

Chapter 2

Environmental Science and Management in a Changing World

Gary Brierley and Carola Cullum

Abstract Recognition of the pervasive impact of human activities on the natural world has prompted a reframing of approaches to environmental repair. Disentangling threads in the evolution of theoretical environmental science and management practice over the last 50 years enables practitioners to position contemporary programmes within a coherent conceptual framework. Over the last 50 years, environmental management strategies have moved beyond concern solely for utilitarian values to recognizing the importance of biodiversity management and associated ecosystem services. Initially, these programmes focussed on management of single issues, emphasizing concerns for endangered species and conservation in designated reserves that retained notionally pristine areas. The transition to an ecosystem approach to environmental management marked the recognition that there are too many species to attempt to save them one at a time and that conservation efforts must focus upon whole ecosystems. However, the ecosystem approach retained a vision of nature in equilibrium and management initiatives were framed in terms of environmental reference conditions and adjustments around a mean condition. Emerging theories in both ecology and earth sciences view nature as a complex adaptive system, often involving non-linear relationships and stochastic events which lead to outcomes that are unpredictable in time and space. Explicit recognition of inherent uncertainties in the character and behaviour of environmental systems has prompted a shift towards application of adaptive and participatory management principles. Recognizing directly the imperative to integrate scientific thinking with social-ecological

G. Brierley (✉)

School of Environment, University of Auckland, Private Bag 92019,
Auckland, New Zealand
e-mail: g.brierley@auckland.ac.nz

C. Cullum

Centre for Water in the Environment, University of Witwatersrand,
Johannesburg, South Africa

considerations, post-normal scientific practice embraces a more inclusive approach to the management of complex adaptive systems, striving to maximise the resilience of any given system. Prospective opportunities for geographers in meeting the needs of this emerging framework are considered.

Keywords Environmental management • Ecosystem management • Biodiversity • Post-normal science

2.1 Introduction

The last 50 years have seen a dramatic shift of perspective in our scientific understanding of the natural world. The traditional view of the ‘balance of nature’ was embedded in conceptual frameworks that built upon equilibrium notions and related conceptualisations of succession, climax communities and notional ‘end-points’ of ecosystem trajectories (Botkin 1989; Wu and Loucks 1995). Over the last decade or so, this view has been supplanted by a vision of nature as a complex adaptive system, characterised by non-linear relationships, random events and interactions that generate uncertainties and discontinuities (O’Neill 2001; Perry 2002). It is now recognised that environmental interactions and responses are place and time specific, so that different catchments will react in different ways to similar interventions, depending on their climatic and geological context, spatial configuration and their history of evolution and land use (Brierley and Fryirs 2005).

As theoretical perspectives have evolved, so too have their applications in environmental management. For example, as long as natural systems were understood to be generally stable if unaltered by humankind, then conservation efforts could aim to preserve or restore a pristine state. Conceptualizations of nature in terms of mechanical models and linear, causal relationships enabled indicators to be used to evaluate environmental health and to track progress towards restoration goals. However, a new, emerging paradigm views the natural world as a complex system that is not necessarily in equilibrium. Multiple states are possible within the same boundary conditions, and the same impact may have very different consequences in different contexts. Such thinking undermines the use of pristine conditions as reference points and broadly applied indicators. In response, adaptive and participatory management frameworks provide the most reliable platform to work with, and plan for, uncertainties (Walters and Holling 1990). They recognise explicitly that our understanding will never be complete, and that sustainable environmental management is inherently dependent upon societal engagement and empowerment in the design, implementation and maintenance of management activities (Rhoads et al. 1999).

The shift in theoretical perspective not only has far-reaching implications for its practical application in management, but also for the way environmental science needs to be conducted in order to usefully inform policy and decision making.

As noted by Ravetz (1999, p 649), in such 'issue-driven' science "typically facts are uncertain, values in dispute, stakes high, and decisions urgent.... the previous distinction between 'hard', objective scientific facts and 'soft', subjective value-judgements is now inverted. All too often, we must make hard policy decisions where our only scientific inputs are irremediably soft". Funtowicz and Ravetz (1993) argue that 'normal' science, based on reductionist theories supported by experimental evidence and notionally value-free deductive reasoning, needs to be replaced by 'post normal science', characterised by uncertainty analysis and management, lay participation and the integration of scientific knowledge not only across disciplines, but also across the lay-expert divide.

The new scientific paradigm of natural systems thus presents significant challenges to scientists and managers alike. Scientists cannot provide secure predictions to inform managerial policy and interventions, solutions are not universally applicable, desired outcomes are negotiable and the involvement of local communities and stakeholders is essential. In many instances, institutional structures and practices have only recently been reformed in light of international, national and local environmental legislation developed during the 1990s such as the 1992 Rio Convention on Biological Diversity (United Nations Environmental Program 1992).

Although there have been many statements of the principles of adaptive management and post normal science (e.g. Kay et al. 1999), uptake has been slow in practice as practitioners are often trapped within the bounds of discipline-bound academic institutions and legislatively-bound environmental management agencies. Inevitably, there is a lag between the evolution of scientific thinking and management practice. The nature and extent of this dislocation varies markedly from place to place, as institutions themselves respond to their own histories and associated cultures (framed in light of prevailing policy imperatives). As in natural systems, the drivers of change can lead to different responses in different institutional situations. Context and history are important constraints on potential outcomes. In this changing world, variability in both natural systems and in the people that use and inhabit them, present significant challenges to environmental scientists and managers.

In seeking to unravel some of these complexities, it is important to ground the evolution of conceptual developments and managerial responses, thereby providing the context with which to position the status and prospects for practitioners and institutions that work in environmental management. This manuscript endeavours to disentangle the strands of scientific and managerial practice in environmental management in the western world over the last 50 years, drawing especially upon references from the biodiversity and river management arenas. Three phases in the development of conservation theory and practice are identified. 'Command and control' environmental management and early conservation efforts focussed around single issues and was informed by ecological theory that stressed the composition of ecosystems. This gave way to a more holistic 'ecosystem' approach, in which functional elements were emphasized. The contemporary view focuses on system dynamics and complexity. Each paradigm implies quite different relationships between scientists, managers, society and the natural world, reflected in distinct styles of conservation practice and environmental management.

It is hoped that this classification of managerial approaches and their theoretical foundations will help practitioners to critically appraise current and future initiatives. Post normal science and adaptive management techniques are overviewed as responses to the uncertainty implicit in complex, adaptive ecosystems. In the concluding section, we suggest that geographers are well placed to take a leading role in the uptake of these emerging approaches to environmental management.

2.2 Interplay Between Ecological Theory and Management Over the Last 50 Years

Over the last half-century, environmental management practices have moved beyond approaches that treat components of natural systems in isolation towards more holistic approaches that recognise ecosystem connectivity and the need to encompass both natural processes and those resulting from human intervention. Three phases can be differentiated over this era, each characterised by a different understanding of the concept of biodiversity (Table 2.1). A clear appreciation of these differences is critical to constructing a coherent conceptual framework that does not conflate conflicting views of theory and practice.

2.2.1 Single Issue Focus in the era of ‘Command and Control’

The notion of ‘biodiversity’ emerged in the 1960s as a theme linking scientific study of biological heterogeneity, popular concern with increasingly visible environmental degradation and the establishment of professional environmental managers and conservationists (Gaston 1996). Initially, the focus was on ecosystem composition, with scant attention to spatial or functional context. Natural systems were generally viewed as static, or in dynamic equilibrium once succession had reached the ‘climax’ stage (Wu and Loucks 1995; O’Neill 2001; Perry 2002, *inter alia*). Natural phenomena such as flood, fire and earthquakes were seen as ‘disturbances’ that turned back the clock, resetting the system to an earlier successional stage, rather than as integral components of the system. Human intervention was seen in a similar way, such that the aim of conservation efforts was to preserve pristine landscapes or to restore them to a ‘natural’ state, which it was assumed would then persist indefinitely (Sprugel 1991). It was believed that scientific progress would ultimately reveal the mechanisms of natural systems, such that remedial engineering could reverse adverse human impacts.

In this era, species were considered as the ‘units of biodiversity’ (Claridge et al. 1997). A plethora of quantitative biodiversity indices was developed, designed either to evaluate the relative conservation value of different areas or to compare measurements at different times when monitoring the impact of land use changes or restoration programmes. Most centred on measurements of species richness and

Table 2.1 Developments in ecological theory and their expression in environmental management

	Single issue	Ecosystem	Complex adaptive system
Biodiversity: concepts and emphasis	Collection of individual species	Interactions between species and physical habitat—the field of dreams hypothesis	Complexity—non linear relationships, stochasticity, historical path dependence, contingency, unpredictability, uncertainty, alternative states possible
	Structure-composition	Function	Dynamics-process
Human relationship to nature	Control and exploitation of resources	Management of ‘natural’ systems	Humans viewed as part of social-ecological systems
Management goals	Management of risk		
Theoretical framework	Command and control; Make nature conform to human needs; Uniform, generally applicable solutions; Conservation of individual species	Pressure-State-Response Conservation of entire (local) systems; Reference state—pristine condition (end points)	Adaptive management; Place-specific goals negotiated between stakeholders; System sustainability, maintenance of ecosystem services
	Stability	Dynamic equilibrium, disrupted by disturbance	Complexity, self-organisation; Natural variability, disturbance part of the system
Dominant disciplines	Individual components	Web of interactions centred around species/area of interest	Nested hierarchies, level characterised by relative temporal/spatial scales
	Engineering	Ecology (with links to other natural sciences)	Transdisciplinary—human and natural sciences
Methods	Single- purpose engineering projects	Indicators of system health, Targets enshrined in protocols/legislation	Thresholds of probable concern; Targets locally negotiated
	“Normal” science	Cross-disciplinary, summative approach	“Post-normal” science. Integrative, transdisciplinary, systems-based thinking about social-ecological interactions
Biodiversity indices	Mechanistic models	Process based models with predictive ability to forecast outcome	Simulation models suggesting possible outcome of processes; Spatially explicit models and GIS; Foresighting of scenarios
		Keystone/umbrella species	System resilience

evenness, although some indices also incorporated measures of rarity or endemism (Ricotta 2005). Thus the assessment of biodiversity involved counting the number of species present in a particular area and their relative abundance. To circumvent the need to identify and count the vast number of species present in even a very small area, surrogate taxa were sought as indicators of the total level of diversity likely to be present (e.g. Pearson 1994). However, several studies showed that no single component could consistently indicate overall biodiversity, since the diversity of different groups can vary independently at almost every biological scale, from genes through to whole ecosystems (e.g. Prendergast 1997; Heino et al. 2005). Biodiversity indices are now also criticised as gross oversimplifications, failing to distinguish the relative functional or conservation importance of different species (Noss 1990; Hooper et al. 2005; Ricotta 2005).

Given the challenge of measuring biodiversity, it is no surprise that early conservation efforts focussed on the preservation of individual threatened species (Simberloff 1998). Underpinned by emerging theories of population dynamics, management initiatives concentrated on large, relatively easily sampled, well-studied and charismatic organisms. For example, in 1991, 51.5% of all US government spending on the protection of endangered species was concentrated on only seven taxa (Losos 1993; Simberloff 1998).

Single-issue thinking also characterised the ‘command and control’ era of river management that prevailed in the wake of the industrial revolution (Cosgrove and Petts 1990; Holling and Meffe 1996; Hillman and Brierley 2005). Driven by political and social concerns for protection against natural hazards and the development of resources, this engineering-based approach was framed in terms of deterministic thinking about river stability and natural processes. Grounded in the reductionist scientific method derived from physics and chemistry, it assumed that nature can be described in terms of linear causal relationships and mechanistic models. The ‘command and control’ approach also positioned rivers outside their landscape context, treating individual components of the system in isolation, such that ecosystems were often harmed as a result of unanticipated knock-on effects (Richter and Postel 2004). Strategies applied over relatively short reaches of river targeted stability, conformity and simplicity, epitomised by the construction of uniform, homogenous, hydraulically smooth channels, dams, drained wetlands and fixed flood barriers. The range of natural variability was limited as the system was forced to conform to human needs, often resulting in a decrease in system resilience to disturbance and heightening the effect of extreme events (Holling and Meffe 1996). Many river conservation projects also failed as symptoms were treated without addressing the root cause (e.g. Hilderbrand et al. 2005).

2.2.2 A Holistic Ecosystem Approach

By the 1990s, the conservation focus on individual species was under attack as extinction rates continued to soar. It was recognised that there are just too many

species to attempt to save them one at a time and that conservation efforts must be directed at whole ecosystems. A new view of biodiversity was emerging, in which the composition, structure (spatial pattern) and function (ecological and evolutionary processes) of an ecosystem both determined and constituted its biological diversity (Noss 1990; Franklin 1993). Multiple biotic and spatial scales were considered, from genetic diversity through to the variability of whole ecosystems (Wegner et al. 2005). Whilst acknowledging the value of a species approach as a valid ‘emergency-room’ tactic to bring species back from the verge of extinction, environmental management efforts started to focus on the preservation or restoration of entire habitats and their ecological ‘integrity’ rather than on individual species or the overall number of species present. Such an approach served to protect the numerous, small and often undescribed species of invertebrates, fungi and bacteria that carry out critical ecosystem functions such as decomposition or nitrogen fixation (Franklin 1993). In contrast to basic biodiversity indices, analyses framed in terms of the ecosystem approach recognise that unmeasured external factors such as invasion by weedy or exotic species may compromise the ecological functioning and evolutionary potential of an ecosystem (Noss 1990).

Methods of biodiversity assessment changed to reflect the new theoretical insights. Rather than attempting to enumerate all species present in an area, or to identify taxa or species whose presence would signal diversity in all other groups of organisms, indicator taxa or species were sought that could detect and monitor compositional, structural and functional biodiversity at multiple levels of organisation (Noss 1990). Concepts such as keystone species (Paine 1995), umbrella species (Launer and Murphy 1994; Lambeck 1997), functional guilds (Severinghaus 1981; Block et al. 1987) and ecosystem engineers (Jones et al. 1994) were developed by ecological theorists and used by conservation managers to justify the selection and establishment of reserves.

Many environmental managers, policy makers and members of the public welcomed the advent of ecological indicators that enabled complex systems to be summarised in ways which could be simply communicated. Indicators could be used to signal progress towards targets based on notions of a pristine system or high-quality reference sites (Niemi and McDonald 2004). A Pressure-State-Response framework (OECD 2003) was commonly adopted, assuming cause-effect relationships between pressures on an environment and its response(s) to them. Indicators were enshrined in policy and are still widely used to demonstrate compliance with international, national and regional protocols and legislation. These frameworks enforced the call to ‘think globally while acting locally’ (United Nations Environmental Program 1992), recognising that without strategic top-down initiatives, framed at global or regional scales, competing local interests would likely compromise the capacity to achieve success, as no one would take responsibility for large-scale, gradual degradation.

Bioindicators were adopted with alacrity in the river management arena, where concerns for river health focussed on water quality problems, typically point source industrial pollutants. For example, the US introduced legislation requiring each state to biannually report the quality of its waters to the US Environmental

Protection Agency, specifying the use of bioindicators as well as other, more direct measures of contaminants (Niemi and McDonald 2004). Recognising that water quality concerns cannot be viewed independently from the physical structure of the river system itself (e.g. Graf 2001), a 'field of dreams' approach to river restoration emerged (Lake 2001). This approach is founded on the belief that biotic communities would colonise or recover if suitable physical habitat was provided. It also sought to address the habitat loss caused by interventions such as changes to channel morphology, the separation of channel and floodplain systems, and the near-complete removal of riparian vegetation and wood loadings (or their replacement by exotic species). Eventually it was realized that unless these applications built upon insights into broader ecosystem or landscape dynamics, they were doomed to fail (Postel and Richter 2003; Lepori et al. 2005; Palmer et al. 2005; Wohl et al. 2005).

Endeavours to work within an 'ecosystem' approach to environmental management recognized the need to work across disciplines. However, approaches tended to be summative, piecing together contributions from different fields of enquiry rather than developing integrated conceptual frameworks and methods (e.g. Uys 1994). Ecosystems still tended to be viewed independently from each other, with little appreciation of spatial context and connectivity (e.g. analysis of interactions among terrestrial and aquatic ecosystems remains in its infancy). The 'balance of nature' paradigm prevailed, suggesting that without human intervention, natural systems would generally evolve to a state of equilibrium. The goal of conservationists remained the restoration or preservation of this pristine state, epitomised in reference sites. The goal of environmental scientists was to understand the functional mechanics of natural systems, with much effort devoted to the development of ever more detailed process based models aiming to predict the impacts of human intervention or environmental change (e.g. eutrophication models, reviewed in Koelmans et al. 2001).

2.2.3 Chaos and Complexity: Nature as a Complex Adaptive System

Just as the ecosystem approach was being operationalized in new institutions and legislation, a dramatic shift in scientific perspective has emerged that challenges or undermines its theoretical foundation. The new paradigm in both ecology and earth sciences views natural systems as complex and adaptive, often involving non-linear relationships and stochastic events that result in effects that can be unpredictable in time and space (Phillips 1992, 2003; Perry 2002; Wallington et al. 2005; Harris 2007). It is now recognised that stability and equilibrium are merely illusions of scale (see Bracken and Wainwright 1996). Observed patterns are the cumulative result of many processes operating at many scales, in which the sequence of events and spatial configuration may be critical in determining the outcome. Furthermore, some systems may be subject to 'catastrophic shifts' in

response to relatively small trigger events (Scheffer et al. 2001). A given sequence of events may potentially generate a variety of possible outcomes, such that the effects of change cannot be reliably predicted (Wallington et al. 2005).

The concept of biodiversity has widened still further. Many would now prefer the term ‘biocomplexity’, defined as “the multiplicity of interconnected relationships and levels” (Ascher 2001). The new term reveals its roots in systems theory, where complexity and chaos theory deal with issues such as non-linearity, self-organisation and emergence, the contingency of initial conditions and historical path dependence. Pickett et al. (2005) describe biocomplexity as having three dimensions, spatial, organizational and temporal. They argue that spatial analysis must be explicit, taking location and neighbourhood relations into account, rather than merely focusing on the number and type of entities contributing to spatial heterogeneity. Organizational complexity encompasses not only functional units, but also their connectivity, which often constrains or drives their interactions, in many cases across organizational levels. Temporal complexity reflects system evolution and legacies of past history, which may continue to impact through lagged interactions or slowly emerging indirect effects. Landscape ecology has come to the fore as two-way relationships between pattern and process are explored (Turner et al. 2001). For example, the theory of patch dynamics informs studies of the relationships between different landscape units and flows of the energy and resources vital to ecosystem function are modelled (e.g. Forman 1995; Poole 2002).

The contemporary focus is on the processes responsible for generating and maintaining observed structures and patterns. Disturbances such as fire and flood are no longer considered as aberrations, but as an integral part of system dynamics, often required for its persistence (Turner et al. 1993). The management focus has moved from conserving static ecosystems and seeking to repair damage by restoring the (definitive) ‘natural’ landscape, towards strategies that seek to maximise or conserve ecosystem resilience, so that systems can continue to function in the face of unexpected disturbances and human impacts (e.g. Holling 1973; Peterson et al. 1998; Gunderson 2000; Carpenter et al. 2001; Folke 2003; Walker et al. 2004). Emphasis is placed on patch boundaries and the connectivity between patches, since the maintenance of flow paths is vital to ecosystem sustainability (Forman 1995). In many systems, heterogeneity and connectivity are associated with increased system resilience, resistance to exotic invasions and the maintenance of renewal processes and ecosystem services such as nutrient recycling, pollination, detoxification and the biological control of parasites and pathogens (Hooper et al. 2005). In the river management arena, these developments are exemplified by efforts to allow river systems to self-adjust, such as the ‘space to move’ programmes adopted for various European rivers (Everard and Powell 2002).

Importantly, contemporary scientific thinking views humans as part of environmental systems, recognizing human needs and abandoning unrealistic assumptions that the ideal or reference state of all ecosystems is one that lacks human presence (Waltner-Toews and Kay 2005). This introduces a political

dimension to determining an acceptable or desirable ecosystem state before conservation or rehabilitation goals can be set. In each landscape, contemporary local interests and cultural values need to be balanced against the sustainability of ecosystem services for use globally and by future generations (e.g. Rhoads et al. 1999). Explicit recognition of the inherent uncertainties and complexities of social-ecological systems has highlighted the need for much greater collaboration among natural and social scientists, the research community and environmental managers, management processes and the community. This is exemplified by increased emphasis on links between ecological and societal resilience, in a sense paralleling earlier relationships between ecosystem and societal health (e.g. Folke et al. 2002, 2004, 2005; Berkes et al. 2003; Dietz et al. 2003).

These considerations have prompted the emergence of a probabilistic approach to science and a precautionary, adaptive approach to decision-making and the prioritisation of issues (Ravetz 1999; Walters and Holling 1990). Realization of the non-deterministic behaviour of social-ecological systems has prompted more relaxed approaches to consideration of uncertainty, recognizing the inherent limitations of the unknown and the unknowable. For example, Palmer et al. (2005) indicate that contemporary approaches to river management should emphasize concerns for natural variability, biophysical linkages, ecosystem dynamics, resilience, uncertainty and inherent complexity, recognizing that short-term, small-scale practicalities must be framed in the context of large scale, long time scale processes. The emphasis has moved from generally applicable models designed to predict specific outcomes towards abstract simulation models and spatially explicit GIS methods that are used to suggest possible outcomes under different scenarios (e.g. Montgomery 2001; Perry 2002; Millennium Ecosystem Assessment 2005). Integrative, transdisciplinary conceptual frameworks and methods that reach across both human and physical sciences are slowly replacing the summative cross-disciplinary approach (Tress et al. 2005). These frameworks reach outside science, including both managers and stakeholders in their development and application, challenging conventional approaches to science and its uptake.

2.3 The Emergence of ‘Post-Normal’ Science

The ‘single issue’ and ‘ecosystem’ approaches outlined above involve the use of the traditional scientific method. This is characterised by reductionist thinking based on deductive reasoning, in which experimental methods are applied to test hypotheses that build upon established theories. Statistically rigorous procedures are used to appraise the outcomes of plot-based experiments, progressively eliminating potential explanations that are framed in terms of causal mechanisms (Popper 1959). Deterministic, quantitative relationships build on documented knowledge and are applied to develop optimum outcomes that address particular problems. The effectiveness of engineering science is testimony to our success in these endeavours. While these practices can be extremely effective in addressing

Table 2.2 Principles of normal and post-normal science

Established paradigm ('normal science')	Novel framework ('post-normal science')
<p>Employs recognized methods:</p> <ul style="list-style-type: none"> • Deterministic • Steady accumulation of relatively stable and certain facts • Experimental, deductive reasoning that focuses on elimination of potential explanations <p>Simplifies reality using a summative approach—works on parts of systems (only those deemed relevant to the target purpose), identifying core relationships which can be quantified, later piecing them together and manipulating them in management applications</p> <p>Considers itself to be 'valueless' (i.e. notionally objective)</p>	<p>Move beyond standard procedures:</p> <ul style="list-style-type: none"> • Probabilistic—applies the precautionary approach • Moves beyond cause and effect experimentation, recognizing multiple (non-linear) causation, using a multiple lines of evidence approach • Recognizes the inherent variability and complexity of the natural world <p>Integrative, holistic approach involving systems-based conceptual models that include all parameters and interactions of importance (scientific and social)</p> <p>Merges qualitative and quantitative reasoning, placing due regard on the knowledge structures of cognate disciplines, and associated notions of precision, error, reliability and uncertainty, whilst acknowledging and incorporating local 'non-expert' knowledge</p> <p>Explicitly emphasizes broader-scale processes</p> <p>Recognizes that knowledge generation and analytical procedures are value-laden, and that interpretations vary</p>

concerns for a particular purpose, many unwanted side effects may be experienced. For example, levee construction and dredging may create a smooth channel with sufficient flow for navigation purposes, but may compromise the integrity of aquatic ecosystems.

The emergence of 'post normal' science (Ravetz 1999) fundamentally challenges the values and methods of traditional 'normal' science (Table 2.2). By intent and design, 'post normal' enquiry addresses big-picture issues of genuine societal concern. Its agenda is negotiated through stakeholder consultation, set by pressing issues and goals, rather than by discipline-bound theories and institutions. A holistic, integrated approach to enquiry is adopted at the outset, rather than trying to piece together concepts and tools developed separately within different disciplines. Conceptual frameworks seek to organise knowledge derived from both science and experience, accepting inputs from managers and from local communities and experts alongside those provided by individual disciplines. They encompass both human and natural sciences, qualitative as well as quantitative reasoning and are validated by multiple lines of evidence, rather than by scientific proof (Downes et al. 2002).

In developing and adopting new approaches, scientists are increasingly required to go beyond their comfort-zone. Many feel uncomfortable addressing questions posed by others, particularly in situations involving high stakes and contested

values, where facts and understanding are uncertain and scientists are required to make value-laden judgement calls and to incorporate lay knowledge (Funtowicz and Ravetz 1993). However, many scientists continue to consider their work within a societal vacuum. We need to acknowledge prevailing traditions, dogma and belief systems embedded in our paradigms (Kuhn 1962). The new transdisciplinary approach also challenges individuals and institutions that are accustomed to working independently, competing against each other for recognition and funding (Jakobsen et al. 2004).

2.4 Changing Approaches to Environmental Management

Without inferring a causal, linear relationships, the changing approaches to environmental science are mirrored in different styles of managerial governance and applications (Table 2.3). Under the ‘command and control’ approach, politically driven agendas are implemented via top-down management frameworks. Site-specific projects are framed within a decadal timeframe, using standardised solutions. They tend to have a technical focus and are typically contracted to professionally-accredited engineers with short-term commitment and accountability (e.g. Higgs 2003). Maintenance is divorced from design and construction (e.g. Williams 2001; Hillman and Brierley 2005).

The ‘ecosystem’ approach is also characterised by top-down management, with agendas set by professionals and little community involvement. However, the professionals are now the new class of managers established to implement the legislation and protocols designed to protect the environment (e.g. planning applications/resource consent). Indicators are widely used to set targets, often reflecting internationally or regionally set standards of acceptability. Ambitious and costly monitoring programmes are adopted, implemented by professionals. Projects still remain site-specific and tend to involve standardised solutions. Effort is devoted to the development of ‘toolkits’ that can be widely used (e.g. river erosion/bank stabilisation kits). Unfortunately, they are often applied with little attention to local context or expertise or the range of secondary consequences that may result. Many institutional arrangements bear the legacy of this approach, with large investment in the development of indicators and long term data sets that are difficult to abandon, even when they are no longer convinced that the measures are useful or appropriate. Even more alarming, however, was the lack of coherent management processes to clearly articulate the aims and audit the effectiveness of interventions (e.g. Bernhardt et al. 2005). Unfortunately, even when they are applied, assessment procedures that are used to appraise environmental health are often unduly prescriptive and rigid, framed largely in terms of structural measures rather than addressing broader-ranging concerns for ecosystem functionality and complexity.

Recognizing that our understanding will never be complete, adaptive and participatory management frameworks provide the most reliable basis with which

Table 2.3 Contrasting styles of environmental management

	Governance	Management applications
'Command and control' management	Top-down, politically driven	Applies 'average' or 'normal' solutions Site-based projects
	Short-term commitment (and contract) with limited accountability	
	Monitoring is internalised or overlooked	Construction focus—typically hard engineering
	Maintenance is divorced from design	
'Ecosystem' management	Extension science that 'educates' people about the environment	Projects focus on whole ecosystems, but at reach scale only 'Toolkit' solutions applied irrespective of local context or expertise
	Top-down, driven by standards enshrined in international and local legislation and protocols	
	Indicators extensively used in ambitious monitoring programmes implemented by professionals	
	Institutions reorganised to bring experts together	
Adaptive management	Little community involvement or responsibility	Catchment based projects and organizations Emphasize concerns for the rare, unique or culturally sensitive attributes of any given system, focussing on elements of distinctiveness Continuum of interventions, including 'do nothing', soft engineering or hard engineering options
	Bottom-up, participatory—inclusive approach to visioning and prioritisation	
	Long term (ongoing) commitment	
	Monitoring is externalised, placing due regard on pre/post project appraisals	
	Maintenance is a core activity	
	Action research that promotes mutual (adaptive) learning from outcomes	

to work with, and plan for, uncertainties (Walters and Holling 1990). This approach to environmental management views people as part of nature and 'works with' the diversity and dynamics of ecosystems, aiming to restore sustainable relationships between nature and culture. Recognising a multiplicity of options, the first stage in adaptive management is to determine the desired or acceptable landscape state, balancing human and environmental needs, rather than imposing a culturally derived vision of a pristine state. This entails negotiation among conflicting interests, and associated trade-offs between sustainability and development. Participatory frameworks engage a range of stakeholders in decision-making processes. System-wide managerial actions are applied as experiments (Walters and Holling 1990), with community involvement in achievable long-term

monitoring and maintenance programmes. The results feed back as learning, informing both scientific enquiry as predictions are tested and managerial practice as methods are improved. A living information-base, developed and applied within an appropriate information management system, uses best available knowledge, identifies gaps, then targets areas of deficient insight (Hillman and Brierley 2002).

2.5 Conclusion: Opportunities for Geographers in the Management of Complex Adaptive Systems

Uncertainty is a prevalent theme in the new paradigm of environmental science and management, pervading contemporary insights into ecosystem behaviour, our understanding of such phenomena, the process of knowledge transfer, and the political dimension of institutional/social applications. In this situation, scientists cannot be relied upon by managers to provide mechanistic models of nature. Outcomes are unpredictable, such that forecasting is replaced by foresighting based on probable scenarios that are constrained by the boundaries of natural variability and human actions (e.g. Millennium Ecosystem Assessment 2005). Targets are negotiable, demanding consensus between stakeholders within the limits of available tools and resources. Standard indicators cannot be used to evaluate system health and sustainability, but need to be developed in the context of local systems and human priorities. Limiting factors that constrain environmental and managerial performance must be sought out, prioritized appropriately, and addressed. Both scientists and environmental managers need to develop new ways of working, challenging established methods, norms and institutional structures (Table 2.4).

Geographers are clearly well-placed to help scientists and managers meet the challenges presented by environmental management in a changing world. Ultimately, concerns for environmental futures must build on the relationship between people and place. A healthy society underpins a healthy environment, and vice versa. People must be seen as part of nature, emphasizing concerns for the mutual interdependence of social and environmental sustainability. Opportunities abound for geographers to help meet the challenges presented in translating the new theory into sound environmental management practice. Centred on concepts of place, geographers bring skills and experience in the marriage of human and physical science that are fundamental to the successful development and implementation of adaptive management programs. Framed in a landscape context, emerging practice depends heavily on the use of modelling, GIS and remote sensing techniques frequently employed by both physical and human geographers. Human geographers have adopted leading roles in the development and implementation of the concepts of sustainable development and community participation in decision-making. Shaping ecosystem futures by working directly with managers and key decision-makers is a form of post-normal practice that lies very comfortably within Geographic discourse. Indeed, concerns for the study of

Table 2.4 Challenges to scientific and managerial practices in an uncertain and changing world (based on Rogers 2003)

Scientists must	Managers must
<ul style="list-style-type: none"> • Accept agendas set by real world issues, tied directly to managerial concerns and incorporating social and economic dimensions • Express opinions and ‘guestimates’, using arguments based on reasonable assumptions rather than scientific proof • Communicate clearly to managers and stakeholders, sharing knowledge to promote informed choices and welcoming the contribution of local ‘lay’ experience • Frame recommendations realistically in terms of budgets and tools available (which may be crude) • Avoid the ‘tyranny of modelling’, hoping that more detailed process-based models will provide all the answers • Develop new ways of legitimising theory in situations where the traditional scientific method is not easily applied—large scale manipulation of ecosystems is usually prohibitively costly and impractical, samples of one are not uncommon. Multiple lines of evidence can be used to support an argument. • Think holistically, avoiding reductionist/ single purpose approaches, working across disciplines and breaking down barriers of language, theories, concepts, methods and institutions 	<ul style="list-style-type: none"> • Negotiate objectives and measures of success agreed between stakeholders, managers and scientists, with collective ownership of outcomes • Accept that scientists cannot provide objective solutions, predictions or measures of success • Undertake experiments—no single course of action may emerge as ‘correct’. Learning by doing turns failures into stepping stones to progress and successes can be reinforced • Be flexible—situations can change as a result of natural variability, evolving theories/ models, changing stakeholder people/needs/ priorities • Develop plans and policies that can be tailored to individual locations—lessons are not easily transferred • Reconcile concern for the long term or widespread impact of small changes with political expediency and short-termism • Cooperate between organizations, avoiding duplication of effort and recognising that the spatio-temporal domains of ecosystem processes do not necessarily match those of the authorities charged with their management

Together, they need to develop conceptual models of how ecosystems work, based on best available knowledge, using them as platforms to organise knowledge, develop treatments, prioritise management actions, develop visions and goals, predict treatment responses and review outcomes

complex socio-ecological systems present an opportunity for convergence of perspectives among physical and human geographers, building upon our traditional emphasis upon specialist-generalist syntheses and the application of divergent methodologies (both qualitative and quantitative).

For example, geomorphologists have a critical role in framing ecological considerations in terms of an appropriate understanding of the physical template upon which ecosystem processes and forms operate. Significant success has been gained in the use of conceptual frameworks with a managerial focus that apply

nested-hierarchical principles to examine geomorphic relationships within catchments (e.g. Petts and Amoros 1996; Rogers and O'Keefe 2003; Brierley and Fryirs 2005). These coherent, spatially-integrated frameworks identify the distinct attributes and patterns of any given system. By extension, they can be used to characterize the key processes and biophysical relationships that maintain the integrity of the system, identifying thresholds of potential concern that may compromise the integrity of the system in the light of environmental and land use changes (Du Toit et al. 2003). When tied to appraisals of environmental history, such insights are a critical component in the assessment of the potential for ecological recovery, an essential process in maximising the efficiency and effectiveness of management programs that target environmental repair.

Adjustments to scientific practice are required as researchers are increasingly drawn into the managerial arena. Emphasis must be placed on asking the right questions, seeking integrative solutions rather than discipline-bound treatments. Ultimately, academic institutions have a significant capacity and responsibility to inform and guide long-term developments through their training of the next generation of environmental management practitioners. Curriculum reform that promotes holistic knowledge of environmental systems and management frameworks is required. Effective management of real-world problems requires a shift in focus from short-term, local-scale, discipline-bound treatments to regional-scale analyses that target particular concerns for ecosystem integrity and functionality on an ongoing basis. These must be set within a coherent framework that can unite different perspectives and methodologies. These frameworks are place-specific, recognising the unique combinations of social and biophysical features and histories that characterise each location. This repository of knowledge must be owned and shared by scientists, managers and stakeholders alike, demanding effective management and communication strategies and common, accessible language and concepts that can facilitate collaboration that moves beyond traditional silos. A proactive, future-focussed approach is needed, with reflection to identify potentially weak links that may compromise success. Weaknesses may arise from limitations in knowledge, cross-disciplinarity, transfer of knowledge (communication or misapplication), use of knowledge or institutional impediments, as well as from limitations in the community/social will, political support (vision) or available budget. However prepared we think we may be, surprising outcomes (or circumstances) are likely, so flexibility to adapt readily to new opportunities or learn from mistakes must be retained. Ultimately, prospects for successful environmental repair are contingent upon effective societal engagement in the setting of environmental goals and the application of measures to address them—regardless of the quality of scientific understanding with which we may aspire to address these issues.

Acknowledgments We thank Susan Owen, Brad Coombes and Mick Hillman for helpful comments in the development of this manuscript, and David Higgitt for his co-ordination of support to present an earlier version of this work at the National University of Singapore Centenary Symposium.

References

- Ascher W (2001) Coping with complexity and organizational interests in natural resource management. *Ecosystems* 4:742–757
- Berkes F, Colding J, Folke C (eds) (2003) Navigating social—ecological systems: building resilience for complexity and change. Cambridge University Press, Cambridge
- Bernhardt ES, Palmer MA, Allan JD, Alexander G, Barnas K, Brooks S, Carr J, Clayton S, Dahm C, Follstad-Shah J, Galat D, Gloss S, Goodwin P, Hart D, Hassett B, Jenkinson R, Katz S, Kondolf GM, Lake PS, Lave R, Meyer JL, O'Donnell TK, Pagano L, Powell B, Sudduth E (2005) Synthesizing US river restoration efforts. *Science* 308:636–637
- Block WM, Brennan LA, Gutierrez RJ (1987) Evaluation of guild-indicator species for use in resource management. *Environ Manag* 11:265–269
- Botkin DB (1989) Discordant harmonies: a new ecology for the twenty-first century. Oxford University Press, Oxford
- Bracken LJ, Wainwright J (2006) Geomorphological equilibrium: myth and metaphor? *Trans Inst Br Geogr* NS31:167–178
- Brierley GJ, Fryirs KA (2005) Geomorphology and river management: applications of the river styles framework. Blackwell, Malden
- Carpenter SR, Walker B, Anderies JM, Abel N (2001) From metaphor to measurement: resilience of what to what? *Ecosystems* 4:765–781
- Claridge MF, Dawah HA, Wilson MRE (1997) Species: the units of biodiversity. Chapman & Hall, London
- Cosgrove D, Petts GE (eds) (1990) Water, engineering and landscape. Belhaven Press, London
- Dietz T, Ostrom E, Stern PC (2003) The struggle to govern the commons. *Science* 302:1907–1912
- Downes BJ, Barmuta LA, Fairweather PG, Faith DP, Keough MJ, Lake PS, Mapstone BD, Quinn GP (2002) Monitoring ecological impacts: concepts and practice in flowing waters. Cambridge University Press, Cambridge
- Du Toit JT, Rogers KH, Biggs HC (eds) (2003) The Kruger experience: ecology and management of savanna heterogeneity. Island Press, Washington DC
- Everard M, Powell A (2002) Rivers as living systems. *Aquat Conserv-Mar Freshw Ecosyst* 12:329–337
- Folke C (2003) Freshwater and resilience: a shift in perspective. *Philos Trans Royal Soc London Ser B* 358:2027–2036
- Folke C, Carpenter SR, Elmqvist T, Gunderson L, Holling CS, Walker B (2002) Resilience and sustainable development: building adaptive capacity in a world of transformations. *Ambio* 31:437–440
- Folke C, Carpenter S, Walker B, Scheffer M, Elmqvist T, Gunderson L, Holling CS (2004) Regime shifts, resilience, and biodiversity in ecosystem management. *Annu Rev Ecol Evol Syst* 35:557–581
- Folke C, Hahn T, Olsson P, Norberg J (2005) Adaptive governance of social-ecological systems. *Ann Rev Environ Resour* 30:441–473
- Forman RT (1995) Land mosaics. The ecology of landscapes and regions. Cambridge University Press, Cambridge
- Franklin JF (1993) Preserving biodiversity: species, ecosystems, or landscapes. *Ecol Appl* 3:202–205
- Funtowicz SO, Ravetz JR (1993) Science for the post-normal age. *Futures* 25:739–755
- Gaston KJ (1996) What is biodiversity? In: Gaston KJ (ed) Biodiversity: a biology of numbers and difference. Blackwell, Oxford, pp 1–9
- Graf WL (2001) *Damage control: restoring the physical integrity of America's rivers*. *Ann Assoc Am Geogr* 91(1):1–27
- Gunderson LH (2000) Ecological resilience: in theory and application. *Annu Rev Ecol Syst* 31:425–439
- Harris G (2007) Seeking sustainability in an age of complexity. Cambridge University Press, New York

- Heino J, Paavola R, Virtanen R, Muotka T (2005) Searching for biodiversity indicators in running waters: do bryophytes, macroinvertebrates, and fish show congruent diversity patterns? *Biodivers Conserv* 14:415–428
- Higgs E (2003) *Nature by design: people natural process and ecological restoration*. MIT Press, Cambridge
- Hilderbrand RH, Watts AC, Randle AM (2005) The myths of restoration ecology. *Ecol Soc* 10(1):19 [online]
- Hillman M, Brierley GJ (2002) Information needs for environmental flow allocation: a case study from the Lachlan River, New South Wales, Australia. *Ann Assoc Am Geogr* 92:617–630
- Hillman M, Brierley GJ (2005) A critical review of catchment-scale stream rehabilitation programmes. *Prog Phys Geogr* 29:50–70
- Holling CS (1973) Resilience and stability of ecological systems. *Annu Rev Ecol Syst* 4:1–23
- Holling CS, Meffe GK (1996) Command and control and the pathology of natural resource management. *Conserv Biol* 10:328–337
- Hooper DU, Chapin FS, Ewel JJ, Hector A, Inchausti P, Lavorel S, Lawton JH, Lodge DM, Loreau M, Naeem S, Schmid B, Setälä H, Symstad AJ, Vandermeer J, Wardle DA (2005) Effects of biodiversity on ecosystem functioning: a consensus of current knowledge. *Ecol Monogr* 75:3–35
- Jakobsen CH, Hels T, McLaughlin WJ (2004) Barriers and facilitators to integration among scientists in transdisciplinary landscape analyses: a cross-country comparison. *For Policy Econ* 6:15–31
- Jones CG, Lawton JH, Shachak M (1994) Organisms as ecosystem engineers. *Oikos* 69:373–386
- Kay JJ, Regier HA, Boyle M, Francis G (1999) An ecosystem approach for sustainability: addressing the challenge of complexity. *Futures* 31:721–742
- Koelmans AA, van der Heijde A, Knijff LM, Aalderink RH (2001) Integrated modelling of eutrophication and organic contaminant fate and effects in aquatic ecosystems. A review. *Water Res* 35:3517–3536
- Kuhn TS (1962) *The structure of scientific revolutions*. University of Chicago Press, Chicago
- Lake PS (2001) On the maturing of restoration: linking ecological research and restoration. *Ecol Manag Restor* 2:110–115
- Lambeck RJ (1997) Focal species: a multi-species umbrella for nature conservation. *Conserv Biol* 11:849–856
- Launer AE, Murphy DD (1994) Umbrella species and the conservation of habitat fragments: a case study of a threatened butterfly and a vanishing grassland ecosystem. *Biol Conserv* 69:145–153
- Lepori F, Palm D, Brannas E, Malmqvist B (2005) Does restoration of structural heterogeneity in streams enhance fish and macroinvertebrate diversity? *Ecol Appl* 15:2060–2071
- Losos E (1993) The future of the US endangered species act. *Trends Ecol Evol* 8:332–336
- Millennium Ecosystem Assessment (2005) *Ecosystems and human well-being: synthesis*. Island Press, Washington DC
- Montgomery D (2001) Geomorphology, river ecology, and ecosystem management. In: Dorava JM, Montgomery DR, Palcsak BB, Fitzpatrick FA (eds) *Geomorphic processes and riverine habitat*. American Geophysical Union, Washington DC, pp 247–253
- Niemi GJ, McDonald ME (2004) Application of ecological indicators. *Annu Rev Ecol Syst* 35:89–111
- Noss RF (1990) Indicators for monitoring biodiversity: a hierarchical approach. *Conserv Biol* 4:355–364
- OECD (2003) Environmental indicators: development, measurement and use. www.oecd.org/dataoecd/20/40/37551205.pdf. Accessed Jan 2011
- O'Neill RV (2001) Is it time to bury the ecosystem concept? (With full military honors of course!). *Ecology* 82:3275–3284
- Paine RT (1995) A conversation on refining the concept of keystone species. *Conserv Biol* 9:962–964
- Palmer MA, Bernhardt ES, Allan JD, Lake PS, Alexander G, Brooks S, Carr J, Clayton S, Dahm CN, Shah JF, Galat DL, Loss SG, Goodwin P, Hart DD, Hassett B, Jenkinson R, Kondolf GM,

- Lave R, Meyer JL, O'Donnell TK, Pagano L, Sudduth E (2005) Standards for ecologically successful river restoration. *J Appl Ecol* 42:208–217
- Pearson DL (1994) Selecting indicator taxa for the quantitative assessment of biodiversity. *Philos Trans Royal Soc London Ser B-Biol Sci* 345:75–79
- Perry GLW (2002) Landscapes, space and equilibrium: shifting viewpoints. *Prog Phys Geogr* 26:339–359
- Peterson GD, Allen CR, Holling CS (1998) Ecological resilience, biodiversity, and scale. *Ecosystems* 1:6–18
- Petts GE, Amoros C (eds) (1996) *Fluvial hydrosystems*. Chapman & Hall, London
- Phillips JD (1992) Nonlinear dynamical systems in geomorphology: revolution or evolution? *Geomorphology* 5:219–229
- Phillips JD (2003) Sources of nonlinearity and complexity in geomorphic systems. *Prog Phys Geogr* 27:1–23
- Pickett STA, Cadenasso ML, Grove JM (2005) Biocomplexity in coupled natural-human systems: a multidimensional framework. *Ecosystems* 8:225–232
- Poole GC (2002) Fluvial landscape ecology: addressing uniqueness within the river discontinuum. *Freshw Biol* 47:641–660
- Popper KR (1959) *The logic of scientific discovery*. Hutchinson, London
- Postel S, Richter B (2003) *Rivers for life Managing water for people and nature*. Island Press, Washington DC
- Prendergast JR (1997) Species richness covariance in higher taxa: Empirical tests of the biodiversity indicator concept. *Ecography* 20:210–216
- Ravetz JR (1999) What is post-normal science? *Futures* 31:647–653
- Rhoads BL, Wilson D, Urban M, Herricks EE (1999) Interaction between scientists and nonscientists in community-based watershed management: Emergence of the concept of stream naturalization. *Environ Manag* 24:297–308
- Richter B, Postel S (2004) Saving earth's rivers. *Issues Sci Technol* 20:31–36
- Ricotta C (2005) Through the jungle of biological diversity. *Acta Biotheor* 53:29–38
- Rogers KH (2003) Adopting a heterogeneity paradigm: Implications for management of protected savannas. In: Du Toit JT, Rogers K, Biggs HC (eds) *The Kruger experience Ecology and management of savanna heterogeneity*. Island Press, Washington DC, pp 41–58
- Rogers KH, O'Keefe J (2003) River heterogeneity: ecosystem structure, function and management. In: Du Toit JT, Rogers K, Biggs HC (eds) *The Kruger experience Ecology and management of savanna heterogeneity*. Island Press, Washington DC, pp 189–218
- Scheffer M, Carpenter S, Foley JA, Folke C, Walker B (2001) Catastrophic shifts in ecosystems. *Nature* 413:591–596
- Severinghaus WD (1981) Guild theory development as a mechanism for assessing environmental-impact. *Environ Manage* 5:187–190
- Simberloff D (1998) Flagships, umbrellas, and keystones: Is single-species management passe in the landscape era? *Biol Conserv* 83:247–257
- Sprugel DG (1991) Disturbance, equilibrium, and environmental variability: what is natural vegetation in a changing environment? *Biol Conserv* 58:1–18
- Tress G, Tress B, Fry G (2005) Clarifying integrative research concepts in landscape ecology. *Landsc Ecol* 20:479–493
- Turner MG, Romme WH, Gardner RH, O'Neill RV, Kratz TK (1993) A revised concept of landscape equilibrium: disturbance and stability on scaled landscapes. *Landsc Ecol* 8:213–227
- Turner M, Gardner RH, O'Neill RV (2001) *Landscape ecology in theory and practice: pattern and process*. Springer, New York
- United Nations Environmental Program (1992) *Convention on Biological Diversity*. <http://www.cbd.int/>. Accessed Jan 2011
- Uys M (ed) (1994) Classification of rivers and environmental health indicators. In: *Proceedings of a Joint South African/Australian workshop, February 7–14 1994, Cape Town, South Africa*. Water Research Commission Report No. TT 63/94

- Walker BH, Holling CS, Carpenter SR, Kinzig AS (2004) Resilience, adaptability and transformability in social-ecological systems. *Ecol Soc* 9(2):5 [online]
- Wallington TJ, Hobbs RJ, Moore SA (2005) Implications of current ecological thinking for biodiversity conservation: a review of the salient issues. *Ecol Soc* 10(1):15 [online]
- Walters CJ, Holling CS (1990) Large-scale management experiments and learning by doing. *Ecology* 71:2060–2068
- Waltner-Toews D, Kay J (2005) The evolution of an ecosystem approach: the diamond schematic and an adaptive methodology for ecosystem sustainability and health. *Ecol Soc* 10(1):38 [online]
- Wegner A, Moore SA, Bailey J (2005) Consideration of biodiversity in environmental impact assessment in Western Australia: practitioner perceptions. *Environ Impact Assess Rev* 25:143–162
- Williams PB (2001) River engineering versus river restoration, ASCE Wetlands Engineering and River Restoration Conference, Reno, NV
- Wohl E, Angermeier PL, Bledsoe B, Kondolf GM, Macdonnell L, Merritt DM, Palmer MA, Poff NL, Tarboton D (2005) River restoration. *Water Resour Res* 41(10):W10301
- Wu JG, Loucks OL (1995) From balance of nature to hierarchical patch dynamics: a paradigm shift in ecology. *Q Rev Biol* 70:439–466

Perspectives on Environmental Management and
Technology in Asian River Basins

Higgitt, D.L. (Ed.)

2012, V, 122 p. 11 illus., Softcover

ISBN: 978-94-007-2329-0