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Synthesis

Resilience, Adaptive Capacity, and the "Lock-in Trap" of the Western Australian Agricultural Region

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ABSTRACT. Using the Western Australian (WA) agricultural region as an example of a large-scale social-ecological system (SES), this paper applies a framework based on resilience theory to examine the region's resilience and capacity for change and renewal. Despite numerous policies directed at controlling natural resource degradation in this SES, sustainable natural resource management (NRM) has not been achieved. Disparities between the scale and complexity of the problem, the design of management policies, and region's history have all contributed to policy resistance. Historically, when considered as an integrated system, changes may be described by two iterations of the adaptive cycle. These cycles are also synchronous with the third and fourth Kondratiev long-wave economic cycles. The WA agricultural region has experienced sequential periods of growth and accumulation followed by reorganization and renewal, and currently is in the backloop (reorganization to exploitation phases) of the adaptive cycle. A region's adaptive capacity is achieved by substituting direct reliance on regional factors with institutional intervention and sophisticated technology, often generated at the global scale. This substitution alters the thresholds of the commodity system and gives the perception of an adaptive system. In contrast, however, if resource depletion, environmental pollution, and population decline, also effects of the commodity system, are included within the model then the region may be considered to be in a "Lock-in" pathological trap. We propose that the dynamics of land-use change between 1900–2003 were driven by macroeconomics at the global scale, mediated by institutions at the national and state scale. Also, the SES, which is composed of relatively fast-moving variables, is largely decoupled from the slow-moving ecological variables.

INTRODUCTION

Natural resource problems are not isolated scientific or technical problems, but are rooted in human failure to understand the links between social, ecological, and economic systems. There are no easy answers to natural resource problems; many organizations have some responsibility for their management and previous attempts at amelioration have failed. Existing policies, based on the science of the 1950s, '60s and '70s (largely disciplinary), were not designed to address the current problems in natural resource management (NRM) (Meadows and Robinson 1985, De Greene 1993, Funtowicz and Ravetz 1993, Lee 1993, Gunderson et al. 1995). When these policies were established, issues were considered to be largely local, reversible, and direct, whereas today impacts are changing rapidly, are considered to be irreversible, and occur geographically (Daily 2000) and economically (Lambin et al. 2001) at a global scale. A principal reason for policy deficiency is that conceptual development has not kept pace with the speed of changes that alter and control the processes in large-scale systems (Gunderson and Pritchard 2002) composed of people and nature are defined as social-ecological systems (SES) (Walker et al. 2002). Poor conceptual development of these systems has hindered our understanding of their systemic behavior and weakened our ability to respond to such questions as "Are current policies maintaining or eroding the resilience of SESs? What are the key driving processes of the system? How does behavior in the social and economic systems affect the ecological system? or How does the productivity of the economic system affect the social system?" In this paper, we discuss the application of a systemic approach using resilience theory and the adaptive cycle heuristic model to the Western Australian (WA) agricultural region (Fig. 1) to (1) test the limits of the model, (2) compare it with the findings of Walker et al. (2002) for the Goulburn Broken Catchment in the Murray–Darling Basin in eastern Australia (Fig. 1), and (3) help refine the

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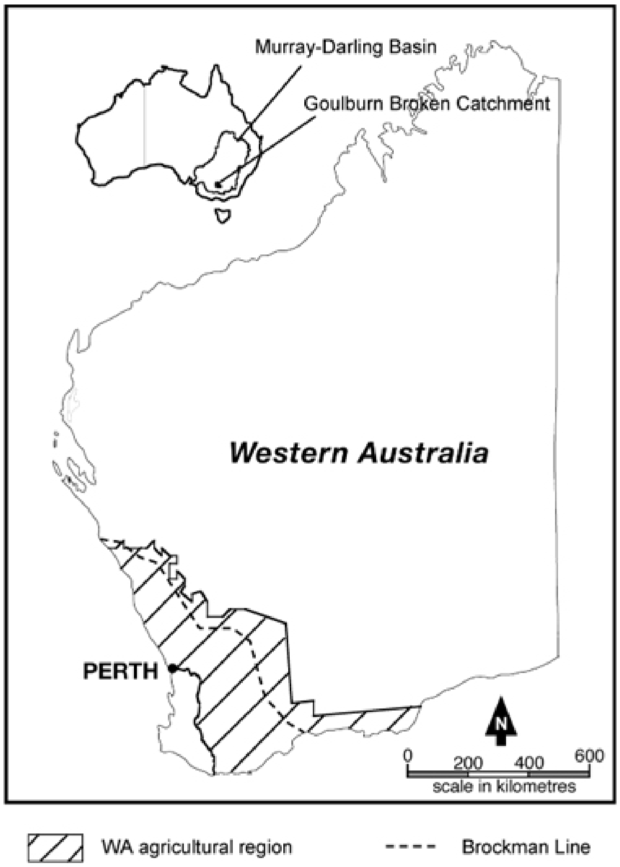
model. We consider whether, if the findings are inconsistent with the adaptive cycle, does the behavior conform to one of the pathological states also described by Holling et al. (2002c).

Fig. 1. A map of the Western Australia agricultural region.



The policy and management responses to natural resource degradation have been unsuccessful, often because of a lack of understanding in the following four areas within systems science: (1) the time-dependent nature of the problems in economic–ecological systems (Meadows 1982); (2) feedback concepts in systems theory and human system analysis (Richardson 1991, Fey 2002); (3) the transformations in interrelated human and natural systems (Gunderson and Holling 2002); and (4) mismatches of scale between human responsibility and natural interactions (Lee 1993). In a review of case studies of land-use change around the world, Lambin et al. (2001) concluded that economic conditions were the predominant factor that controlled individual and social responses. Although conditions were context specific, land-use change was mediated by institutional factors, such as markets and policies, increasingly influenced by global markets, and that extreme biophysical events could occasionally trigger further change. This combination of factors needs to be conceptualized and used as the basis of explanations and models of land-use change. Institutional factors are defined broadly as the set of rules, or structures, that allow people to organize for collective action (Gunderson et al. 2002c).

New concepts, theories, and metaphors are being developed to help understand and predict the links between the social, ecological, and economic systems, and thus meet the real world challenges of policy development and management strategies for sustainable NRM. A number of emerging trends for understanding these complex problems can be identified: for example, multidisciplinary research (Janssen and Goldsworthy 1996, Booth et al. 2000); post-normal science (Funtowicz and Ravetz 1993); system dynamics (Sterman 2001); the integration of theories, including complexity (Waldrop 1992) and its related theories of complex adaptive systems (Holland 1992); adaptive management (Holling 1978, Walters 1986); and resilience theory (Gunderson and Holling 2002).

The WA agricultural region (Fig. 1) is considered here to be more than the geographical region. It is an example of an SES, a large-scale system made up of people and nature (Walker et al. 2002). The major land-use in the WA agricultural region is broadacre agriculture, and this accounts for more than 90% of the area. Historically the main focus for analysis of the impacts of agricultural development have been on both land-use change and management, and the consequential natural resource degradation (this includes both resource depletion and environmental pollution), treating the natural system as if it were independent of the socio-economic system. The removal of extensive areas of native vegetation, primarily between 1900 and 1990 (Burvill 1979, Beeston et al. 1994), altered the region's microclimate (Lyons 2002) and the hydrological cycle, causing watertables to rise (McFarlane et al. 1993, George et al. 1996), and contributing to the reduction in biodiversity (Burbidge 1988). Agricultural intensification since 1961 to produce commercial commodities was a world-wide phenomenon that doubled the world's food production with only a 10%

increase in the area of arable land globally (Lambin et al. 2001). However, this increased level of production came at the cost of continuing and increasingly rapid degradation of the natural resources on which the industry itself depends and in which the true costs of production are not accounted for in either the natural or the social system (Sawin et al. 2003). In the WA agricultural region, numerous statutory and non-statutory policies aimed at controlling natural resource degradation in agricultural areas have failed to achieve sustainable NRM.

A growing body of literature has identified the social perspectives involved with sustainable land management (Gill 1996, Barr 2000, Cary 2000), and the cultural and political perspectives (Brewer 1986, Cary et al. 2002), emphasizing the need for research to embrace a transdisciplinary approach in which social and ecological systems are treated as a single coupled and dynamically complex system (Gunderson and Pritchard 2002). The future of agricultural production in the WA agricultural region and the biophysical condition of the landscapes will be determined by the relationships between the capacity for change in the human systems implemented through individual decisions, and the resilience of ecological systems across spatial and temporal scales. It is crucial to identify the key system variables that characterize the system dynamically in order to determine how producers, land managers, and policy makers may respond to system behavior.

Table 1. Four provisional propositions about large-scale systems

The organization of regional resource systems emerges from the interaction of a few variables. The essential structure and dynamics of complex systems are produced by the interactions of at least three, but no more than six, variables that operate at spatial and temporal scales that differ by approximately an order of magnitude.
Complex systems have multiple stable states. Complex systems can exhibit alternative stable organizations. Transitions between different organizations are due to changes in the interaction of structuring variables. Change often occurs when gradual change in a slow variable alters the interactions among fast variables.
Resilience derives from functional reinforcement across scales and functional overlap within scales. Resilience derives from both a duplication of function across a range of spatial and temporal scales and a diversity of different functions operating at each scale.
Vulnerability increases as sources of novelty are eliminated and as functional diversity and cross-scale functional replication are reduced. Diminished resources of novelty reduce the ability of a system to recover from disturbances. The elimination of structuring species or processes can cause an ecosystem to reorganize. A reduction in functional diversity and duplication of functions reduces the ability of a system to persist.

Source: Gunderson et al. 2002b

THE FRAMEWORK

Resilience theory

Resilience theory (Gunderson and Holling 2002) has its foundation in systems thinking, including complex systems theory, and is essentially about understanding the characteristics of change and the interactions between human and natural systems. Holling (1973) used the term “resilience” to mean the maximum amount of disturbance a system can experience and still return to the same equilibrium. In its current form, resilience theory aims to understand three fundamental themes (Gunderson and Holling 2002). The first considers the characteristics of stability, resilience, and change from one state to another in systems with multiple stable states. The second is cross-scale interactions and the third is one of adaptive change and learning using the heuristic model or metaphor of the adaptive cycle. The two aims of resilience management are (1) to prevent the system from moving to unintended system configurations in the face of external stresses and disturbance; and (2) to nurture and preserve the elements that enable the system to renew and reorganize itself following a massive change (Walker et al. 2002).

In the quest for a theory of adaptive change, Holling et al. (2002b) examined many case studies and identified two paradoxes that prevented any quick and easy predictions about the potential for a system to collapse. The first was the paradox of the pathology of regional resources and ecosystem management and the second was the trap of the expert. In addition, Gunderson et al. (2002b) made four provisional propositions (Table 1) about the behavior of SESs, based on a review of ecological processes, with the proviso that they may not be appropriate for other disciplines. We test these paradoxes and propositions for their applicability to the WA agricultural region.

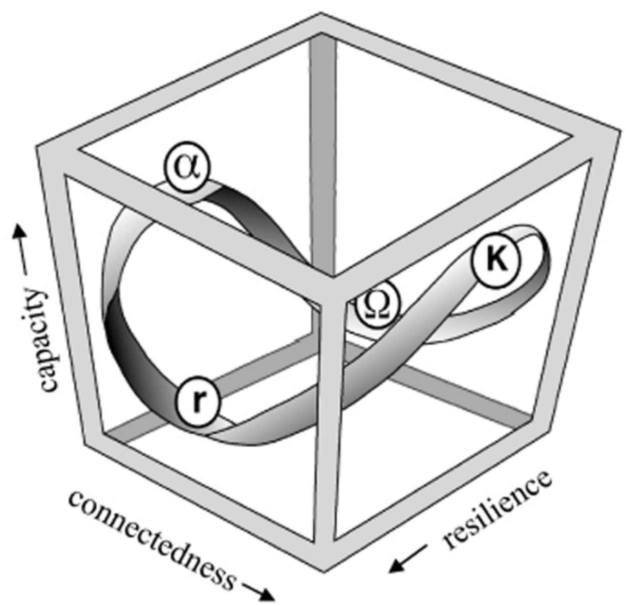
Table 2. The level of each of the three variables that characterize the four phases of the adaptive cycle

Phase	Potential	Connectedness	Resilience
α Reorganization	high	low	high
K Conservation	high	high	low
r Exploitation	low	low	high
Ω Release	low	high	low

The adaptive cycle

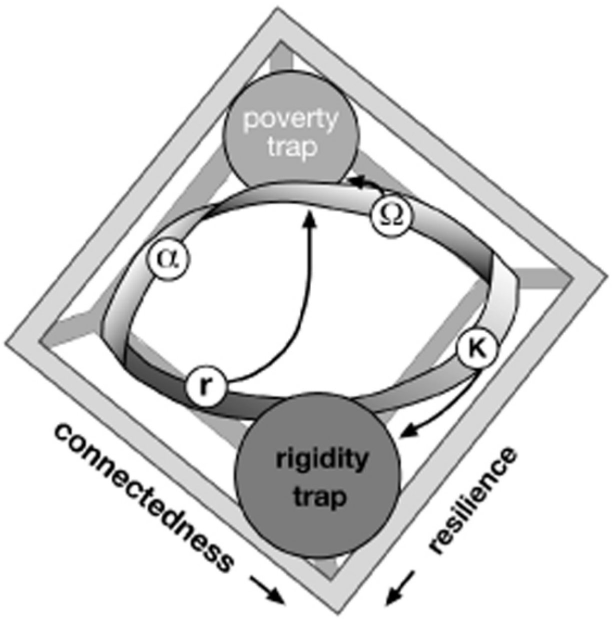
Holling's (1995) four-phase adaptive cycle (Fig. 2) is a heuristic model for understanding the process of change in complex systems and can be used to identify structure, patterns, and causality in the complex adaptive system. The fundamental conceptual model describes in theoretical terms perpetual and ever-changing time periods of the flow of events through four phases in an ecosystem. These four phases are exploitation, conservation, release, and reorganization (represented by r, K, Ω, α, respectively). The relative levels of the three properties (potential, connectedness, and resilience) that are characteristic of each of the four phases of the cycle are shown in Table 2.

Fig. 2. Heuristic model of the adaptive cycle. The adaptive cycle is a three-dimensional heuristic model. The resilience of the system expands and contracts throughout the cycle in relation to the potential and connectedness among the variables. (Redrawn from Holling et al. (2002b), with permission of Island Press, Washington, D. C., USA).



The cycle describes the slow accumulation of capital, for example, natural or social capital, interspersed with rapid phases of reorganization where, for transient moments, novelty can emerge to become subsequently incorporated into another cycle (Holling and Gunderson 2002). Structural changes occur among system variables as the cycle moves through the four phases. These changes are inherent features of evolving systems driven by instability and, therefore, a critical question to ask in these systems is “What are the factors that cause instability in the cycle, making it go from the conservation phase to the release phase and from the reorganization phase to the exploitation phase?”

Fig. 3. Heuristic model of the adaptive cycle, showing the pathological states of the poverty and rigidity traps. The poverty trap has low levels of all three properties and lies below the adaptive cycle in the figure, whereas the rigidity trap has high levels of all properties and lies above the adaptive cycle. The poverty trap may be most easily entered from the release (Ω) or exploitation (r) phase of the adaptive cycle, shown by the arrows in the figure. (Redrawn from Holling et al. (2002b), with permission of Island Press, Washington, D. C., USA).



Although the original concept of the adaptive cycle emerged from case studies of ecosystems in temperate regions of the world, it evolved through the integration of theories of change, not only in ecology but also social and economic disciplines. For example, in economics, Kondratiev's work (see *Kondratiev cycles* below) was extended in the 1930s by the prominent economist Joseph Schumpeter (Schumpeter 1950). Schumpeter emphasized the role of technical innovations and, particularly, the bunching of innovations during the phase of depression. He also emphasized the process of creative destruction, whereby an ensemble of technologies both creates new opportunities for economic growth and paves the way for the slowdown of growth and replacement by newer technologies. Holling and Gunderson (2002) used Schumpeter's theories in the development of the adaptive cycle to describe the changes from the conservation phase (K) to the release phase (Ω). Of three commonly identified classes of social theories of change (life-cycle representation, gradualist life-cycle and revolutionary change models), Schumpeter adhered most closely to the revolutionary change model, recognizing the four-phase properties of complex evolving systems and the tensions they generated to produce stages of growth and transformation. Schumpeter (1950) saw socio-economic transformations proceeding such that market forces controlled the r phase of innovation; institutional hierarchies, monopolism, and social rigidity controlled the K phase of consolidation; forces of “creative destruction” triggered the release (Ω) phase; and technological invention determined the source for a phase transformation to the exploitation phase (α). Such complementary theories of revolutionary change in social and biological systems provided insight for the adaptive cycle (Gunderson et al. 2002a).

Since then, the adaptive cycle has been applied to a variety of case studies from different climatic regions: for example, arid rangelands in Australia, tropical coral reefs, and wet and dry tropical forests (Gunderson and Pritchard 2002). As well, the adaptive cycle has been used to explain and interpret system behavior, not only in human–natural systems, but also in other disciplines, such as the history of business and economics, and is claimed to have universal applicability (Gunderson et al. 2002a).

Pathological states

If each of the three properties (potential, connectedness, and resilience) in the adaptive cycle is given two nominal levels, either low or high, then the adaptive cycle model uses only four of a possible eight combinations (2^3) of the three properties, and two of the other four combinations are suggested as pathological states, labeled the poverty trap and the rigidity trap by Holling et al. (2002c), which are departures from the adaptive cycle (Fig. 3). The levels of the three properties of the poverty trap and the rigidity trap are given in Table 3.

For example, the poverty trap is characterized by all three properties having low values, creating an impoverished system. Unsustainable maladaptive poverty traps, as measured by numerous resource systems that exist in a constant or recurring state of crisis, are common throughout human history (Tainter

1988, Ludwig et al. 1993). Examples of poverty traps can be drawn from natural resource-based societies that are dependent, for example, on natural forest resources (Repetto and Gillis 1988), resulting in rapid depletion of the stock of old-growth forests; or fisheries (Royce 1987), such as the Pacific sardine and Peruvian anchoveta (although the relative importance of climate and exploitation are debatable); culminating in the disintegration of whole societies (Tainter 1988) in which sources of novelty have been diminished, preventing an adaptive response. A commodity market that was uninterested in the negative externalities in economics theory led to the complete loss of soil from many Mediterranean countries (Thirgood 1981, Sala and Conacher 1998). Research in Mediterranean climates has demonstrated the cause-and-effect relationship between vegetation removal and reduced cloud formation and changes in regional climate (Lyons 2002).

Table 3. The level of each of the three variables that characterize the four pathological states

Pathological state	Potential	Connectivity	Resilience
Poverty trap	low	low	low
Rigidity trap	high	high	high
Lock-in trap	low	high	high
?	high	low	low

The rigidity trap may apply to social systems in which the members of organizations and their institutions become highly connected, rigid, and inflexible. Rigidity traps occur over time in bureaucratic systems; Holling et al. (2002c) contend that one example of a rigidity trap may be found in agro-industry, where management by command and control, in an institutional sense, has squeezed out diversity, and power, politics, and profit have reinforced one another. Conventional resource management, based on economic production targets, commonly seeks to reduce natural variation in target resources because fluctuations impose problems for the industry dependent on the resource. The two alternative states were not described by Holling et al. (2002c); however, it is proposed that one might be labeled the "Lock-in Trap" (Table 3), characterized by low potential for change, high connectedness, and high resilience. This proposition is developed below.

The metaphor of the adaptive cycle is applied to the WA agricultural region and examined for conformity with the cycle or departure into one of four pathological states, discussed later in this paper. Consideration is given to the potential for the WA agricultural region to be a reflexive SES, in which humans have foresight to prevent exceedance of biophysical resilience thresholds and to avoid pathological traps through technological or institutional novelty. Pathological traps and biophysical resilience thresholds may be avoided through human innovation that effectively redefines the system by extending the boundaries of the thresholds outward (Walker et al. 2002). Human innovation can take a number of forms, for example, technical or institutional change. In the WA agricultural region, improvements in agronomy and genetics have increased wheat production over time (Passioura 2002) and have more than made up for potential reductions in total production caused by soil salinity, which presently affects 16% of the WA agricultural region. If farmers are to continue to grow wheat and maintain profitability, wheat yield must increase at a sufficient rate to counter the combined effects of declining terms of trade, the short-term fluctuations of climate, and the negative impacts of soil salinity and other types of land degradation.

Long-wave economic cycles—Kondratiev cycles

Evolutionary cycles are ubiquitous in nature and have been identified in systems created by human society, including the economy (Tainter 1988, De Greene 1993, Carry 1996). Cyclicity in the economy was identified in at least four temporal scales (Table 4), ranging from the short-wave Kitchin Cycle of between 3 to 7 years, through the Juglar and Kuznets Cycles, to the long-wave Kondratiev Cycles of between 45 to 60 years (De Greene 1993).

There is controversy regarding the existence of Kondratiev Cycles (De Greene 1993) and their methodology of construction (Carry 1996). However, Carry (1996) critically analyzed the nature of the debate surrounding the deterministic or probabilistic determination of the Kondratiev Cycles and concluded that Kondratiev's treatment of uncertainty in the conception of the long-wave economic cycle is consistent with modern authors and provides evidence for the existence of such cycles. In addition, Berry (1991) made an extensive analysis of economic data and found new evidence for the reliability of long-wave economic theory.

Table 4. Four temporal cycles identified in the economy

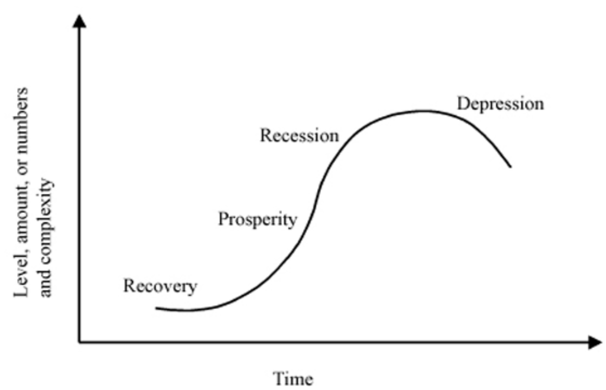
Cycle	Approximate duration (years)
Kitchin, or business cycle	3–7
Juglar	8–10
Kuznets	15–25
Kondratiev	45–60

The Kondratiev Cycles show the behavior over time of the evolution of modern industrial societies, a phenomenon that shows patterns of boom and bust, characterized by four phases (prosperity, recession, depression and recovery) shown in Fig. 4. The Kondratiev upwave consists of the phases of recovery and prosperity and the Kondratiev downwave consists of the phases of recession and depression. Table 5 summarizes the four Kondratiev cycles that have been described between 1785 and 2000, each cycle lasting from 41 to 63+ years. Conceptually, the phases of the Kondratiev Cycle and the adaptive cycle may be compared and such a comparison is given in Table 6. For example, the recovery phase in the Kondratiev cycle corresponds to the reorganization to exploitation phases (α-r) of the adaptive cycle. Once a pattern is formed, it entrains a complex set of related variables. The consequences determine, in part, how resilient the pattern is and how robust it is to modification by policy or exogenous change.

CONCEPTUAL MODEL OF THE DYNAMICS OF THE WESTERN AUSTRALIAN AGRICULTURAL REGION

Conceptual models are representations of our present understanding of the overall system of interest and are an important first step in problem formulation in general systemic analysis, including resilience analysis (Walker et al. 2002). The historical narrative of the WA agricultural region, combined with the principles of resilience theory and system dynamics, has been used to identify the important causal relationships and structure of the system at the macro scale. The model presented in the following sections is the present state of an iterative evolutionary process in model hypothesis testing. The important point to understand is that, by standing back far enough from the problem, the problem within its broader context comes into focus and it becomes clear that the interrelationship of the variables is responsible for the patterns of behavior. Gunderson et al. (2002b) proposed that the organization of regional resource systems emerges from the interaction of a few variables, and suggested that they may be as few as three and no more than six. In developing our conceptual model, we were guided by this proposition.

Fig. 4. Heuristic model of the Kondratiev cycle showing the four phases: recovery, prosperity, recession, and depression.



The history of the Western Australian agricultural region, 1889–2003

A number of historic accounts of agriculture in Australia and Western Australia (Burvill 1979, Australian Bureau of Statistics 1979–1997, Davidson 1981, Burke 1991, Hamblin and Kyneur 1993, Australian Greenhouse Office 2000, Beresford et al. 2001, Frost and Burnside 2001) were used to extract a summary of events in the WA agricultural region

(Table 7). In the development of agriculture in Western Australia, Burvill (1979) identified six distinct temporal periods between 1829 and 1979. These are labeled as (1) the First 60 Years (1829–1889), (2) the Move Forward (1889–1929), (3) Depression and the War (1929–1945), (4) Recovery (1945–1949), (5) the Rural Boom 1949–1969, and (6) A Troubled Decade 1969–1979. We have used these temporal periods because they are convenient categories for identification of successive iterations of the adaptive cycle in the region, discussed below. Three additional periods have been added to cover the period from 1979 to 2003; these are labeled Environmental Awareness (1980–1990), the Decade of Landcare (1990–2000), and the Turn of the Century (2000–2003+) (Allison and Hobbs, *submitted*). Figure 5 presents a chronological sequence of those factors considered to be the most significant and influential in either changing the direction of policy or identifying the direction of change in NRM policy between 1889 and 2003. A brief summary of the history is given in Appendix 1.

Table 5. The four Kondratiev cycles from 1785 to 2000+, showing the duration of the four phases and the dominant new technologies or industries in each cycle

Kondratiev cycle	Recovery	Prosperity	Recession	Depression	Dominant new technologies or industries	Duration (years)
1		1785–1815	1815–1825	1825–1840	steampower, textiles	55+
2	1840–1860	1860–1873	1873–1886	1886–1896	coal, steel, railroads	56
3	1896–1905	1905–1920	1920–1929	1929–1937	oil, electricity, chemicals, automobiles	41
4	1937–1948	1948–1970	1970–1990?	1990?–2000?	aircraft, electronics, computers, control systems, rockets and missiles	63+

Source: adapted from De Greene (1993)
Kondratiev upwave consists of the recovery and prosperity phases
Kondratiev downwave consists of the recession and depression phases

Table 6. Relationship between the phases of the Kondratiev Cycle and the Adaptive Cycle

Kondratiev Cycle	Adaptive Cycle
Recovery	α–r
Prosperity	r–K
Recession	K–Ω
Depression	Ω– α

Characterization of the system

Part of problem formulation is the dynamic characterization of the problem, that is, as a pattern of behavior over time. This is done through a set of reference modes and other descriptive data that show how the problem arose and how it might evolve in the future (Sterman 2001). In this study, we selected five variables, consistent with the “Rule of Hand” (Holling et al. 2000) and the first of four provisional propositions (Table 1) about SESs (Gunderson et al. 2002b) that, we propose, characterize the problem dynamically. They were selected from the ecological, economic, and social systems, and are (1) the area of productive land, (2) the number of agricultural establishments, (3) farmer age, (4) farmer terms of trade, and (5) the wheat yield. In systems analysis, it is the structure of the variables that gives rise to the behavior of the system.

Ecological reference modes of system behavior dynamics of land use

The conceptual model of the dynamics of land-use change patterns is shown in Fig. 6. The land-use system in the WA agricultural region can be classified into six major land-use types:

(1) primary native vegetation: natural native vegetation at or near climax, or regenerating by natural stages of succession;

(2) cropland: cultivated and planted annually with food crops;

(3) pastureland: covered with grasses, legumes, or herbaceous species for grazing livestock;

(4) commercial plantation: land deliberately planted and maintained in tree monoculture and often in exotic species;

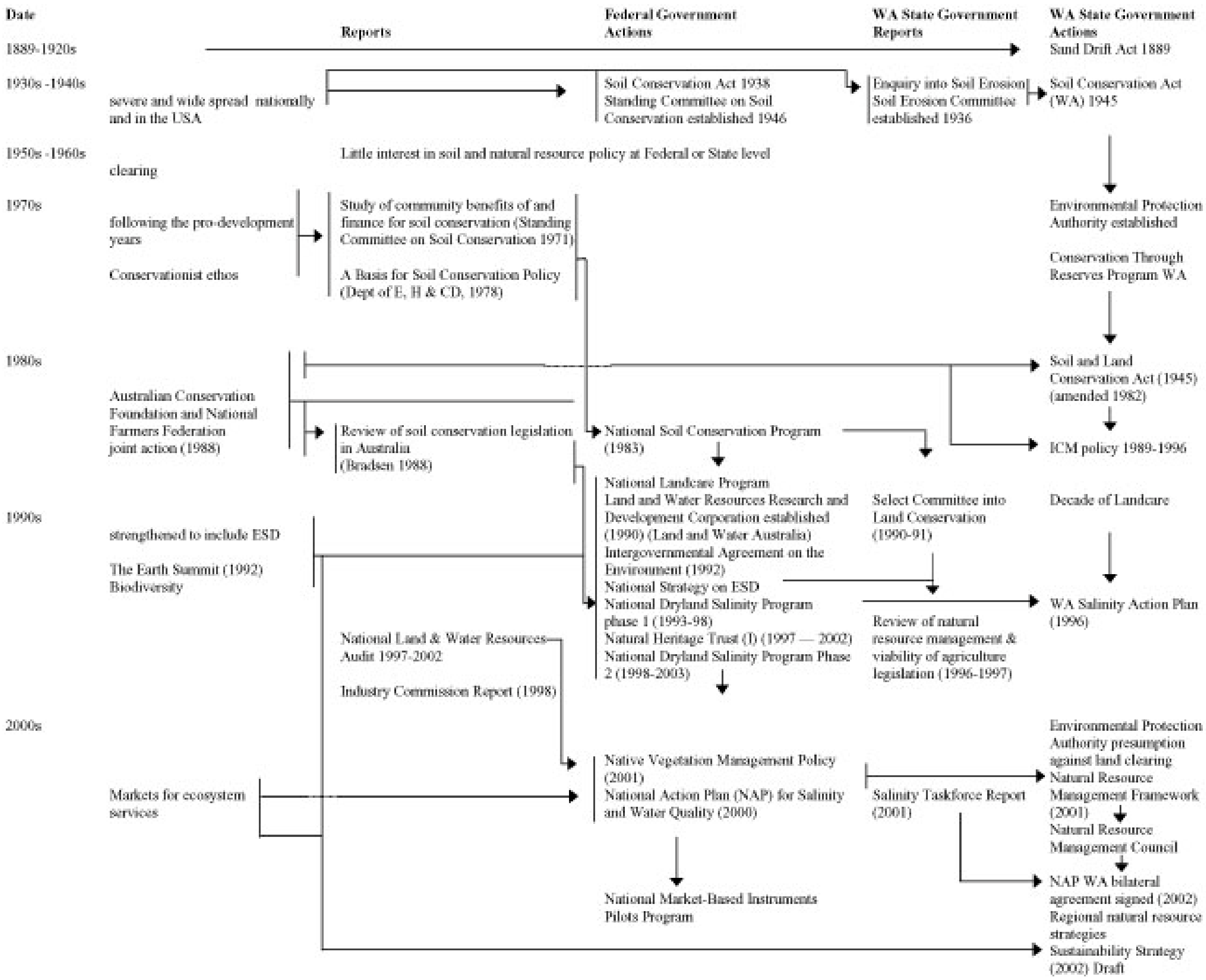
(5) secondary native vegetation or regrowth: land cleared in large areas (often former crop or pasture land) left to natural succession, usually sufficiently degraded not to return to primary native vegetation (in the WA agricultural region the rates of return are unknown); and

(6) unproductive land: land that has been so degraded that it produces virtually no useful species. Usually supports very little growth and will not return naturally to categories 1 or 5.

Table 7. Time course of natural resource management in the WA agricultural region (1889–2003) as represented by successive iterations of the adaptive cycle

Date	Development history	Cycle	Duration (Years)	Phase Social–economic	Event or practices that characterize the phases
1889–1929	The Forward Move	1	40	exploitation (r) conservation (K)	Land settlement and expansion of agricultural areas, high wheat and wool prices
1929–1945	Depression and War	1	16	release (Ω)	Low wheat and wool prices, farms abandoned, drought
1945–1949	Recovery	1	4	reorganization (α)	Farm amalgamation, technological and scientific innovation
Years per cycle: 60					
1949–1969	Post-war Boom	2	20	exploitation (r) conservation (K)	Expansion of agricultural lands, favorable climatic conditions, cheap and abundant fuel, overproduction
1969–1979	A Troubled Decade	2	10	release (Ω)	Market regulation (wheat quota introduced), widespread land degradation, including salinity, drought
1980–1990	Environmental Awareness	2	10	reorganization (α)	Habitat protection (Conservation through Reserves), Australian Conservation Foundation and National Farmers Federation alliance
1990–2000	Decade of Landcare	2	10	reorganization (α)	Institutional reorganization through partnership programs at national, state, and regional levels for natural resource management
2000–?	The Turn of the Century	2	3+	reorganization (α)	Industrial agriculture, increase in use of market-based mechanisms
Years per cycle: 63+					

Fig. 5. Influential events and drivers in the history and policy of natural resources relating to agriculture.



The predominant progression in the WA agricultural region is from primary native vegetation to productive broadacre agricultural system. Although persistent as an intensive agricultural system for more than 100 years, the land use has been dynamic. From a landscape dominated by native vegetation in the late 19th century, it became virtually treeless by the 1990s. The history of the dynamics of land-use change is illustrated by classifying and identifying the temporal patterns of land-use change between 1900 and 2000 and predicted changes to 2050 (Fig. 7). The greatest rates of clearing (Fig. 8) occurred in three phases, the first from 1900 to 1930 (144 000 hectares per year), the second from 1949 to 1969 (364 000 hectares per year) and the third from 1969 to 1994 (164 000 hectares per year) (Burvill 1979, Beeston et al. 1994). In the WA agricultural region, significant areas of non-productive land, due to inundation and soil salinity, appeared within 100 years of the first major phase of land clearing for agriculture. Sixteen percent of the area had developed soil salinity by 2000 and is now largely unproductive (National Land and Water Resources Audit 2001). One very important point is the time delay between the direct cause, land clearing, and the effects, inundation and the appearance of soil salinity, a slowly emerging ecological variable.

Temporal separation between cause and effect often contributes to the intractable nature of problems (Meadows 1982). Recently, some land-use change from cropland to commercial forestry has occurred, in part to combat the hydrological imbalance. However, this represents a very small proportion of the total land area and occurs mostly in areas with rainfall greater than 600 mm; it will have no positive effects for large areas that are or will become salt affected. In 2000, the Environmental Protection Authority (EPA) took a strong position with a presumption against land clearing in the southwest of Western Australia for agricultural purposes and, in recent years, most applications referred to the EPA by the Commissioner of Soil Conservation have been denied.

Fig. 6. A conceptual model of land-use change patterns in the Western Australia (WA) agricultural region. The return of land to secondary native vegetation in WA is under investigation.

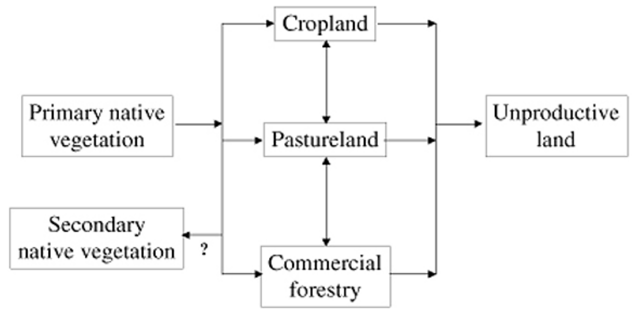
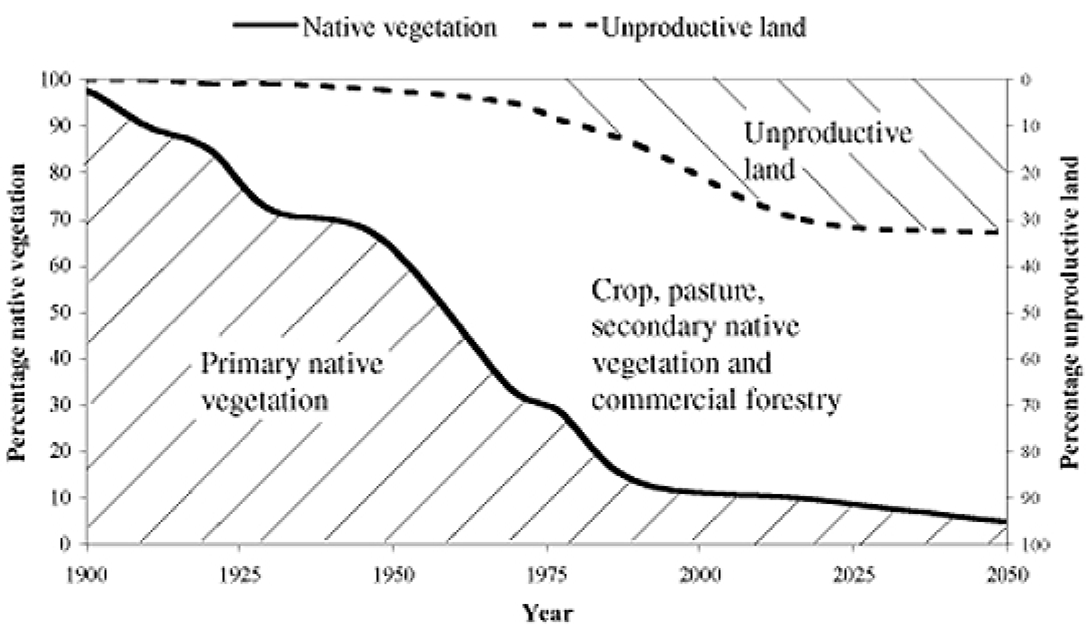
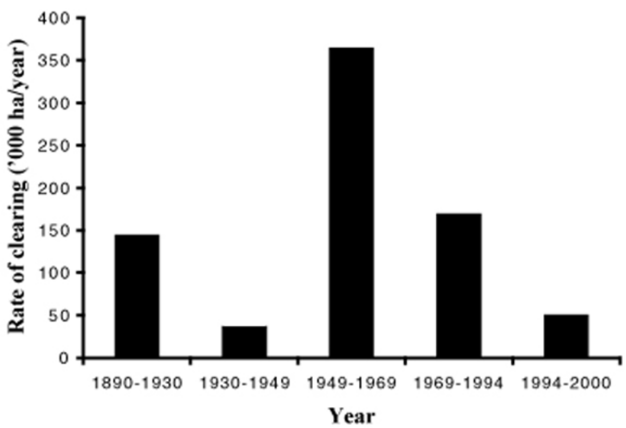


Fig. 7. Changes in land-use in the Western Australia (WA) agricultural region, 1900–2050. (Sources:* 1900–1994 Beeston et al. (1994) and Burvill (1979); ^ Predicted 2000–2030 Government of Western Australia 1996).



The condition of remaining native vegetation will continue to decline due to other effects including salinity, grazing and pest invasions and many more trees will eventually be lost from the landscape (Saunders et al. 2003). The line for the percentage of land use that is unproductive is based on values for agricultural land at risk from salinity in 2000 and the predictions of the extent of salinity (33%) in 2050 and 2300 are based on groundwater trends and "best guess" future land use (Hatton 2003, Hodgson et al. 2003). Hydrological equilibrium is predicted to be achieved between 2030 to 2050 in some areas on the western edge of the agricultural region but may take as long as 300 years in the eastern parts of the region (Hodgson et al., *unpublished*). The prediction of the amount of land that will become unproductive (33%) is based solely on the effects of salinity and does not include any other forms of land-degrading processes that may partially reduce soil fertility, such as acidification, sodicity, and erosion (National Land and Water Resources Audit 2002). To place this rate of change in the global context, one estimate of the total conversion of primary native vegetation to cropland worldwide was 10.7 million km^2, of which 20% was subsequently abandoned (Lambin et al. 2001).

Fig. 8. Rates of clearing land in the Western Australia (WA) agricultural region, 1890–2000. (Sources: Burvill (1979), Beeston et al. (1994)).



Social-economic reference modes of system behavior

The socio-economic variables used in this conceptual model of the WA agricultural region were wheat yield, farmer terms of trade, and the number of agricultural establishments between 1900 and 2000 (Fig. 9 a, b, and c, respectively). Farmer age is also discussed in the text.

Wheat yield (economic production target)

Since the 1960s, farmers have faced constantly increasing costs and declining terms of trade, countered by increased productivity and efficiencies in recent times. Increases in crop production since 1960 have come from increases in yield (National Land and Water Resources Audit 2002). The trends for wheat yield for Australia and Western Australia between 1900 and 2000 (Hamblin and Kyneur 1993, Passioura 2002) are shown in Fig. 9a. The productivity gains for Australia occurred in three phases, 1900, 1950, and 1990, the greatest gains being achieved since 1990 (Passioura 2002). The significance of the increasing wheat yield is that it must be viewed against the economic background. If farmers are to continue to grow wheat, productivity must increase at a sufficient rate to counter the combined effects of declining terms of trade, the short-term fluctuations of climate, and world commodity prices. It was reported that Australia had the lowest rate of increase in wheat yield between 1950 and 1990 compared with its competitors in the world market (Hamblin and Kyneur 1993). The profitability of Australian agriculture, with its orientation towards export trade, remains closely linked to price fluctuations in international markets (Australian Greenhouse Office 2000). The trend of increasing wheat yield whilst achieving productivity targets under conditions of command and control policy masked other social and ecosystem variables that indicated a system in a state of change.

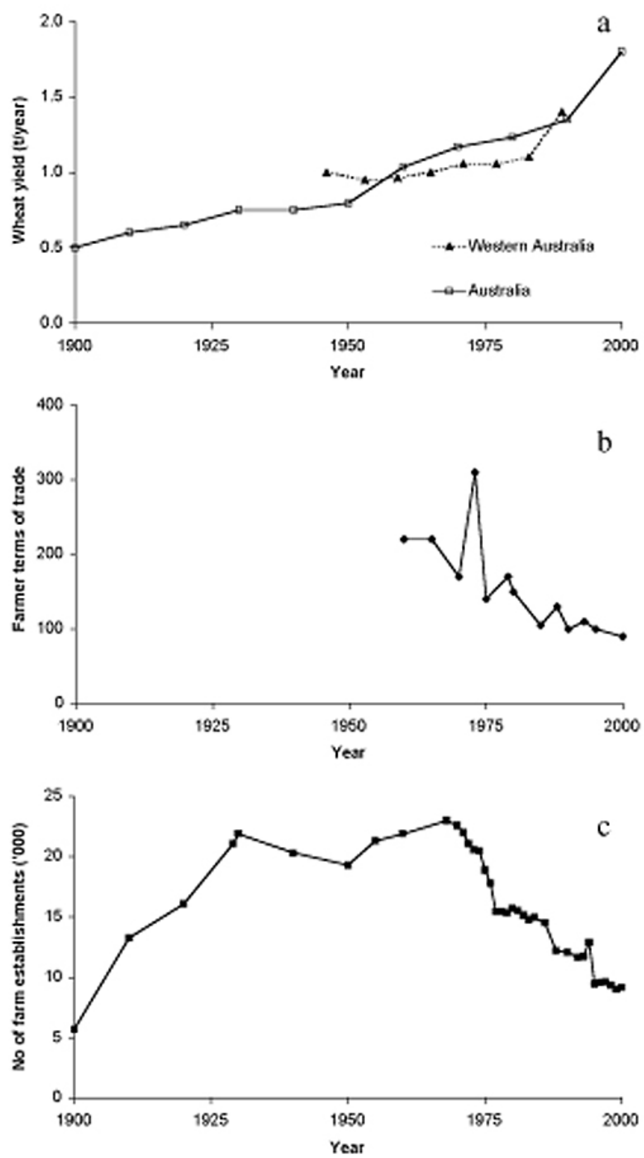
Agricultural terms of trade

Declining agricultural terms of trade (Fig. 9b) (falling prices of agricultural commodities compared with the price of farm inputs) have made it increasingly difficult for small and marginal enterprises to maintain their livelihoods solely by engaging in agricultural activities. Large numbers of farmers in broadacre agriculture in Australia had a zero or negative profit at full equity on the basis of a 5-year average to 1996–1997 (National Land and Water Resources Audit 2002). With no profit, there is little opportunity to adopt sustainable land practices that may include land-use change, and may be potentially risky and costly to adopt in the short term (Cary et al. 2002). Clearing is motivated by the pursuit of agricultural profit, either for immediate returns or for future gains through improved land values (Burvill 1979, Australian Greenhouse Office 2000), and is a practice considered to be one of the greatest natural resource threats in Australia.

The number of farm establishments and farmer median age

The number of farms in the WA agricultural region rose to a maximum of approximately 23 000 in 1968 (Fig. 9c). Since then, this number has been declining. It dropped to approximately 9 000 in 2000. Although the lifestyle of some farmers with small enterprises became less economically viable, farm adjustments and restructuring did not always follow the neo-classical course of farm exits and property amalgamation (Barr 2000), and the decisions are classed as being boundedly rational (Walker et al. 2002), made with imperfect knowledge and context specific. On many farms, the main adjustment was abandoning the expectation of intergenerational transfer; coupled with this, there was a deferral of farm exit in response to a perceived lack of alternatives available to broadacre operators. Consequently, the number of older farmers increased. In Western Australia, the mean age of farmers increased from 48 to 52 years between 1990 and 2000 (ABARE 2002). A similar trend was also recorded for changes in farmer age throughout Australia (Barr 2000). Barr (2000) contends that there will be a major restructuring of farming enterprises caused by the unsustainable rise in farmer age as older farmers exit the industry.

Fig. 9. Social and economic reference modes: (a) Trends in wheat yields in Australia and Western Australia between 1900–1994 (sources: Hamblin and Kyneur (1993), Passioura (2002)). (b) Trend in Australian farmer terms of trade between 1960–2000. Farmer terms of trade: the ratio of the index of prices received by farmers to the index of prices paid by farmers. Reference year 1997–1998 =100 (source: National Land and Water Resource Audit 2002). (c) Trend in the number of agricultural establishments in Western Australia agricultural region between 1900–2000 (sources: 1900–1976 Burvill (1979), 1977–1994 Australian Bureau of Statistics (1979–1997), 1995–2000 ABARE (2002)).



The reference modes show an increasing area of unproductive land, declining terms of trade, rapidly declining number of farm establishments and an increasing average age of farmers over time. Although the wheat yield is increasing, this increase is not as strong as in other countries that compete in the global marketplace. These features were found to be common characteristics of commodity systems (Sawin et al. 2003) and are considered to be examples of diminished sources of novelty, which increase vulnerability of the system, the fourth provisional proposition about SESs (Table 1). The reference modes, together with the historical account, were used to identify the adaptive cycles in the region, described below.

AN ADAPTIVE OR PATHOLOGICAL SYSTEM?

The events or practices that characterized the different phases of the adaptive cycles are summarized in Table 7. The management history of the region between 1889 and 2003 can be described by two iterations of the adaptive cycle, the first occurring over the 60 years between 1889 and 1949, and the second over the 63+ years between 1949 and 2003.

First cycle

For the first 60 years of the Western Australia colony's history, pastoral activities were developed ahead of agriculture; only 28 000 ha were developed for cropping by the 1880s. In the period labeled the “Move Forward,” Western Australia government policy drove development; railways were initially constructed along valley floors and, consequently, the land adjacent to the railways was cleared for agriculture first (Frost and Burnside 2001). Government institutions, such as the proclamation of the Homesteads Act (1893) and the Land Act (1898) that set out the concessions and conditions for obtaining farmland, enabled land-use planning and accelerated land release for agriculture. By the late 1920s, 50% of the area now identified as the WA agricultural region was cleared of native vegetation. Prices for both wool and sheep were high. The features of this period are characteristic of the forward loop (r-K) of the adaptive cycle. In the adaptive cycle, this is explained by an increase in the capacity or potential for change and an increase in the degree of connectivity among the variables (Table 2). However, variables may become over-connected, reducing resilience, and the cycle moves into the backloop. The 16-year period between the Great Depression of the 1930s and WWII was marked by hardship in agriculture, with low potential for change and low resilience. Record low prices for wool and wheat and dry climatic conditions caused farms to be abandoned, producing conditions in which novelty could occur. Recovery began in 1945, major advances in technological and scientific innovation occurred, and there was also institutional change, such as farm amalgamation to make farm sizes more viable. The internal structure was low, which allowed the potential for change to increase. The resilience to external disturbance was also greater at that time. This completed one iteration of the adaptive cycle (Table 7).

Second cycle

The second iteration and the frontloop of the adaptive cycle began with the Post-war (WWII) Boom. Fuel was cheap and abundant, labor was also abundant, and these factors combined with favorable climatic conditions and a development-orientated Government to produce a rapid expansion of agricultural lands. The rate of clearing increased from 36 000 ha a year between 1930 and 1949 to 364 000 ha a year between 1949 and 1969 (Fig. 8), which increased the area of cleared land from approximately 50 to 90% of the region. The major commodities experienced high prices in the 1960s (Burvill 1979, Hamblin and Kyneur 1993), resulting in overproduction on the global market of wool and wheat. This period is represented by the exploitation to conservation phases (r to K) of the adaptive cycle. There followed a “Troubled Decade,” marking the beginning of the backloop of the adaptive cycle with the release phase, in which the Australian Government introduced quotas to regulate the production of wheat, and prices fell. Land degradation was perceived as a greater problem and there was a drier than average period. From 1980 onward, there was massive change and reorganization in institutions at the regional level, marking the beginning of the reorganization phase and continuing the backloop through to the present. Two marked examples of institutional change are the unprecedented alliance of the Australian Conservation Foundation and the National Farmers Foundation, who joined together to try to combat the growing problem of salinity. The need to allocate lands for conservation was also recognized at this time and was implemented through the Conservation Through Reserves Program.

In the 1990s, further institutional reorganization occurred through the construction of partnerships across scales in government from regional natural resource groups to state and national organizations. In 2003, institution restructure continues, including the development of policy that incorporates economic solutions for NRM. Increasingly, market-based mechanisms and creation of property rights for ecosystem services are being promoted for NRM policy (National Action Plan for Salinity and Water Quality 2002a).

Lock-in Trap

The WA agricultural region is an ecological system whose species mix has been transformed for commodity production. The area of original native vegetation was reduced to less than 10% of its original extent. Hydrological modelling (Hodgson et al., *unpublished*) predicts the continuing loss of area of native vegetation, further reducing biodiversity. The ecosystem has been transformed from a species-rich system to a specialized system with low species richness and loss of system function. There are high costs to maintain productivity function and ecosystem function. For example, agriculture supports an extensive industry to maintain productivity, including the costs of fertilizers, new wheat varieties, and agronomy to mitigate soil degradation including acidification and soil erosion, drainage, and revegetation (Passioura 2002). An extreme example of the costs of maintaining ecosystem function is provided by Toolibin Lake and its catchment in the WA agricultural region (Toolibin Lake Recovery Team and Toolibin Lake Technical Advisory Group 1994). In 1990, the lake was listed as a wetland of international importance under the Ramsar Convention and was selected as a Natural Diversity Recovery Catchment in 1996. Both increasingly saline surface water inflows and rising saline groundwater seriously threaten the biodiversity values and the ecosystem function of the lake. The protection of these functions requires a complex integrated management strategy comprising a number of actions, including changing agronomy practices in the catchment, surface water management, and increasing groundwater discharge with groundwater pumping to lower the watertable below the lake (Wallace 2003). The WA agricultural region has lost important system components involved with the hydrological cycle and the system has been irreversibly modified.

The reference modes portray the WA agricultural region as a system with resource depletion, environmental pollution, and social decline. Could we conceive that the WA agricultural region is in a poverty trap or alternatively in one of the other pathological states? Holling et al. (2002c) proposed that an adaptive cycle will cease to be adaptive because the potential and diversity have been eradicated by misuse or an external force, and they use as an example the degradation of savannas that enters an irreversible eroding state (Holling and Gunderson 2002). Human activity such as agriculture may “mine” the resource (for example, soil (Passioura 1999)) in a lock-in situation, in which the land manager is under greater and greater pressure to produce more, while the economic return from the land diminishes, either because of lowered productivity, reduced terms of trade, or both. Ultimately, the ecological system will become severely impoverished as the variables and players in the commodity system become more tightly connected, causing the resilience to increase because the system has reached such a depauperate state that it is extremely stable. Greater connectivity emerges from complex systems of relationship and dependence between producers and the agro-industry they support. This situation is represented by one of the remaining two unaccounted pathological states. This state we have labeled “lock-in” which, in economics, describes an industry that has so much “sunk-costs” that it may continue to degrade the resource it relies upon until the capital is totally removed. The lock-in pathological state has low potential for change, high connectivity, and high resilience. High resilience would mean a great ability for the system to resist external disturbances and persist due to the depauperate ecological system.

Scale and dynamics

The duration of each of the two cycles described above is synchronous with the third and the fourth long-wave economic Kondratiev cycles. The upwaves of the Kondratiev cycles shown in Table 5 are in the order of 50–60% of the total duration of the cycle, and this is consistent with the duration of the forward loop in the two adaptive cycles that describe the behavior of the WA agricultural region. The model for the adaptive cycle heuristic was developed for biological systems in which the characteristics for biological processes may be described by means of a slow build-up of resources in the frontloop in the order of 75% of the total time, as suggested by Walker (2002), or capital that can be lost in one catastrophic event. However, the driving variables in the WA agricultural region were the long-wave economic cycles that do not conform to the organismic model of long, slow accumulation of capital and comprise between 40–60% of the total cycle time.

Macroeconomics and technological development were the prime drivers behind clearing native vegetation in the development of agricultural land in Western Australia, as promoted and sanctioned by government policy. The duration and structure of the two cycles in the WA agricultural region, with an area of 14 million ha (Legislative Assembly Western Australia 1990), is inconsistent with those found for the Goulburn Broken Catchment (Walker et al. 2002) with an area of 2.4 million ha (Goulburn Broken Catchment Management Authority 2002). In a resilience analysis of the dynamics of the Goulburn Broken Catchment in Victoria, Australia, stakeholders identified an historical profile of major events and developments in the catchment (Walker et al. 2002). These factors were, in general, socio-economic; from them, Walker et al. (2002) identified four periods of major changes over 150 years (1750–2000) and suggested that a general pattern, where 75% of time is spent in the forward loop (exploitation to conservation phases, with slow accumulation of capital), may be typical for regional systems. However, this finding of Walker et al. (2002) is inconsistent with the pattern found in the WA agricultural region in which, over its 114-year history, only 66 and 48% of the time was spent in the forward loop or the upwave of the Kondratiev cycle, respectively. One possible explanation for the temporal differences is the difference in spatial scales of the two regions which may have resulted in a greater influence of more local events in the Goulburn Broken region; for example, the influence of the depression of the 1890s before the significant agricultural development in Western Australia, regional drought and dust storms, and poor success of stone fruit, for example. The regions also differ markedly in biophysical characteristics. On first appearance, although not directly comparable, the durations of the adaptive cycles between the WA agricultural region and the Goulburn Broken Catchment may appear inconsistent, but the authors believe that further detailed analyses and additional case studies would be beneficial and add strength to the argument.

Thresholds, stability, and resilience

A key aim of resilience analysis (Walker et al. 2002) is to identify thresholds, their nature, and what determines how they prevent the system from moving into an undesirable system configuration. Ecosystems of renewable resources threatened by the interactions of economic and social systems may lose resilience (i.e., the ability to absorb shocks and disturbances) and may suddenly break down or settle into a different system with less resilience (Gunderson and Holling 2002). This implies that there are thresholds at which the levels of stress will lead to the disruption of the system, the first of the six assumptions ascribed to complex systems (Walker et al. 2002).

The ecological buffering that helps a system cope with surprise (Folke et al. 2002) has been lost from the WA agricultural system, that is its resilience, the tendency of a system to remain unchanged, or nearly unchanged, when exposed to perturbation (Hansson and Helgesson 2003). For example, loss of perennial vegetation and consequent elevation in watertables saturates the subsoil, reducing its ability to absorb further rainfall and its buffering capacity, particularly under conditions of greater than average rainfall. Often a system can be stabilized by increasing the size of a buffer (Meadows 1970) but, like the hydrological system, it is a physical entity the size of which cannot be changed. As a result, flood events have occurred, such as was experienced in the Moore River catchment in the northern area of the WA agricultural region in 1999 (Water Studies Pty Ltd 2000) and in the Avon River catchment in 2000 (Hatton and Ruprecht 2001). In addition, the predicted changes in annual total rainfall and distribution for the southwest of Western Australia, in the form of extreme events, as a consequence of global climate change (CSIRO 2001) may create periodic crises that could have an overwhelming impact on the SES. When there is little or no ecological buffering capacity, or it has been exceeded, the control shifts to regional economic, demographic, or social factors. The potential impact could be a retraction of the area under annual cropping, with areas being abandoned or a threshold being reached in the number of farmers, as hypothesized as a major restructuring of the rural demographics by Barr (2000), with enterprises at the margins exiting the agricultural industry.

Agricultural intensification was a major feature of the second adaptive cycle. It was agricultural intensification involving changes in technology that largely masked the degradation of natural resources and helped to produce the perceived stability in the system. Novelty in technology effectively redefined the system and thus prevented the whole system from crossing critical thresholds and changing from one stable state to another. Even with the ability to redefine the system by creating novel futures through technological advances, this system will still rely on a continuous stream of new technologies, institutions, or social adaptations to add resilience and maintain the adaptive capacity of the whole system.

Technological advances make single variable interventions or create interventions without regard for their impacts on other parts of the systems. This has been described as human propensity to focus on “single cause-and-effect solutions” (means–ends logic designed to solve a particular problem) (Westley et al. 2002), and this has serious implications for continuing resource misuse. For instance, as a solution is found for each problem, it will create other effects, referred to as side effects or perverse and unintended effects. In economics, side effects are often called externalities and an important component of ecological economics is estimating the value of these externalities (Costanza et al. 1997). The creation of new institutions (e.g., policies and markets) is being promoted in Australia as one way to help to account for the full costs to society of NRM (Agriculture, Fisheries and Forestry - Australia 2001, National Action Plan for Salinity and Water Quality 2002a).

Policy responses

In the WA agricultural region, we have shown that the time-dependent nature of the problems in economic–ecological systems, feedback concepts in systems theory, the transformations in interrelated human and natural systems, and mismatches of scale between human responsibility and natural interactions have contributed to a Lock-in Trap. An example is the effects of clearing land, which were known in the early 1900s but not treated seriously until the 1990s. Reactive policy and command and control management in response to crises has dominated the WA agricultural region, each new policy responding to the effects (side effects or unintended effects) of the past policy. This is a well-known phenomenon in system dynamics, “policy resistance” (Sterman 2001) that is also described as the bite-back paradox in large-scale systems (Gunderson et al. 2002c). A sequence of three types of NRM policy can be recognized over time in Western Australia (Allison and Hobbs, *submitted*). Command and control or regulatory policy was in place from the 1890s until the 1990s. The second policy approach was voluntary participatory policy encouraging partnerships of institutions at catchment, regional, state, and national levels. The third approach, now promoted at the national level, involves market-based mechanisms to manage natural resources (National Action Plan for Salinity and Water Quality 2002b) in response to a perceived lack of property rights, which is proposed as a cause of natural resource degradation. It is no longer reasonable to assume that environmental feedbacks are not a dynamic component of the economic system (O'Neill et al. 1998). This is not a new concept and many papers in the literature identify the link between the economic and the ecological system, for example Daly (1991).

When faced effects that are perceived as crises, management options fall into one of three general classes of response. The first is to do nothing and wait and see if the system will return to some acceptable state while sacrificing benefits of the desirable state. The second option is to actively manage the system and try to return it to a desirable stability domain. The third option is to admit that the system is irreversibly changed, and hence the only strategy is to adapt in a world characterized by crises and shifting stability domains. All three of the responses were seen sequentially in the WA agricultural region. The problem of soil salinity was known early in the history of the WA agricultural region and for economic, social and political reasons the Government chose to ignore the scientific advice and released land for agriculture in areas known to be susceptible to salinity and in areas known to be marginal for agriculture because of both climatic variability and poor soil characteristics. The second response was to put in place actions directed at fixing the symptom (the bite-back phenomenon), as opposed to actions to address the systemic causes of the problem. For instance, many tree planting programs designed to alter the changing hydrological patterns failed and advice on where and what to plant changed as our scientific understanding of the hydrological system improved.

The third and current response contains a number of strategic actions aimed at adapting to the current situation. One strategy of current policy is that of environmental triage, in which it is acknowledged that some areas will not be able to be managed positively and no further pubic funds will be directed to these areas. The second strategy is the introduction of market-based instruments. This is based on the premise that many of the changes including biodiversity loss are caused by inadequate institutions, in particular ill-defined property rights (Hanna and Munasinghe 1995) and the impact of this on resource use. The design of institutions such as property rights is a major thrust in Australia natural resource policy. Young and McCay (1995) argue that by adding flexibility and renewable structures to property right regimes they can be adapted to incorporate social and environmental objectives, and this is one way to increase resilience. However, the use of market-based instruments for NRM is in its infancy and further research is required to better understand the relationships between various property rights regimes and the dynamics of complex systems where the interactions between variables occur at different temporal and spatial scales.

Nonetheless an important research question would be “Are there times within the economic cycle that provide times of greater leverage for different types of policy?” In other words, is it possible to create policies that are most appropriate for the dynamics of the system; “Let the policy fit the time.” In the agricultural industry, times of rapid change and restructuring may be the most appropriate period to implement policies that create the greatest change to meet the desired objectives of society; for example retiring severely degraded land, allocating land for conservation of biodiversity and the maintenance of ecosystem services. This may be particularly relevant if there is a trend away from the family farm to the corporate far, which is able to adopt precision farming methods which can identify areas which give little return or incur a cost to the farmer (Passioura 2002). Such areas may be retired out of production and planted for biodiversity and ecosystem function benefits. Alternative policy approaches which have met with some success in achieve sustainable resource use, in specific circumstances, take the form of social institutions such as supply and production limits, certification for best practices, tax and payments based on stewardship that expand the goals of the natural resource economy to encompass more than the standard definition of efficiency (Sawin et al. 2003).

CONCLUDING REMARKS

Natural resource problems are characterized by increasing complexity and unprecedented connectivity both within scales and across scales. Conventional environmental decision-making methods have been unsuccessful in resolving these problem situations because of our lack of understanding in certain areas of system science, discussed in the introduction. We proposed that the use of a number of different tools increased our understanding the problem situation, from an epistemological perspective.

In this paper we have made a diagnosis of the current situation of WA agricultural region by applying a systemic approach. We developed a conceptual model of how we perceive the problem situation. The conceptual model was composed of the history of the system, the reference modes that characterized the behavior of the system over time, and their interpretation with reference to long-wave economic cycles and the adaptive cycle. The development of the history was the first important step in an examination of the SES but histories tend to be static and event orientated. However, we overcame this static interpretation by constructing reference modes and interpreting the behaviour through the use of the adaptive cycle metaphor and the Kondratiev cycles. Our conclusion was that the two adaptive cycles described in the WA agricultural region were synchronized with the 3rd and 4th Kondratiev cycles. Because the Kondratiev Cycles are based only on economic and political behavior, the inclusion of resilience theory moves beyond the economic and political behavior of the system and requires causal explanations not only for the economic cycles but also for the ecological and social behavior of the system. The integration of these tools has shown not only the dominance of the long-wave economic cycle in the WA agricultural region but also how the economic cycles composed of fast moving variables have been largely decoupled from the slow moving ecological variables.

We suggest that the current state of the WA agricultural region is the balance between those processes that erode resilience and those processes that have maintained it through the expansion of the thresholds. The continuing degradation of natural resources shown by the reference modes is a syndrome that involves the breakdown of several resilience mechanisms. The changes in land-use and the ensuing natural resource degradation are rooted in economic, demographic and social changes that link the variables in the ecological system to those in the social system. We showed that resilience in the WA agricultural region was derived from functional reinforcement across and within scales, and the adaptive capacity from across systems through interaction between the social-economic system and the ecological system. We claim that the driving forces in the dynamics of the WA agricultural region were macroeconomics mediated to some extent by institutional factors such as government policy and markets.

Through the application of the metaphor of the adaptive cycle, Holling et al. (2002a) proposed that ecological collapses and the subsequent need to innovate, create, reorganize, and rebuild, are inevitable consequences of human interactions with nature. The WA agricultural region exhibits the common pattern of westernized commodity systems in which the stabilization of the agro-ecosystem (one system) has led to the progressive decline of the whole system. The adaptive cycle metaphor is applicable to the WA agricultural region, has shown the sequential progression between the phases that maximize production and accumulation and the phases that maximize invention and reassortment in the socio-economic system. We propose that successive cycles in the socio-economic system will continue to impact on the slow ecological variables reducing the potential or capital through time. However, we might ask the question "Is it possible for the system to escape the Lock-in Trap?" For this we have to make further inferences from resilience theory.

The application of proximate drivers (policy instruments) aimed at the mitigation of any or all of the three symptoms of the commodity system may produce short-term changes. However, as described above, policy resistance will most likely occur. In contrast, for systemic change to occur, Gallopin (2002) suggests that three pillars of decision making, willingness, capacity and understanding, must be applied. Any change in these three areas will require the application of ultimate drivers that shape the fundamental structure of values, knowledge and empowerment.

Using the metaphor of the adaptive cycle, the Lock-in Trap is characterized by low potential for change, high degree of connectedness among the structural variables and, because of the extremely degraded state, a high resilience to change. The system has become vulnerable as sources of novelty have been eliminated and as functional diversity and cross-scale functional replication are reduced. This suggests that the forces of the commodity system will continue to produce the three symptoms, the erosion of the resource base, increasing environmental pollution and continuing social decline within the region, all else being equal.

Responses to this article can be read online at:
http://www.ecologyandsociety.org/vol9/iss1/art3/responses/index.html

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APPENDIX 1. A Brief Summary of the History of the Western Australia Agricultural Region

In the history of Western Australia, agriculture and natural resource policies were reactive, in response to reports about the declining condition of soil, land, or water. Figure 5 presents a chronological sequence of those factors considered to be the most significant and influential in either changing the direction of policy or identifying the direction of change. Soil erosion was the first category of natural resource degradation to attract legislation directed at its mitigation, namely the Sand Drift Act (Western Australia) 1889.

In 1916, a Royal Commission was appointed to review agriculture (Royal Commission on the Agricultural Industries of Western Australia 1917) and the mallee lands in the southeast of Western Australia (Royal Commission on the Agricultural Industries of Western Australia 1918). Following this review, a map was prepared defining the area considered to be the safe rainfall limit for wheat. This line became known as the Brockman Line after the Surveyor-General F.S. Brockman; it is shown in Fig. 1 (Burvill 1979). Even then, agriculture extended beyond this line, raising concern about the long-term viability of agriculture in these areas. Soil salinity was already apparent in the mallee region but was discounted as a concern in the report of 1918 (Royal Commission on the Agricultural Industries of Western Australia 1918). However, within another 10 years, soil salinity was again presenting as a problem in certain soil types.

The dust bowl in the USA in the 1930s and widespread wind and water erosion in Australia led to a revived interest in soil conservation as a national concern. During the years of the Depression and the War (WWII), the federal Soil Conservation Act 1938 and, in Western Australia, the Soil Conservation Act (Western Australia) 1945 were enacted in direct response to the extent of the problem. They were soon followed by the establishment of the federal Standing Committee on Soil Conservation in 1946. During this period, a combination of social, economic, and ecological factors caused many farmers to declare bankruptcy and abandon their farms (Burvill 1979). Wheat prices dropped from $23 (AUD) to $8 (AUD) per ton in the early 1930s. Simultaneously, the wool price dropped, removing the opportunity for farmers to move between the production of these two commodities, which was common practice in the ley-farming method. The rate of clearing dropped by about 75%, from 143 750 ha a year before 1929 to 36 789 ha a year between 1930 and 1945 (Fig. 6).

In stark contrast to the poor conditions (economic, environmental, and technical) in the period labeled the Depression and the War, the 20 years of the Rural Boom were the only period of untroubled prosperity (Frost and Burnside 2001). At this time, a combination of four key factors in the economic, social, ecological, and technological systems encouraged very high rates of clearing. These were: cheap fuel; increasing technology in the form of heavy machinery and the use of heavy chain to clear native vegetation; high wheat and wool prices; and government policy encouraging the clearing of 1 million acres per year. The prices for both wheat and wool escalated in the early 1950s, the period following WWII. In 1950–1951, wool was approximately ten times the value it was during the war and wheat reached five to eight times the value of crops in 1930 to 1944. As a result of these four factors, the rates of clearing increased by a factor of ten, doubling the area cleared from 6.48 million hectares in 1949 to 13.77 million hectares in 1969, to capitalize on the high commodity prices (Cary et al. 2002).

The Rural Boom was sustained by both ecological and technical factors. Favorable rains for a 10-year period between 1958 and 1968, combined with technological advances in fertilizers, operated to overcome soil deficiencies and encouraged the expansion of agriculture into areas with proportionately more second- and third-class soils. Third-class soils were classified as marginal and it was not expected that landholders would clear such land, although invariably they did (Australian Greenhouse Office 2000). Once the limiting factors of soil deficiencies had been overcome, climate rather than soil capability was, in most instances, the limiting factor in agricultural production. Expansion into areas with poorer soils and less reliable rainfall, beyond the Brockman Line (Fig. 1), laid the way for many future difficulties in the following decades, particularly in extended periods of dry climatic conditions. Technological innovations in other areas of the agricultural industry occurred, producing new chemicals for the control of pests and weeds, new crop varieties, and new farm machinery that together increased the intensity of agricultural production.

The Rural Boom from 1949 to 1969 produced record numbers of sheep and record quantities of wheat, causing an oversupply on world markets (Burvill 1979). In response, the Australian Government intervened by introducing wheat quotas in 1969, the beginning of the Troubled Decade. Wheat production dropped by one third between 1969 and 1972. In the late 1970s, new trends in agriculture emerged that were accompanied by new constraints. The general trend in agriculture was toward increased specialization, more technically complex and more intensive agriculture. The lack of infrastructure that had constrained agriculture in the past was replaced by the limitation of unreliability of the growing season due to annual rainfall variability, particularly in the newer, less favorable, areas developed after 1950 during the Rural Boom. Declining agricultural terms of trade (falling prices for agricultural commodities compared with the price of farm inputs) compounded the problem, making it increasingly difficult for small farmers to maintain their livelihoods solely by engaging in agricultural activities (Barr 2000). Large numbers of farmers left agriculture during the Troubled Decade. The number of agricultural establishments in Western Australia fell from approximately 23 000 to 17 800 between 1968 and 1976, the trend being mirrored throughout Australia (National Land and Water Resources Audit 2002).

In the Troubled Decade, soil conservation again began to emerge as a matter of national importance and concern, triggered by a rising conservationist ethos and increased land degradation caused by two decades of pro-development agricultural policies in the 1950s and 1960s. By the end of the 1970s, it was estimated that just over half of Australia's agricultural land was degraded (Department of Environment, Housing, and Community Development 1978).

In the 1980s, the environment became a political issue and, in 1988, the Australian Conservation Foundation and the National Farmers Federation engaged in a cooperative agreement to combat the problems of land degradation at the national policy level (Toyne and Farley 2000). The joint action of these two groups, which previously had taken opposing positions on land conservation policy, was an unprecedented effort to try to solve an intractable national-scale problem. As a consequence of this alliance and in collaboration with the Federal Government, the National Soil Conservation Strategy was released in 1989 aimed at mitigating land degradation.

As the environmental movement increased its pressure, the Federal Government declared the "Decade of Landcare"' initiative in the 1989 Statement on the Environment, under the National Landcare Program, a voluntary community participatory program supported by funding through the National Heritage Fund (see Fig. 5). During the Decade of Landcare, the rate of land clearing dropped from 188 000 ha per year between 1977 and 1994 to about 42 800 ha per year between 1994 and 2001. The Landcare Plan was an important strategy that helped inform and change the attitudes of many land managers in relation to the need to change current land management practices. However, a change to more sustainable land-use practices requires more than a change in attitude (Cary et al. 2002).

The Landcare Plan was criticized even by its originators (Toyne and Farley 2000) for its lack of strategic and co-ordinated action. The most recent coordinated regional approach comes under the National Action Plan for Salinity and Freshwater. The Western Australia Government signed a bilateral agreement with the Federal Government in 2002 (Government of Western Australia 2002) to initiate the National Action Plan in Western Australia, coordinated and delivered by the newly formed Natural Resource Management Council through the Western Australia State Natural Resource Policy (Government of Western Australia 2001).

LITERATURE CITED

ABARE. 2002. AgSurf: Farm survey data [Online] URL: http://agsurf.abareconomics.com.

Agriculture, Fisheries and Forestry - Australia. 2001. Market-based incentives for natural resource management. Agriculture, Fisheries and Forestry - Australia, Canberra, Australia.

Allison, H. E., and R. J. Hobbs. 2004. Sustaining the social memory of the historical and policy context of natural resource management in Western Australia. *Environmental Management*: submitted.

Australian Bureau of Statistics. 1979–1997. *Western Australian Year Book 1979–1997*.

Australian Greenhouse Office. 2000. *Land clearing: a social history*. Australian Greenhouse Office, National Carbon Accounting System, Canberra, Australia.

Barr, N. 2000. *Structural change in Australian agriculture: implications for natural resource management.* Theme 6 Project 3.4. National Land and Water Resources Audit, Canberra, Australia.

Beeston, B. R., R. G. Mlodawski, A. Sanders, and D. True. 1994. *Resource Management Report No 149*. Department of Agriculture, Perth, Australia.

Beresford, Q., H. Bekle, H. Phillips, and J. Mulcock.

2001. *The salinity crisis. Landscapes, communities and politics.* University of Western Australia Press, Perth, Western Australia.

Berry, B. J. L. 1991. *Long-wave rhythms in economic development and political behavior.* Johns Hopkins University Press, Baltimore, Maryland, USA and London, UK.

Booth, M., S. Rodgers, and AgInsight. 2000. *Interdisciplinary research methodologies in natural resource management.* Report to Land and Water Resources Research and Development Corporation, Social and Institutional Research Program. The Institute for Sustainability and Technology Policy, Murdoch University, Canberra, Western Australia.

Brewer, G. B. 1986. Methods for synthesis: policy exercises. *In* R. E. Munn, editor. *Sustainable development of the biosphere.* Cambridge U.P. for the International Institute for Applied Systems Analysis, Cambridge, Melbourne, Australia.

Burbidge, A. 1988. The why and how of managing biological resources. *In* A. A. Burbidge, editor. *Ecological theory and biological management of ecosystems.* Occasional Paper No. 1/88, Department of Conservation and Land Management, Perth, Australia.

Burke, G. 1991. *The economic and political factors affecting the viability of farmland restoration in the Great Southern Region of Western Australia: a historical perspective on the British economic paradigm.* Thesis, Murdoch University, Perth, Australia.

Burvill, G. H., editor. 1979. *Agriculture in Western Australia. 150 years of development and achievement 1829–1979.* University of Western Australia Press, Perth, Western Australia.

Carry, A. 1996. Uncertainty in the writings of Kondratiev. *In* C. Schmidt, editor. *Uncertainty in economic thought.* Edward Elgar Publishing Ltd, Cheltenham, UK.

Cary, J. 2000. *Social perspectives on technology transfer to meet economic and environmental objectives. Emerging technologies in agriculture: from ideas to adoption.* Canberra, Australia.

Cary, J., T. Webb, and N. Barr. 2002. *Understanding landholder's capacity to change to sustainable practices. Insights about practice adoption and social capacity for change.* Agriculture, Fisheries and Forestry - Australia, Canberra, Australia.

Costanza, R., J. Cumberland, H. Daly, R. Goodland, and R. Norgaard. 1997. *An introduction to ecological economics.* St. Lucie Press, Boca Raton, Florida, USA.

Commonwealth Scientific and Industrial Research Organisation (CSIRO). 2001. *Climate change projections for Australia.* CSIRO, Canberra, Australia.

Daily, G. C. 2000. Management objectives for the protection of ecosystem services. *Environmental Science and Policy* **3**:333–339.

Daly, H. E. 1991. *Steady-State Economics.* Island Press, Washington, D. C., Covelo, California, USA.

Davidson, B. R. 1981. *European farming in Australia. An economic history of Australian farming.* Elsevier Scientific Publishing Company, Amsterdam, The Netherlands; Oxford, UK; New York, New York, USA.

De Greene, K. B., editor. 1993. *A systems-based approach to policy making.* Kluwer Academic, Boston, Massachussetts, USA.

Department of Environment, Housing, and Community Development. 1978. *A basis for soil conservation policy in Australia.* Commonwealth and State Government collaborative soil conservation study 1975–1977. Report 1. Canberra, Australia.

Environmental Protection Authority. 2000. *Environmental Protection of native vegetation in Western Australia.* EPA position statement No. 2. Environmental Protection Authority, Perth, Australia.

Fey, W. R. 2002. *Organizational change from a new perspective: pattern feedback control in human systems.* 20th International Conference of the System Dynamics Society. 28 July–1 August, 2002. System Dynamics Society, Palermo, Italy.

Folke, C., J. Colding, and F. Berkes. 2002. Synthesis: building resilience and adaptive capacity in social-ecological systems. *In* C. Folke, editor. *Navigating social-ecological systems: building resilience for complexity and change*. Cambridge University Press, Cambridge, UK.

Frost, F., and D. Burnside. 2001. Appreciating and creating history. In V. Read et al. Proceedings, Wheatbelt Valleys Conference, Merredin, Washington, USA, July 30-August 1, 2001.

Funtowicz, S. O., and J. R. Ravetz. 1993. Science for the post-normal age. *Futures* **25**(7):739–755.

Gallopin, G. C. 2002. Planning for resilience: scenarios, surprises, and branch points. *In* C. S. Holling, editor. *Panarchy*. Island Press, Washington, D. C., USA.

George, R. J., D. J. McFarlane, and R. J. Speed. 1996. The consequences of a changing hydrologic environment for native vegetation in southwestern Australia. *In* E. M. Mattiske, editor. **Nature conservation 4: the role of networks.** Surrey Beatty and Sons Pty Limited, Chipping Norton, Australia.

Gill, R. 1996. An integrated social fabric matrix/system dynamics approach to policy analysis. *Systems Dynamics Review* **12**(3):167–181.

Goulburn Broken Catchment Management Authority. 2002. Draft Region Catchment Strategy, Goulburn Broken. Goulburn Broken Catchment Management Authority, Shepparton, Victoria, Australia.

Government of Western Australia. 1996. *Salinity: a situation statement for Western Australia.* A report to the Minister for Primary Industry, Minister for the Environment. Agriculture Western Australia, Department of Conservation and Land Management, Department of Environmental Protection, Water and Rivers Commission, Perth, Australia.

Government of Western Australia. 2001. *Natural resource management in Western Australia. Western Australian Government framework to assist in achieving sustainable natural resource management.* Perth, Western Australia.

Government of Western Australia. 2002. Government signs national salinity and water quality plan. Media release, May 23, 2002, Perth, Australia. **Gunderson, L. H., and C. S. Holling, editors.** 2002. *Panarchy.* Island Press, Washington, D. C., USA.

Gunderson, L. H., C. S. Holling, and S. S. Light, editors. 1995. *Barriers and bridges to the renewal of ecosystems and institutions.* Columbia University Press, New York, New York, USA.

Gunderson, L. H., C. S. Holling, and G. D. Peterson. 2002a. Surprises and sustainability: cycles of renewal in the everglades. *In* C. S. Holling, editor. *Panarchy.* Island Press, Washington, D. C., USA.

Gunderson, L. H., and L. Pritchard, Jr., editors. 2002. *Resilience and the behavior of large-scale systems.* Island Press, Washington, D. C., USA.

Gunderson, L. H., C. S. Holling, L. Pritchard, Jr., and G. D. Peterson. 2002b. Resilience of large-scale resource systems. *In* L. H. Gunderson and L. Pritchard, Jr., editors. *Resilience and the behavior of large-scale systems.* Island Press, Washington, D. C., USA.

Gunderson, L. H., L. Pritchard, Jr., C. S. Holling, C. Folke, and G. D. Peterson. 2002c. A summary and synthesis of resilience in large-scale systems. I*In* L. H. Gunderson and L. Pritchard, Jr., editors. *Resilience and the behavior of large-scale systems.* Island Press, Washington, D. C., USA.

Hamblin, A. P., and G. Kyneur. 1993. *Trends in wheat yields and soil fertility in Australia.* Australia, Bureau of Resource Sciences, Australian Govt. Pub. Service, Canberra, Australia.

Hanna, S., and M. Munasinghe. 1995. *Property rights and the environment: social and ecological issues*. Beijer International Institute of Ecological Economics and the World Bank, Washington, D. C., USA.

Hansson, S. O., and G. Helgesson. 2003. What is stability? *Synthese* **136**(2):219–235.

Hatton, T. J. 2003. Preclearing hydrology of the Western Australia wheatbelt: target for the future? *Plant and Soil*: in press.

Hatton, T. J., and J. Ruprecht. 2001. Watching the rivers flow: hydrology of the wheatbelt. Wheatbelt Valley Floors Conference, September 2001, Merredin, Washington, USA.

Hodgson, G. A., T. J. Hatton, and R. B. Salama. 2003. Modelling rising groundwater and the impacts of on terrestrial remnant vegetation in the Blackwood Basin. *Ecological Management and Restoration*: Submitted.

Holland, J. H. 1992. *Adaptation in natural and artificial systems: an introductory analysis with applications to biology, control, and artificial intelligence.* MIT Press, Cambridge, Massachusetts, USA.

Holling, C. S. 1973. Resilience and stability of ecological systems. *Annual Review of Ecological Systems* **4**: 1–24.

Holling, C. S., editor. 1978. *Adaptive environmental assessment and management.* International Series on Applied Systems Analysis. John Wiley, Chichester, UK; New York, New York, USA; Brisbane, Australia; Toronto, Canada.

Holling, C. S. 1995. What barriers? What bridges? *In* S. S. Light, editor. *Barriers and bridges to the renewal of ecosystems and institutions.* Columbia University Press, New York, New York, USA.

Holling, C. S., S. R. Carpenter, W. A. Brock, and L. H. Gunderson. 2002a. Discoveries for sustainable futures. *In* C. S. Holling, editor. *Panarchy*. Island Press, Washington, D. C., USA.

Holling, C. S., C. Folke, L. Gunderson, and K. G. Maler. 2000. *Resilience of ecosystems, economic systems and institutions.* Final Report, The Resilience Alliance. (online.) URL: http://www.resalliance.org.

Holling, C. S., and L. H. Gunderson. 2002. Resilience and adaptive cycles. *In* C. S. Holling, editor. *Panarchy*. Island Press, Washington, D. C., USA.

Holling, C. S., L. H. Gunderson, and D. Ludwig. 2002b. In quest of a theory of adaptive change. *In* C. S. Holling, editor. *Panarchy*. Island Press, Washington, D. C., USA.

Holling, C. S., L. H. Gunderson, and G. D. Peterson. 2002c. Sustainability and panarchies. *In* C. S. Holling, editor. *Panarchy*. Island Press, Washington, D. C., USA.

Janssen, W., and P. Goldsworthy. 1996. Multidisciplinary research for natural resource management: conceptual and practical implications. *Agricultural Systems* **51**:259–279.

Lambin, E. F., B. L. Turner, H. J. Geist, S. B. Agbola, A. Angelsen, J. W. Bruce, O. T. Coomes, R. Dirzo, G. Fischer, C. Folke, P. S. George, K. Homewood, J. Imbernon, R. Leemansm, X. Li, E. F. Morano, M. Mortimore, P. S. Ramakrishnan, J. F. Richards, H. Skanes, W. Steffen Glenn, D. Stone, U. Svedin, T. A. Veldkamp, C. Vogel, and J. Xu. 2001. The causes of land-use and land-cover change: moving beyond the myths. *Global Environmental Change* **11**: 261–269.

Lee, K. N. 1993. *Compass and gyroscope. Integrating science and politics for the environment.* Island Press, Washington D. C., Covelo, California, USA.

Legislative Assembly of Western Australia. 1990. Select Committee into Land Conservation. Discussion paper No. 2 Agricultural Region of Western Australia. Legislative Assembly, Western Australian Parliament, Perth, Western Australia.

Ludwig, D., R. Hilborn, and C. Walters. 1993. Uncertainty, resource exploitation, and conservation; lessons from history. *Science* **260**(5104):17–18.

Lyons, T. J. 2002. Clouds prefer native vegetation. *Meteorology and Atmospheric Physics* **80**:131–140.

McFarlane, D. J., R. J. George, and P. Farrington. 1993. Changes in the hydrologic cycle. *In* R. J. Hobbs, and D. A. Saunders, editors. *Reintegrating fragmented landscapes: towards sustainable production and nature conservation.* Springer-Verlag, New York, New York, USA.

Meadows, D. 1970. Dynamics of commodity production cycles. Productivity Press, Portland, Oregon, USA.

Meadows, D. H. 1982. *Sustaining tropical forest resources. A systems approach.* Unpublished manuscript obtained from Jennifer Robinson. Resource Policy Center, Dartmouth College, Hanover, New Hampshire, USA.

Meadows, D. H., and J. M. Robinson. 1985. The electronic oracle: computer models and social decisions. John Wiley, Chichester, UK; New York, New York, USA.

National Action Plan for Salinity and Water Quality. 2002a. *Investigating new approaches: a guide to the National Market-Based Instruments Pilots Program.* Canberra, Australia.

National Action Plan for Salinity and Water Quality. 2002b. *Investigating new approaches: a review of natural resource management pilots and programs in Australia that use market-based instruments*. Canberra, Australia.

National Land and Water Resources Audit. 2001. *Australian dryland salinity audit. Extent, impacts, processes monitoring and management options*. Land and Water Australia, Canberra, Australia.

National Land and Water Resources Audit. 2002. *Australians and natural resource management 2002.* Land and Water Australia, Canberra, Australia.

O'Neill, R. V., J. R. Kahn, and C. S. Russell. 1998. Economics and ecology: the need for detente in conservation ecology. *Conservation Ecology* **2**(1):4. [Online.] URL: http://www.consecol.org/vol2/iss1/art4/.

Passioura, J. B. 1999. Can we bring about a perennially peopled and productive countryside? *Agroforestry Systems* **45**:411–421.

Passioura, J. B. 2002. Environmental biology and crop improvement. *Functional Plant Biology* **29**:537–546.

Repetto, R. C., and M. Gillis. 1988. *Public policies and the misuse of forest resources.* Cambridge University Press, Cambridge, UK.

Richardson, G. P. 1991. *Feedback thought in social science and systems theory.* University of Pennsylvania Press, Philadelphia, Pennsylvania, USA.

Royal Commission on the Agricultural Industries of Western Australia. 1917. *Progress report of the Royal*

Commission on the Agricultural Industries of Western Australia on the wheat-growing portion of the south-west division of the State, together with minutes of evidence, indices, and appendices. Commission on tour in South Australia en route to Port Augusta, March/April 1917. Perth, Western Australia.

Royal Commission on the Agricultural Industries of Western Australia. 1918. *Second progress report of the Royal Commission on the Agricultural Industries of Western Australia on the settled portions of the south-west coastal districts, including minutes of evidence, indices, and appendices, together with a final review of the operations of the commission.* Perth, Western Australia.

Royce, W. F. 1987. *Fishery development*. Academic Press, New York, New York, USA.

Sala, M., and A. J. Conacher. 1998. *Land degradation in Mediterranean environments of the world: nature and extent, causes and solutions.* John Wiley, Chichester, UK; New York, New York, USA.

Saunders, D. A., G. T. Smith, J. A. Ingram, and R. I. Forrester. 2003. Changes in a remnant of salmon gum *Eucalyptus salmonophloia* and York gum *E. loxophleba* woodland, 1978 to 1997. Implications for woodland conservation in the wheat-sheep regions of Australia. *Biological Conservation* **110**:245–256.

Sawin, B., H. Hamilton, A. Jones, P. Rice, D. Seville, S. Sweitzer, and D. Wright. 2003. *Commodity system challenges. Moving sustainability into the mainstream of natural resource economies.* Sustainability Institute, Hartland, Vermont, USA.

Schumpeter, J. A. 1950. *Capitalism, socialism and democracy.* Harper and Row, New York, New York, USA.

Sterman, J. D. 2001. System dynamics modeling: tools for learning in a complex world. *California Management Review* **43**(4):8–25.

Tainter, J. A. 1988. *The collapse of complex societies.* Cambridge University Press, Cambridge, UK.

Thirgood, J. V. 1981. *Man and the Mediterranean forest: a history of resource depletion.* Academic Press, London, UK.

Toolibin Lake Recovery Team and Toolibin Lake Technical Advisory Group. 1994. Toolibin Lake recovery plan. Unpublished report.

Toyne, P., and R. Farley. 2000. *The decade of landcare. looking backward* **-** *looking forward.* The Australia Institute, Canberra, ACT 0200, Australia.

Waldrop, M. M. 1992. *Complexity: the emerging science at the edge of order and chaos.* Simon and Schuster, New York, New York, USA.

Walker, B., S. Carpenter, J. Anderies, N. Abel, G. Cumming, M. Janssen, L. Lebel, J. Norberg, G. D. Peterson, and R. Pritchard. 2002. Resilience management in social-ecological systems: a working hypothesis for a participatory approach. *Conservation Ecology* **6**(1):14. (Online.) URL: http://www.consecol.org/vol6/iss1/art14.

Wallace, K. J. 2003. Confusing means with ends: a manager's reflections on experience in agricultural landscapes of Western Australia. *Ecological Management and Restoration* **4**(1):23–28.

Walters, C. J. 1986. Adaptive Management and Renewable Resources. Macmillan, New York, New York, USA.

Water Studies Pty Ltd. 2000. *Moora flood management study.* Water and Rivers Commission, Perth, Western Australia.

Westley, F., S. R. Carpenter, W. A. Brock, C. S. Holling, and L. H. Gunderson. 2002. Why systems of people and nature are not just social and ecological systems. *In* C. S. Holling, editor. *Panarchy*. Island Press, Washington, D. C., USA.

Young, M. D., and B. J. McCay. 1995. Building equity, stewardship, and resilience into market-based property rights systems. *In* M. Munasinghe, editor. *Property rights and the environment: social and ecological issues.* Beijer International Institute of Ecological Economics and the World Bank, Washington, D.C., USA.