; had the French or Dutch been the colonisers this framework would have been different – an example of initial conditions and path-dependency. Likewise the colonisers imported an ideology (collective mental model) in which “development” was the dominant paradigm. It remains so today. It is the use of technology, social and human capital to extract value from the natural capital that resides in ecosystems. Some of the value is used to meet current needs, some is reinvested in human-made, social and human capital. Implicit assumptions are that natural and other forms of capital are substitutable (e.g. industrial fertiliser for a nutrient cycle), that the natural capital remaining will regenerate itself and provide life support for humans, and that consumption of natural capital yields a net gain to society, including future generations. The extraction of value at the rate currently regarded as normal is made possible by fossil fuels and associated technology. System drivers are international markets and technology changes. Benefits and costs of the system are distributed among groups in society through markets, policies and institutions.

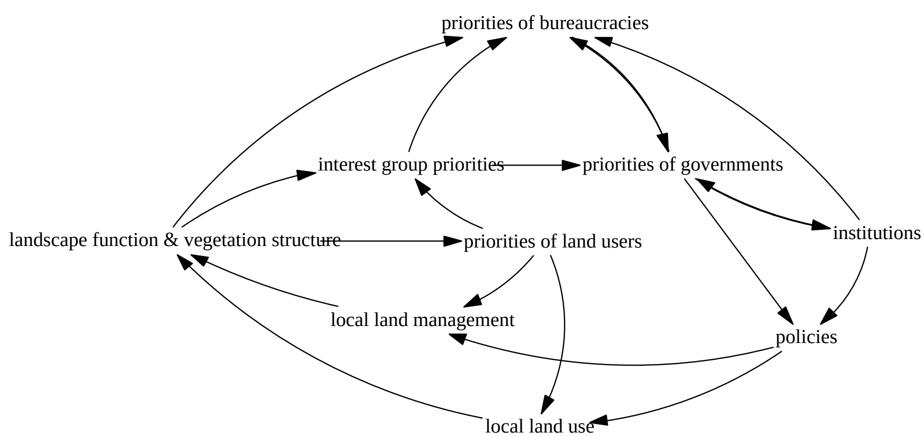
Godden (1997) uses modified public choice theory to explain how political processes affect policies, institutions and ultimately land use and management in a pluralistic society. He treats a democratic political system as an imperfect market in which participants attempt to maximise their utility. Participants are voters, political parties, bureaucracies and interest groups, including industries, firms, the media, and groups of citizens pursuing a particular interest – pastoralists, Aboriginal peoples, and conservationists, for example. Politicians aim be elected or re-elected. Political parties offer competing sets of policies and institutional changes to voters. The design of the sets is based on the expected net return to the party in terms of political support – votes and party funds. The sets are designed to win at least 50% plus one of votes in 50% plus one of electorates (assuming unimodal, continuous and symmetrical frequency distributions). Votes are given by all citizens (voting is compulsory in Australia). However, parties need campaign resources, hence policies and institutional changes must also earn these. They are supplied by interest groups that calculate the likely returns to their members in terms of favourable policies and institutions. The set of existing institutions, such as laws, established by similar processes in the past, constrain the behaviour of all current participants in the process, because of broadly shared views about the rule of law and respect for the constitution. Examples include legislation governing constituency boundaries, the rules of voting (transferable or non-transferable votes), double or single chamber representation and so on. All these factors strongly affect subsequent outcomes, including patterns of resource use and management, landscape function and vegetation structure (figure 1).

Governments on both sides of the political spectrum intervened increasingly strongly in the implementation of development policy until the 1970s. Since then Federal governments have been attempting to reduce intervention because of its perceived negative effects for a society that is increasingly dominated by urban and large business interests. Rural interest groups have been lobbying and voting to maintain support, often successfully. Government support has included (Davidson 1992):

- provision of infrastructure and communications
- support for agricultural research and extension
- tariffs to exclude competitors
- tax relief, and tax averaging to ameliorate market and climatic impacts
- loan subsidies
- direct income subsidy
- subsidisation of produce, or of inputs
- price support
- currency devaluation to increase revenue to farmers
- subsidising the withdrawal from the industry of farmers with low incomes.

Thus political bargaining at State and Federal levels affects the regional economy, society and environment. The distribution and quality of infrastructure and services, land tenure, drought relief, tax arrangements, wildlife policies and laws all affect patterns of land and water management and use, which in turn impact upon the regional economy, population, and the condition of its land and water resources. The priorities, thence the voting patterns of land users and other interest groups, are influenced by their mental models of these impacts, and can bring about changes in policies, institutions or governments through marginal changes in voting patterns. Goddens calls the influence of landholders on the formation of policies and institutions "farming the government". The impacts of policies and institutions at local scales occur through the response of household economies to changes in costs and prices, infrastructure and services. Households are assumed to react by reallocating labour, capital and land, or changing land management, thus affecting landscape function and vegetation structure (Figure 2). Examples are changing stocking densities or type of animal, including a shift from sheep to goats, or to wildlife harvesting, or getting off-farm work. They may also react as members of interest groups by shifting their political allegiance thus impacting upon government priorities (Figures 2).

Figure 2. Political interactions affecting land use and land management.



This model shows how landscape function, mental models and political processes interact as adaptations occur within an evolving system. No one group or institution is "in charge" – the system is self-organising. Strong path dependency is created by shifts in culture, investment, population change, the adoption of new technologies, losses of species, outbreaks of pests and diseases, and resource degradation. The first challenge for those attempting to influence the emergence of a pattern of sustainable land use is to accept that we are merely adaptive agents located within the system, rather than managing it from outside. The second is to learn when and how to intervene to enhance the resilience of the system.

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