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Diversity in Current Ecological Thinking: Implications for Environmental Management

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Abstract Current ecological thinking emphasizes that systems are complex, dynamic, and unpredictable across space and time. What is the diversity in interpretation of these ideas among today's ecologists, and what does this mean for environmental management? This study used a Policy Delphi survey of ecologists to explore their perspectives on a number of current topics in ecology. The results showed general concurrence with nonequilibrium views. There was agreement that disturbance is a widespread, normal feature of ecosystems with historically contingent responses. The importance of recognizing multiple levels of organization and the role of functional diversity in environmental change were also widely acknowledged. Views differed regarding the predictability of successional development, whether "patchiness" is a useful concept, and the benefits of shifting the focus from species to ecosystem processes. Because of their centrality to environmental management, these different views warrant special attention from both managers and ecologists. Such divergence is particularly problematic given widespread concerns regarding the poor linkages between science (here, ecology) and environmental policy and management, which have been attributed to scientific uncertainty and a lack of consensus among scientists, both jeopardizing the transfer of science into management. Several suggestions to help managers deal with these differences are provided, especially the need to interpret broader theory in the context of place-based assessments. The uncertainty created by these differences requires a proactive approach to environmental management, including clearly identifying environmental objectives, careful experimental design, and effective monitoring.

Keywords Contingency · Landscape ecology · Nonequilibrium ecology · Policy Delphi survey · Succession · Uncertainty

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Introduction

Environmental management relies on current ecological knowledge to inform both research and practice. Access to recent knowledge is particularly important given the significant shift in emphasis and perspective in community and ecosystem ecology during the past 30 or so years (Falk and others 2006; Pickett and others 1992; Pimm 1991; Botkin 1990). Of particular importance to environmental management are ideas relating to the dynamics of ecosystems and the relations between biodiversity and ecosystem function. Both provide guidance on how ecosystems respond to environmental management. Increasingly, ecosystems are perceived as exhibiting complex, nonlinear dynamics. This has led to a move away from using deterministic equilibrium models to describe ecosystem development (Pahl-Wostl 1995) toward the view that ecosystems are complex, adaptive systems (Levin 1999). The influences of scale on ecological processes have also been increasingly emphasized (Peterson & Parker 1998).

Many of the concepts associated with current thinking in ecology remain contentious and have prompted a number of responses from ecologists (e.g., Lindenmayer and others 2008; Seastedt and others 2008). One view is that the "balance of nature" notion associated with equilibrium theories in ecology is simply "wrong" (Botkin 1990). Another view admits the persistence of core ecological concepts, such as succession and equilibrium, from older ideas (Fiedler and others 1997). These debates are not new. The theoretical building blocks of ecology have always been vigorously debated in the scientific literature (Porritt 1994). Although the emphasis on disturbance that characterizes current ecological thinking has become more prominent in the scientific literature since approximately the mid-1980s, a number of reviews note earlier recognition of these ideas (Pickett and White 1985).

The debate that characterizes ecology is the mark of a healthy scientific community. It is difficult, however, for environmental managers and policymakers to analyze the merits of different theories and to know how much uncertainty is associated with current ecological knowledge (Hobbs 1998). Uncertainty continues to be an issue for those involved in translating science into management (Cullen 1990; Pouyat 1999; Hayward 2006). Both Pouyat (1999) and Hayward (2006) commented that scientists and policymakers have different rules regarding uncertainty, making communication and shared understandings difficult. Added to this is the desire expressed by policymakers and managers for scientific consensus as a basis for action (Pouyat 1999). As such, the extent of divergence or convergence around current ecological ideas has critical implications for the translation of ecology into practice, including environmental management.

This article presents and discusses the findings from a Policy Delphi survey (Turoff 1975) of ecologists, which explored their diversity of views regarding concepts and issues central to today's ecology. A comprehensive review of these issues is provided elsewhere (Wallington and others 2005). The intention of this study was to understand how ecologists interpret this conceptualization of current topics in ecology, with its nonequilibrium emphasis, and where their opinions were the same and differed from each other. The article concludes with a discussion of the implications of these differences for the practice of environmental management and for ecology as a science.

Methods

A Delphi survey was used to access ecologists' interpretations. Such surveys have been widely used to research complex issues because they offer the opportunity to bring together expert judgment (Hess and King 2002; Crance 1987; Ludlow 1975). They have been applied in a range of disciplines, including environmental science (e.g., Ludlow 1975), marine tourism (Garrod 2003), ecosystem management (Forest Ecosystem Management Team 1993), and biodiversity management. Examples of biodiversity applications include Crance's (1987) work on habitat suitability and Hess and King's (2002) Delphi survey to guide focal species selection.

Such surveys rely on a small panel of experts commenting individually on a set of questions or statements. Their feedback is then distributed anonymously to other panelists between question rounds (usually three) to illicit further input. The Delphi technique allows issues that cannot be dealt with easily using conventional questionnaires or interview-based survey techniques to be usefully elucidated (Garrod 2003).

A Policy Delphi was selected for this study because it enables researchers to expose and explore opposing views from a heterogeneous group (Turoff 1975). Such an approach contrasts with the more widely recognized and applied Delphi approach, in which consensus amongst a homogeneous group is the aim. This Policy Delphi approach rests on the premise that the preferred outcome is having all options and associated reasoning exposed rather than reaching a single agreed position (Clayton 1997). Given the diversity of current thinking evident in ecology (Hobbs 1998), this study sought to capture that diversity and the associated informed judgments of the group (Ludlow 1975).

A panel of eight ecologists completed the study. The expertise and mix of participants in terms of background, interests, and expertise was more important than the size of the panel (Crance 1987). This mix was achieved using nonprobability criterion sampling (Hasson and others 2000). The selected panelists had an international reputation in ecology. Judgment regarding international reputation was based on being extensively cited in the references sourced by the ISI Web of Knowledge Cited Reference Search.

The panel included theoretical, empirical, and applied scientists, with a number of countries and both sexes represented. This broad range from theoretical to applied ecology was selected to access and draw on the issues (Wallington and others 2005) central to nonequilibrium ecology at all levels. A deliberate choice was made not to seek topical representatives (e.g., aquatic, terrestrial, marine) because this would have resulted in a panel too large to manage (Crance 1987). Instead, the selection of ecologists was restricted to those working in terrestrial community ecology given that much, but by no means all, environmental management activities are focused here. A design and monitoring team of three researchers, who were collectively knowledgeable about ecology and had strong editorial skills, ran the survey (Turoff 1975).

The objectivity of Delphi design and monitoring teams, as well as how they generate or reduce items and decide on the most appropriate feedback to panelists, has not been examined in previous Delphi studies. Crisp and others (1997) previously noted this as an important oversight. In this study, objectivity was sought through methodological strictness (using three rounds, each clearly delineated with clear instructions), pragmatism (seeking general knowledge and understanding rather than complete clarity on and comprehensive descriptions of every item), and ethical practice (avoiding leading phrases, emotive wording, or sweeping statements to make sure that phrasing did not bias the panelists' responses) (Crisp and others 1997).

The fundamental aim was to explore how a range of nonequilibrium concepts were interpreted by ecologists with different theoretical and practical backgrounds. Great care was therefore taken to identify and invite panelists whose published views were both different from and similar to those of the design and monitoring team. Twenty ecologists were invited to be involved. Of these, 10 agreed to participate, but 2 withdrew during the study. The final response rate of 8 of 20 (40%) is similar to other reported response rates (e.g., Hess and King 2002).

Although having an expert panel is a widely agreed basis of Delphi studies, discussions about the "best" panel size continue (Crisp and others 1997). Crance (1987) used a Delphi survey to develop habitat suitability index curves. After downplaying the importance of panel size, he commented that at least 8 panelists, ideally 10, are needed. This number should be governed by how many respondents are needed to provide a "representative pooling" of judgments and the information-processing capabilities of the design and monitoring team (Crance 1987). The panel in this study included theoretical, empirical, and applied ecologists to provide this breadth. In terms of the design and monitoring team, managing 8 panelists proved labor intensive, with the process taking more than 1 year to complete. In large part this was because of the complexity of the ideas presented and the associated complexity of responses by panelists. Having 8 panelists in this study satisfied the suggestions made by previous researchers and was manageable for the design and monitoring team.

One of the greatest challenges with Delphi surveys is keeping the panelists involved throughout multistaged surveys, often with a large amount of associated reading and analysis (Garrod 2003). In this study, panelists were offered coauthorship of this article in recognition of their contribution and to provide an appropriate incentive for their continued involvement. As such, this article was authored by the design and monitoring team and the panelists.

This Policy Delphi study was conducted in three rounds by way of e-mail. The first round involved distributing a set of statements providing a synthesis of and interpretation of current ideas in ecology based on an extensive literature review by the design and monitoring team (see Wallington and others 2005). Panelists were asked to agree or disagree, including giving reasons, with each statement. A number of these statements incorporated the concept of disturbance, given its centrality in environmental management, and especially in efforts to restore degraded landscapes where managing disturbance is critical for success. In the second round, a revised version of the statements was distributed; the revision sought to capture the panel's collective breadth of views. For each statement, the extent and nature of agreement and disagreement and associated reasoning was also provided. Panelists were asked to reconsider their round 1 responses based on the responses provided by other participants. Participants remained anonymous to each other throughout the first two rounds. Table 1 provides the final statements, edited by the design and monitoring team to ensure clarity, reflecting the focus of the Delphi survey. The third round sought the participants' input to a first draft of this article.

Results and Discussion

The results showed general concurrence with nonequilibrium views about ecology as summarized in Table 1. For more than half of the issues, panelists agreed with the statement and with each other (Tables 2 and 3). This included agreement about ecological responses to disturbance being historically contingent, the importance of recognizing multiple levels of organization, and the role of functional diversity in environmental change. There was also agreement about spatial scale as a critical

Table 1 Statements regarding issues of central concern in current ecological thinking

Issue	Description
1. Stability, disturbance, and multiple stable states	Ecosystems are dynamic, open systems existing in a constant state of flux, usually without long-term stability. Disturbance constantly pushes ecosystems in alternative directions, and multiple stable states may exist concurrently.
2. Nonlinear development and uncertainty	Ecosystems are (cyclic) systems that are often subject to sudden, unpredictable change. Therefore, uncertainty is normal, and predictable end points to successional processes are rare.
3. Openness, contingency, and heterogeneity	Ecological systems are open, heterogeneous systems. Their structure and function are variable across multiple spatial and temporal scales and levels of organisation. The successional development of ecosystems is historically contingent depending on particular biophysical conditions.
4. Levels of organization	Insights into the dynamic nature of ecological systems have meant a shift in emphasis from structure, and an emphasis on species, to the processes that maintain structure. Biodiversity must be considered beyond species to include a number of hierarchical levels (individual organisms, populations, communities, ecosystems, landscapes).
5. Spatial scale and hierarchy theory	Dominant ecosystem processes change with scale. However, the structure and overall behavior of ecosystems can be understood in terms of a few dominant processes. For example, biotic factors (e.g., individual species) are of central interest at intermediate spatial scales, rather than primary functions (e.g., transfers of energy, nutrients).
6. Patchiness and landscape ecology	Issues of variability across space and time, fragmentation, and natural resource problems at large spatial and temporal scales suggest greater attention to landscape ecology. When ecological systems are recognized as open and heterogeneous, landscape-level patchiness has strong potential as a guiding conservation principle.
7. Species richness and ecosystem function	The maintenance of functional ecosystems is essential to sustain high species diversity, whereas the contribution of such diversity to ecosystem function is less clear. However, given the high societal value afforded biodiversity, increased efforts should be made to maintain the ecosystem processes on which it depends.
8. Functional diversity and environmental change	The attention to temporal variability in nonequilibrium ecology suggests an emphasis on species' responses to environmental change. This approach unites the focus on particular biotic elements with one on the functional types of species present. The role of species with similar ecosystem effects but different responses may be one of the most important mechanisms for sustaining functional ecosystems in the long term.
9. "Pristine" versus human-modified systems	Human disturbances are now amongst the most important factors shaping ecosystem change. Therefore, biodiversity conservation must recognise the role of humans as primary agents of flux in ecosystems and as an integral component in ecological, evolutionary, and environmental processes.

consideration in ecology and the importance of understanding human-modified as well as "pristine" systems.

For the remaining issues, the panelists either disagreed with the statement, disagreed with each other, or both. The predictability of successional development, "patchiness" as an ecologically meaningful concept, and the benefits of shifting the focus from species to ecosystem processes elicited divergent responses among the panelists as well as disagreement with the statements. For stability and disturbance, the result was even more complex. Although there was agreement that disturbance is a widespread, normal feature of ecosystems, diverse views were expressed about how it is best conceptualized and understood.

In reading the following results, it is important to keep in mind the complexity of the statements and how this led to complex responses. This complexity is captured in Tables 2 and 3 in three ways. First, the extent of agreement *with* each issue statement is detailed. Table 2 provides summary details (columns 2–5). Where there was qualified agreement it was usually because a panelist agreed with part but not all of the statement (column 3). Table 3 details where there was clear agreement on an issue (column 2) as well when parts of issue statements were problematic for panelists (column 3).

Second, the extent of agreement *among* panelists rather than with each issue statement is provided in column 6 of Table 2. This column provides a nuanced capturing of panelists' responses. For example, although most panelists agreed with the disturbance issue statement, there was disagreement between them regarding the attributes of disturbance. This is reflected in column 6 of Table 2 by "no." Third, the last column in Table 2 provides a summary comment for each issue statement based on *combining* the extent of agreement with the statement and among other panelists. Some of the disagreement reported in these tables and in this article may have been generated by these complex statements; however, the approach detailed previously helps to better understand the panelists' responses to this complexity.

To assist interpretation of the results, the terms "some" (2 to 3 panelists), "half" (4 panelists), and "most" (6 to 7 panelists) are used in the following discussion to describe the extent of agreement or otherwise with a statement or part of it. These terms are not used to impose a level of

Table 2 Extent of agreement and disagreement with the issue statements and other panelists from the Delphi survey (sourced from three rounds)[a]

Issue statement	Extent of agreement or otherwise with issue statement				General agreement[b] among panelists (>75% of panelists)	Convergence/ divergence within Delphi panel
	No. in agreement	No. in qualified agreement	No. in disagreement	General agreement[b] (>75% of panelists)		
1. Stability, disturbance	1	7	1	Yes (8 of 9)	No	Qualified convergence
2. Nonlinear development	1	3	5	No (4 of 9)	No	Divergence
3. Openness, contingency	5	3	1	Yes (8 of 9)	Yes	Convergence
4. Levels of organization	3	3	2	Yes (6 of 8)	Yes	Convergence
5. Spatial scale	2	1	6	No (3 of 9)	Yes	Convergence
6. Patchiness	3	4	1	Yes (7 of 8)	No	Divergence
7. Species richness	1	3	5	No (4 of 9)	No	Divergence
8. Functional diversity	5	3	1	Yes (8 of 9)	Yes	Convergence
9. Pristine versus modified	4	5	0	Yes (9 of 9)	Yes	Convergence

[a] $n = 9$ (from round 1) with 8 panelists completing the survey

[b] "General agreement" equates with the term "most" as used and explained in the text

precision that is unachievable given the panel size and the complex issue statements under consideration. Rather, they are relied on to give a sense of the strength of support or otherwise for a statement and of agreement or disagreement between panelists. The terms are a communication tool more than analytic statements.

Other Delphi studies (e.g., Hess and King 2002) devote most of their results and discussion to an analysis of the substantive changes between rounds. An alternative approach of providing summative conclusions has been deliberately taken here for the purposes of progressing our understanding of current thinking and informing future research and environmental practice. These summative conclusions provide the range of views presented by panelists and, for many statements, the material used by panelists to support these views (i.e., empirical evidence, conceptual reasoning or arguments based on experience—see Wallington and Moore 2005). As such, in this section, references serve a dual purpose. They form part of the evidence provided by panelists to support their views as well as being used by the authors of this article to position the study findings relative to other published work.

Stability, Disturbance, and Multiple Stable States

"Disturbance" was widely viewed as a normal feature of most ecological systems, and most panelists offered qualified agreement with the statement provided (Table 1 [issue 1] and Table 2). Natural disturbance regimes were identified by these panelists as an important characteristic of ecosystems. It was also agreed that disturbance is easily misunderstood. For example, a panelist noted that disturbance can refer to a single tree falling or to plate tectonics, so that what is considered disturbance may be a matter of semantics. Disturbance was also noted as a matter of scale. The phrase "constant state of flux" (Table 1, issue 1), was noted as being problematic by some panelists and as being prone to exaggeration and misunderstanding by nonecologists.

Despite agreement by most panelists about the importance of clearly defining "disturbance," there were different opinions about how to define "stability," the ability to generalise about frequency and intensity of disturbance, and the possibility of multiple stable states (Table 3). As such, the collective response by the panel to this issue is best described as "qualified convergence" (Table 2). Although most panelists agreed with disturbance as an integral part of ecosystems, a diversity of views was expressed on how disturbance is best conceptualized and understood.

The contrasting definitions of stability recorded during this survey are illustrative and reflect the broader stability–disturbance debate of recent years (Ehrlich and Hanski 2004; Loreau and others 2002a) and even earlier. These include the idea of stability as "resilience" (Holling and others 1995), where stability refers to the ability to experience disturbance without decreasing into a qualitatively different state. A contrasting view is stability as "persistence" (Pimm 1991), where populations tend to return to some central value in the short term after disturbance but show increasing variance during longer periods.

Nonlinear Development and Uncertainty

For "nonlinear development and uncertainty," panelists disagreed with the statement and with each other (Table 2). Disagreement centered on the predictability of successional change after disturbance occurs. Some panelists also considered the term "cyclic" to be problematic because it implies that ecosystem change follows a deterministic,

Table 3 Nature of agreements and disagreements with issue statements from the Delphi survey

Issue statement	Agreement	Disagreement with statement/other panelists
1. Stability, disturbance	Disturbance a widespread, normal feature	Definition of stability; ability to generalise about disturbance frequency and intensity; possibility of multiple stable states
	Clear definitions important	
2. Nonlinear development	Nonlinear development of ecosystems is possible	Use of "cyclic"
		Successional predictability after disturbance
3. Openness, contingency	Ecological systems are variable	"Openness" and "heterogeneity" are vague terms
	Development is historically contingent	Differing opinions regarding availability of empirical evidence for contingency effects
4. Levels of organization	Emphasis on multiple levels	Interest in retaining a species focus and problems noted with the concept of "ecosystem processes"
5. Spatial scale	Spatial scale critical	Concern regarding hierarchy theory and whether dominant ecosystem processes do change with scale
		Differing opinions about which process(es) dominate at which scale(s)
6. Patchiness	Landscape-level approaches are important	Differing opinions regarding the concept of patchiness, including objections to its use
	Clear definition and consistent use of terms (e.g., "patchiness") important	
7. Species richness	Focus on both biodiversity and ecosystem function	Opposition to shifting to a focus on ecosystem processes for different reasons
8. Functional diversity	Functional diversity is important	Sufficiency of evidence for functional diversity hypothesis contested
9. Pristine versus modified	Understanding altered systems is important	–
	Current and future research issues raised	

repetitive pattern. The dominant variability in systems may be stochastic and aperiodic. Participants' responses may reflect recent increased attention in the literature paid to the usefulness of the concepts of nonlinear dynamics and alternative stable states (Suding and Gross 2006; Mayer and Rietkerk 2004; Suding and others 2004).

Some panelists noted that succession is remarkably predictable. For example, classic "old field" succession follows generally predictable patterns. Although these panelists mentioned interesting exceptions, they argued that communities almost always come back to the end points expected by local natural historians, whereas serious evidence of widespread unpredictable successional trajectories has not been produced. Empirical evidence was invoked by some other panelists to support the contrasting view, that succession after disturbance is unpredictable. One panelist drew on paleoecological evidence from Mount Rainier in the Pacific Northwest of the United States (Dunwiddie 1986) suggesting that climate change has altered the regeneration niche for tree species so that a disturbance event "flipped" the forest system to a completely new species assemblage.

Openness, Contingency, and Heterogeneity

"Openness, contingency, and heterogeneity" are increasingly being emphasized as cornerstones in ecological thinking (Ostfeld and others 1997). Most panelists agreed that ecological systems are variable across multiple spatial and temporal scales and levels of organization, although there were concerns about the vagueness of the terms "openness" and "heterogeneity" (Table 3).

Most panelists also agreed that the successional development of ecosystems is generally historically contingent and depends on local biophysical conditions and the dynamics of neighboring or connected ecosystems. Although contingency effects are increasingly recognized, some panelists argued that their importance is not supported by empirical evidence (Table 3). Others suggested that the importance of historic land use and disturbance in explaining contemporary community composition and ecosystem characteristics has been strongly demonstrated during the past two decades (e.g., Foster and others 2003; Dupouey and others 2002; Turner and others 1997a).

Levels of Organization

In terms of "levels of organization," most panelists supported a general shift in biodiversity conservation beyond species to incorporate higher levels of organization, such as populations, ecosystems, and landscapes (e.g., Peterson and others 1998; Pickett and others 1992). Those who disagreed noted that a species focus is the most effective means of conserving biodiversity. They argued that although alternatives to a species focus are theoretically appealing, these alternatives have no practical utility within the time scale over which conservation measures must be implemented. They attributed this lack of utility to ecosystem ecologists being unable to agree on definitions and measures for individual organisms, populations, communities, ecosystems, and landscapes. Some panelists commented that focusing on "ecosystem processes" alone is unlikely to be sufficient because the term is loose and poorly defined (Table 3). Such processes may also be difficult to measure.

Spatial Scale and Heirarchy Theory

Thinking about "spatial scale" has been dominated by theoretical developments largely under the rubric of hierarchy theory (Allen and Hoekstra 1992). Although most panelists agreed that spatial scale is a critical consideration for biodiversity conservation, most disagreed, for generally similar reasons, with this issue statement (Table 3). Half noted that although hierarchy theory was helpful conceptually, testing or using it in a predictive sense was problematic. Some noted the lack of sufficient comparative empirical evidence for the scale-dependence of ecosystem processes. Panelists also expressed differing views regarding which ecosystem processes dominate at different scales (Tables 1 and 3).

Patchiness and Landscape Ecology

For "patchiness and landscape ecology," there was divergence in the views of the panelists regarding both the intent and usefulness of patchiness, although most panelists agreed that landscape-level approaches are central to ecology (Tables 2 and 3). Most agreed that an understanding of landscape-scale and patchiness issues depends critically on the clarity of associated terms such as "patchiness," "patch," "matrix," "context," and "flux." Patchiness was objected to by some panel members, however, as a catagorical approach to heterogeneity that is based on discrete classes. These panelists also commented that the classes used to define patches will vary depending on the response variable of interest (Gustafson 1998). Although it is often viewed as being central to landscape ecology (e.g., Wiens 1996, 1997), patchiness is coming under increasing scrutiny as its relevance is questioned (Lindenmayer and others 2003; McIntyre and Hobbs 1999).

Some panelists commented that consideration of spatial context need not be limited to discrete approaches (e.g., Turner and others 1997b). An alternative to codifying patchiness is broadening heterogeneity to include continuous variation (Austin 1999). These panelists suggested that a more general term, such as "spatial heterogeneity," could be more acceptable. Another suggestion was to include functional terms to help better explain and understand spatial heterogeneity. Networks and gradients were also suggested as being more appropriate conceptual frameworks, rather than patchiness, in some cases.

A further objection by some panelists to the patchiness concept focused on its anthropocentric nature. They noted that patchiness is an organism-based concept (just like habitat is a species-specific concept), so that what humans perceive to be a patchy environment may not be so for a particular species. Finally, a panelist noted that there is danger that the recent emphasis on large- and landscape-scale perspectives may result in the neglect of smaller-scale phenomena. The panelist referred to empirical data from work in the fragmented landscapes of eastern Australia to support their ideas on the importance of multiscaled approaches (Lindenmayer and Franklin 2002; Lindenmayer and others 2002).

Species Richness and Ecosystem Function

In recent years, interest in the relation between "species richness and ecosystem function" has increased (e.g., Naeem 2006; Kinzig and others 2002; Loreau and others 2002b) (issue 7). The debate over the ecosystem function of biodiversity has continued for the past decade (Loreau and others 2001, 2002b). Half of the panelists disagreed both with the issue statement (Table 1) and with each other. They objected to shifting the focus of conservation from species to ecosystem processes, a concern also associated with the statement on levels of organization (Table 3, issue 4). They also objected to a focus on processes because they remain unconvinced of the connection between biodiversity and ecosystem services that often underpins this argument. The body of work considering ecosystem services as a focus for ecosystem management was noted as growing rapidly (Daily and Ellison 2002; Clewell 2000; Costanza and others 1997; Daily 1997). Some panelists commented that shifting the emphasis toward ecosystem processes was problematic because they are poorly understood by both scientists and the general public (McIntyre and others 2002).

Functional Diversity and Environmental Change

In contrast, most panelists agreed that "functional diversity" is important (Table 1, issue 8). They noted that species diversity has been advocated as enhancing the long-term resilience, or adaptive capacity, of an ecosystem through underwriting the provision of ecosystem functions under a range of environmental conditions (Holling and others 1995). Whether there is sufficient evidence for the functional diversity hypothesis was contested. Some panelists noted that there are no empirical data to suggest that a multispecies, locally stable equilibrium characterizes any ecosystem. They commented that, at best, the empirical evidence remains weak. Adding further complexity to the responses, some others referred to empirical evidence demonstrating that different species respond differently to environmental change (Lindenmayer and others 2002; Robinson and others 1992). This evidence was used to support the case for drawing a clear distinction between the influence of species richness on ecosystem processes, for which there is a lack of evidence, compared with the influence of particular species' traits, or occasionally species-combinations, for which evidence is accumulating (Harte 1997).

"Pristine" Versus Human-Modified Systems

Despite most panelists agreeing that it is important to understand and research altered systems—i.e., "'pristine versus human-modified systems," the ninth issue—several challenges were raised regarding current and future ecological research and management. Some panelists noted that clarification is required regarding the relative research and management effort devoted to systems that are less modified by humans. Such systems provide critical baselines for comparison with modified systems; however, the extent of human influence in many countries makes it increasingly difficult to find such areas. Other panelists noted that consideration must be given to the intent of management for these systems (Hobbs 2004).

Before moving on to the conclusion, it is worth briefly commenting on the usefulness (or otherwise) and robustness of the Policy Delphi method in this particular study. The complexity of the statements (Table 1) was potentially problematic. Other Delphi studies have focused solely on one or a few statements only, and the whole study has been devoted to reworking these few statements. The objective of the present study was to get an overview of the field of ecology (an enormous task), thereby requiring a set of statements covering the field, which was an ambitious undertaking. These statements were published previously by Wallington and others (2005). A similar broad-ranging approach, using expert workshops rather than a Delphi survey to consider these issues, was recently successfully undertaken and reported by Lindenmayer and others (2008).

Conclusions and Implications

The simulated "discussion" between ecologists reported in this article has suggested a number of similarities and differences, with more of the former than the latter, in how a panel of respected ecologists interpreted statements about a number of current topics in ecology. The different responses have implications for environmental management as a practical activity as well as for the priorities and approaches to the practice of ecology as a science. They also provide a microcosm of current areas of debate in ecology of direct relevance to environmental management. In addition, these findings provide insights warranting further reflection and investigation, as have the findings from other similarly run Delphi studies (e.g., Hess and King 2002; Crance 1987).

Agreement or convergence of views, as was the case with more than half of the statements (Table 2), provides guidance for managers making decisions about environmental management while remaining aware that these views reflect the judgments of a small group of people. For a number of ecological principles, such as disturbance as a widespread normal feature of ecosystems, a sound, relatively uncontested basis for environmental management activities exists. Where such consensus among scientists exists, use of their science by environmental policymakers and managers becomes more likely (Pouyat 1999).

For the other issues, where divergence of views was apparent, the future is necessarily more complex, challenging, and interesting for managers and scientists alike. The divergence regarding the predictability of succession has consequences for environmental management where information regarding the processes and outcomes of succession is essential to underpin environmental choices and subsequent site management. For example, understanding and working with succession underpins fire management in many biomes throughout the world as do other contested areas of environmental management, such as forest insect attack and wetland restoration. As such, whether successional processes are predictable or not (and these results showed disagreement) is important to managers. If ecologists are providing different advice then the ability of managers to confidently move forward may be jeopardized (Cullen 1990). One way forward has been offered by recent work in old-field ecology on "bounded generalizations" (Cramer and others 2007). This concept recognizes that some generalizations are possible, but they are strongly influenced by the conditions of the site. The importance of place-based knowledge is emphasized while being cognizant of generalizations that might also apply.

Divergent views about patchiness are also critical because of its central place in landscape ecology and the landscape-level approach taken to many environmental management activities. Having landscape-level ecological information is also critical for environmental management because of the increasingly (political) importance of ecosystem services to environmental management and its positioning at the landscape level. Such divergence of views can be addressed by taking a pluralist approach to landscape classification, where patchiness is one classification system. How a landscape is perceived and classified can be determined by the problem being addressed and what management is subsequently planned (Lindemayer and others 2008). For example, when managing for biodiversity as an ecosystem service, the management of different species contributing to that service may benefit (or not) from different landscape classifications, with the choices depending on both the issues and outcomes sought.

The idea of moving beyond a species focus to ecosystem processes stimulated disagreement among panelists. Given that environmental management activities often focus at the landscape, ecosystem, and community levels, the continuing focus on species to the potential exclusion of other levels of organization is unlikely to provide managers with the information they need. Increasing interest in ecosystem services also emphasizes the importance of having a detailed understanding of the ecosystem processes that underpin or provide these services. Lindenmayer and others (2008) recommend managing both species and ecosystems at multiple ecological scales. Thus, returning to the example of forest insects as pests, environmental management would seem to require a focus on both the species (trees and pests) and the communities and landscapes, and associated ecosystem processes, of which they are part.

These results also have implications for the practice of ecology as a science. Given the suggestion that the ecological ideas explored through this study are best applied in the context of place-based knowledge, there is a need for ecologists to continue to empirically research a diversity of species and ecosystems, both to assist managers through collaborative efforts and to further conceptual understanding. It also seems imperative that ecologists spend more time considering how their conceptual and theoretical ideas can be transferred to management. Equally as important is whether these ideas are valuable for managers as heuristics or if they can be further developed to provide explicit guidance on management approaches. These efforts could be encouraged in the most contested areas: nonlinear development and uncertainty, patchiness, and moving beyond species to focus on ecosystem processes.

Ecology has long been characterized by apparently antithetical concepts, such as continuity and change (Ingerson 2002). Although debate and disagreement are signs of a vibrant community of scholars, a critical challenge is having useful information for managers. One way of achieving this is to have ecologists and managers working side by side; a "science of engagement" (Meffe 2001) for ecologists. Such engagement, led by managers and including ecologists, policymakers, and other stakeholders, is critical given the uncertainties and divergence in current ecological thinking. Active adaptive management, ideally achieved by an ongoing, interdependent relations between research and management (Shea and others 2002; Hobbs 1998), takes this engagement one step further.

Recent ecological research (e.g., Seastedt and others 2008) advocates that where uncertainty is a feature of ecological systems, that environmental management proactively identifies and works toward environmental objectives irrespective of the scale or focus of management. This should be accompanied by careful "experimental" design (where management is an experiment) and monitoring. Given uncertainties from multiple sources, it seems "crucial not to do the same thing everywhere so that we limit the risk of making the same mistake everywhere" (Lindenmayer and others 2008, p. 88).

Also, scientists and managers have different ways of dealing with uncertainty that make communicating ecological findings to managers and their subsequent uptake by managers difficult (Pouyat 1999). Scientists never discover "truth"; their results are always accompanied by uncertainty. As a group, they are quite accepting of uncertainty. In contrast, policymakers and managers often "expect it [science] to deliver a truth that is nonarguable" (Cullen 1990, p. 201). A need emerging from this difference is honing managers' skills in dealing with scientific uncertainty and complexity. In addition, with complex problems, there is rarely a right or wrong answer, only better or worse solutions depending on one's goals. Important skills include keeping up-to-date with scientific research, being able to evaluate the contributions of empirical and theoretical findings to practice, and developing management systems and approaches for dealing with risk and uncertainty. Uncertainty and risk are inherent features of working with ecological systems, and increased awareness and skills in these areas are essential for environmental management.

In conclusion, these differences in how a panel of respected ecologists interpreted statements about a number of current topics in ecology provide an opportunity for collaboration and further research attention. This is an opportunity for collaboration between empirical and theoretical ecologists and between those involved in the science and practice of environmental management. The final place where collaboration is essential is between managers and citizens, because ultimately citizens determine the goals of environmental management. Resolution of this nexus between ecology, management, and society is essential to ensure that ecological research remains relevant to real world issues, that environmental management is informed by the best science, and that society has the best chance possible of achieving its preferred outcomes.

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