REDEFINING ROLES OF SCIENCE IN PLANNING AND MANAGEMENT: ECOLOGY AS A PLANNING AND MANAGEMENT TOOL

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Abstract: Science as a way of knowing has great value to decision-making but there is need to consider all its attributes and assess how science ought to be informing decision-making. Consideration of the critiques of science can make science stronger and more useful to decision-making in an environmental and ecological context. Scientists, planners, and managers need to consider the critiques of science and ecology, and examine how science can adapt and incorporate these critiques into the application of science and decision-making. This paper outlines many of the challenges facing the use of science (specifically ecology) in decision-making and shows possible areas for overcoming these challenges.

Critiques have questioned the following assumptions of science: 1) whether it is value-free, 2) concepts of order and predictability and 3) modern science's claim to being the key way of 'knowing'. Challenges have also been issued to the application of science such as: 1) the simplistic causal mechanisms used and 2) the lack of consideration for complex interactions and multi-scale issues. Science can be seen as a process of understanding rather than as a collection of facts. As a process, knowledge is changeable and adaptive, precautionary approaches become vital.

Ecology is a science that is beginning to recognize the need for value identification, the need for a multi-scale and multi-perspective approach. Ecology itself requires a multi-disciplinary systems approach. Solutions provided by ecology should stress relative merits instead of absolute answers. Rather than being viewed as a 'weak' science may be the most useful science and tool for dealing with environmental problems that are complex, multi-scale, and cannot necessarily be solved by reductionist measures alone. Ecology and the philosophy of science can be shown to advocate an adaptive precautionary approach given the complexity of social and bio-physical interactions.

Introduction

Questions abound regarding the roles of science in planning and management decision-making. These roles are debated at many levels and generate diverse responses. Two examples of these responses have stemmed partially from post-normal science and post-modernist critiques. Post-normal analysis evaluates assumptions of linear causality in a quest for unerring predictability and control of nature; the implications of these assumptions are also examined. Post-modernists indicate that science is relative and, as such, the predominant use of science as a key mode of "knowing" may be fundamentally misguided when it is applied to decision-making. These insights, among others, are helping to redefine a role for science that appears to coincide with a new era of planning that includes a civics model, precautionary principles, and an ecosystem approach.

Despite emergent models of the use and definition of science, current management and planning may not be able to easily incorporate redefined concepts, nor experience the ideals represented by those models. In short the adaptability of institutions to these concepts remains questionable (Holling, 1995; Kay et al., 1999). The conceptual jumps required may be too great for current practices to deal with, as often, theoretical ideas lack the means for pragmatic implementation. Finding a middle ground for the role of science that can allow adaptation of these new concepts may be required. Despite numerous arguments from scientists, planners, managers, and academics that planning and management should be more science-based, these new models advocate a defined role for science set within a well established construction of social values and objectives to guide both the planning and management process.

Ecology, a key science in environmental decision making, provides an opportunity for scientists, planners, managers, politicians, and all of society to reshape interactions with the natural world. Many use ecology as a scientific tool to support desired decisions and as a means of understanding human impacts on the environment. Ecology is also used in attempts to transform ecological concepts into ethical, prescriptive stances (Callicott, 1986). While I agree with many of these attempts, and understand the need to adopt an ecological perspective, there is an equal need to consider what ecology, and specifically what ecology as a science, actually has to offer society. This process starts with an understanding of what is meant by science, followed by descriptions of what shapes ecology.

Critiques of science suggest that science, as a way of knowing, may be seriously misguided when it is applied to decision-making in an environmental and ecological context (Funtowicz & Ravetz, 1994; Schneider & Kay, 1994a). Scientists, planners and managers need to appreciate the critiques of science and ecology, and examine if, and how, science can adapt to incorporate such critiques into the application of science in decision-making. These critiques may be particularly salient for recreation research as many of the models for recreation planning and management are based in assumptions of scientific method.

Poor use of science includes simplification of diverse social contexts for planning and management as reflected in such models as Limits of Acceptable Change, Recreation Opportunity Spectrum and others. Secondly, biophysical impact assessments, monitoring, and carry capacity considerations make simplistic assumptions (linear, mechanistic causality) about the bio-physical world (Schneider & Kay, 1994a). These models often do not, and possibly cannot, grasp the complexity of social and ecological systems in order to provide for effective, beneficial, and long-term decisions. A brief look at some of the characteristics of environmental and ecological problems helps explain the difficulty of planning and managing in social and ecological domains.

The Nature of Ecological Problems

Ecology, in its most general form, is the study of changing interrelationships between organisms and their biotic and abiotic environments (Loeb et al., 1998; Schneider & Kay, 1994a). Studies of ecology occur at multiple levels of interaction but no matter what the level, it is important to remember that each level is influenced by, and in its own turn influences, interactions and processes at other levels (Loeb et al., 1998). The diversity of interactions in ecology has created such concepts as emergent complexity (Schneider & Kay, 1994b), multiple scales and non-linear dynamics (Holling, 1992) that require approaches beyond the mechanistic, reductionist methods often used in a Newtonian-portrayed, modern science (Slocombe, 1998; Schneider & Kay, 1994a). Because of inherent uncertainty and movement away from traditional approaches, ecology is often seen as being a weak science, as intractable, messy, and unpredictive (Slobodkin, 1988; Peters, 1991).

Much of the reason for the "messiness" and conflict with ecology has emerged because of the following: the types of problems that it has been asked to solve (Slobodkin, 1988); the types of questions that ecology, in turn, is forced to ask (Grumbine, 1992; Schneider & Kay, 1994a); and the nature of the social settings in which these problems are being asked (Walters & Holling, 1990; Holling, 1995). On the environmental movement front, concern over ecological problems were motivated by analogies between the dynamics and complexities of ecological systems and human societies and a concern to plan and manage human societies within their ecological context and constraints (Slocombe, 1998).

Similarly, ecology was being asked to address problems in various resource industries (forestry, fisheries, etc.) where the scientific concepts traditionally used were not providing accurate predictions and resulting ecological disturbances were causing considerable economic problems (Gunderson, Holling, & Light, 1995). Global population growth and resource crises shaped ecological problems primarily as problems of scale. Decisions made at one particular scale created problems at multiple scales and often hidden at the scale of the initial implemented decision. Reactions to the new problems often focus, again, at only one scale (Norton, 1995) rather than attempting to view a complete scaled system.

Additionally, an ecological problem could depend largely on popular perception (Slobodkin, 1988). People will care for what they see and not necessarily think about what they definitely know. The popularity of cute, furry species or majestic landscapes as symbols for environmental groups illustrates this dynamic and these symbols often become the focus of concern rather than root ecological problems and knowledge. Recognizing this, Slobodkin (1988) is quick to point out that solutions to environmental problems depend as much on the power of poetry and arts, as on economics, while the techniques of carrying out the resolution hinge on ecology. That is to say that environmental problems and perceptions of environmental problems have at least two aspects to them: value statements of what is desired and ecological understanding, explanation, and definition of what might be possible.

Ecological problems manifest themselves as multi-scale problems, require multiple types of perspectives (nutrients, populations, landscapes, etc.) and do not appear to be adequately solved using traditional linear, mechanistic approaches to scientific understanding. As well, a complex social dynamic merges with this bio-physical reality such that ecological planning and management of environmental and ecological issues requires acknowledgement of social values. Defining socially desired goals for an ecosystem is quickly becoming an important aspect of planning and management. In this form, ecology is a science that challenges much of the core modernist approaches to science.

What is Science?

Science is first and foremost a philosophy of understanding and learning. As a philosophy it shapes the process by which we go about learning and understanding the world around us. Its strength lies in its search to acquire knowledge that has the greatest likelihood of being true (Goldsmith, 1993). Science, as a philosophy and in practice is also subject to critique from diverse arenas of society. One notable critique portrays science as manifesting perceptions of today's world as normal, simplistic and unchanging (Goldsmith, 1993). Others suggest that science's claim to neutrality (or being value-free) is impossible and that the introduction of values to science invalidates scientist's work. A brief explanation of the philosophy of science helps to explain how some of these critiques are not necessarily critiques of the philosophy of science but rather of the practice of modernist science.

Biggins (1978) suggests that science is about our views on the possibilities for using nature, the constraints on our using nature, and our relationship to nature or, in short, it is about understanding the human-environment interaction. Science is a form of logical investigation about the how things work. Popper (1994a) would argue that science is about rational criticism; through discussion of ideas, knowledge and understanding can be furthered. This is an important distinction as society, decision-makers, and indeed many scientists and researchers, have established science as a static and concrete collection of facts and predictive tools rather than as a process of learning.

For Popper (1994a) and other scientific philosophers (Peters, 1991; Callicott, 1986), science is defined by the following: investigating the world by creating conjectures or hypotheses (problem creation); testing the hypotheses and developing evidence (hypothesis testing); and presenting the train of thought (or theory) to critical examination by both the proprietor of the theory and by others who wish to examine and test the theory (critique).

Problem creation is arguably the least understood component of the scientific process but remains a crucial component of the scientific endeavour. In theory, researchers examine the literature about other theories and weigh out the relative merits of different methodologies, theories, and ideas, in an attempt to establish some new theory or direction for research. In practice however, it has been shown that researchers often turn a blind eye to the diversity of theories, instead focusing a smaller set, in attempts to provide evidence to strengthen their own theories or "pet" ideas (McIntosh, 1980). At a basic level, problems are tensions between knowledge and ignorance; they are imperative for the progress of knowledge (Popper, 1994a). The hypothesis creation phase develops the questions or discovers the problem to be researched and then creates ideas (conjectures) about the possible reasons for the existence of the problem. Problems may arise when we look at the world and perceive differences between observation and perception. That is to say, that the art of creating hypotheses may be a largely internalized process in which we mix our ideas of how things work with previously discovered phenomenon, other research, and our observations (Peters, 1991). As such, a hypothesis is formed which makes formalized statements about how the world might work, in preparation for a formalized testing of these statements.

From problem creation, the next phase is to test hypotheses. Hypothesis testing is perhaps what scientists do best. There are well established procedures and protocols for the multitude of tests that need to be done. They range from statistical sampling protocols to established tools and measurement techniques, most developed in attempts to reduce researcher bias. Testing is done by comparing deduction to observation (Peters, 1991). The original theory is tested by whatever means of observation are available and relevant. A positive test of a hypothesis proves only that in the context of the test, the theory is correct. It does not prove that the theory will be correct in all cases. Indeed, Popper (1994b) suggests that even the most rigorously tested theories will always be conjectures and hypotheses. This means that a new hypothesis can and should be created which can be further assessed against others. Popper (1994b) argues that we regard one hypothesis as better than another if, when testing is complete, it fulfils three requirements:

1) the new hypothesis must explain all the things that the old hypothesis successfully explained;
2) it must avoid at least some of the errors of the old hypothesis;
3) it should, where possible, explain things that could not be explained or predicted by the old hypothesis.

This amounts to the basis of the scientific critique and is how scientific understanding constantly evolves (Funtowicz & Ravetz, 1993).

Critical examination of theories follows this process and provides further problems for examination. Popper's form of critical discussion is in actual fact the explaining of a new theory, in light of, and better than an old theory. We have already seen this in his explanation of the three parameters by which an old hypothesis is rejected for a new one. But what is necessary is to know if a new theory would be considered acceptable. For Lee (1993), "an experiment is a systematic way of answering a question. Whether the results constitute a valid answer is a test of the competence of the experimenter."

In order for results to constitute a valid answer, internal and external validity must be made (Lee, 1993). Internal validity might be described as correct inferences: those considerations and decisions made in the course of developing and testing a hypothesis. According to Lee (1993), internal effects to experimental validity occur due to: the following factors: historical events, events that would have occurred anyway, flukes, effects caused by the experimenter, results that occurred because of measurement tools, and decisions of sampling. These factors consist of all things that would effect and bias the answers due to the experiment itself.

External validity constitutes whether the results can and are correctly applied to other situations (Lee, 1993). Threats to external validity generally take the form of changes to the subject matter, because of measurement, such that replication is not possible. Some examples include: multiple interventions causing non-linear changes, and complex interventions which are not repeatable due to failures or impossibilities in including those components actually responsible for the effects (Lee, 1993). Lee realizes that the approach offered may prove too idealistic but suggests that insisting on an idealistic approach to science does not entail refusing to do science unless it is invulnerable to criticism. Rather, it entails approaching a problem scientifically. For Lee (1993), evaluating internal and external validity provide an orderly framework in which to make assessments about the objectivity of an experiment and hence of a theory.

Schrader-Frechette and McCoy (1993) make an argument for what constitutes the objectivity of ecology that applies equally well to science in general. Ecology can be objective, not because it is empirically confirmable, but rather if it is not obviously biased or subjective. They define the objective result as being obtained through survival of intelligent debate and criticism, and if it appears to have more explanatory power and internal and external validity than alternative theories. They argue that objectivity is not tied to value-free confirmability but tied (as Lee [1993] also suggests) to the practices and procedures of intelligent criticism of the scientific community as well as to the practices and procedures of the methods used. Popper (1994a) would concur with these statements adding that, "to attain objectivity we cannot rely on the empty mind." Objectivity rests on criticism, on critical discussion, and on the critical examination of experiments. A right and wrong method of critical discussion emerges. A wrong one would start with the question: How can we establish or justify our theory? This leads, Popper argues, to dogmatism. By contrast, the right method of critical discussion starts with: What are the consequences of our thesis or our theory? Are they all acceptable to us?

Because science is a process of learning, knowledge should be seen as changeable. Current theories and predictions may change dramatically with new knowledge and may not be appropriate to address future problems. The philosophy of science may necessitate an adaptive approach with a cautionary use of knowledge. This becomes even more important when we consider uncertainty, complexity, surprise, and social conflict in ecological problems.

Post-Modernism and Post-Normal and How Ecology and Science Can Respond

Many ecologists and decision-makers demand a more rigorous science, with greater predictability and understanding (Peters, 1991; Szaro et al., 1998). Such simplistic demands are seen, by Kay and Schneider (1994a), as the classical Newtonian cause and effect, modern scientific approach. The post-modernist critique challenges the fact-value dichotomy portrayed by modern science, the concept of order and predictability from a reductionist perspective, and the notion that science is the only way of knowing.

The knowledge and understanding that science is not value-free is not new; objectivity in science is perhaps questionable. Post-modernists insist that science like other intellectual disciplines is influenced by the social and political context within which they are embedded (Tauber, 1999; Howarth, 1995). Benson and Licht (1997) suggest that the experimental method of science often portrays results as supporting or refuting a hypothesis instead of focussing on the possibility that the methods used might be mistaken or lead to errors. This is a valid concern and scientists should be prepared to analyse and critique the methods used, assumptions made, and thus the relevance and objectivity of the outcome.

Despite these efforts by scientists, it is still argued that the very methods, models, and theories used, presuppose a set of values (Howarth, 1995). These values are often depicted as the modernist values of mechanistic control and domination of nature. Questioning this, Masters (1993) questions the importance of the critique that science might be value-laden. Tauber (1999) suggests that considerations of neutrality versus objectivity help to break this argument down. Objectivity can be maintained through the philosophy of science and its methods (as described earlier), whereas the scientist or the science may not be neutral. Tauber suggests that neutrality of science "depends on regarding nature as holding no value". Neutral science would not take a stand, while objective science has claims to reliability. As such, objectivity is an ideal to be attained through a process.

If, however, the argument still rests on whether science can indeed be objective, it may be useful to think of objectivity and subjectivity on a continuum with the two at opposite ends. Knowledge shifts along this continuum. Perceptions of environmental problems consist of varying degrees of factual concepts, desired ends and varying degrees of objective information. Lee (1993) suggests that perceptions of individuals and collective human populations can be disconnected from reality under certain circumstances. These may be seen as "optical illusions" or situations in which the ideas and inferences people create are systematically mistaken. Often, these perceptions could be so strong as to have problems wished into reality; a more subjective rendition of knowing. Norton (1995) points also to individual perception as geared toward short-term changes rather than long-term perspectives demanded for parts of ecological understanding. Perceptions have considerable importance for decision-making. They influence allocation of funding and political and societal focus, possibly moving focus away from what is really at stake in the broader ecosystem. The role that ecology has in these situations is to create more objective ideas of what is needed for greater sustainability. Modern science should not posit that it is value free and completely objective. Rather, science has the capacity to be neutral, and more objective than not.

A second post-modern critique is that ecology in the modern scientific paradigm portrays nature to be ordered and structured and this leads to decisions that in longer timelines elicit greater surprise and uncertainty. Benson and Licht (1997) argue that under a post-modernist world-view, order and predictability are no longer possible, nor are they desirable. Schneider and Kay (1994) similarly argue that the Newtonian perspective of order and predictability cannot be used when studying ecosystems because of inherent complexity created through the number, and specificity of interactions. Despite these thoughts, this perspective does not preclude a modernist scientific approach to understanding the solution. Modernists are not necessarily stuck within the "universe is ordered and predictable" paradigm and the world-view of ecology is shifting away from such simplistic assumptions (Norton, 1995; Holling, 1986, 1995; Schneider & Kay, 1994a).

A further line of thought is that reductionist science cannot possibly explain ecosystems, however, modernist science is inherently reductionist, even in its attempts at holistic understanding (Trepl, 1994; Goldsmith, 1993). Goldsmith, (1993) rejects the ecologist who would attempt to reduce things in models of understanding, arguing instead that nature can only be understood holistically. While I agree that making models to encompass all of the complexity of natural systems may not be possible, holistic research methods and ways of knowing are not abundant and can be cumbersome and time-consuming to implement. As 'parts', a reductionist approach will always be incomplete, but necessary. Taken in stride with the philosophy of science which forces contextual understanding, the proprietor of the model should no doubt understand the implications and short-comings of the model and seek a more holistic understanding of the context of their work; both holistic and reductionist methods are needed. Arguably, many scientists do not seek to merge the two.

The final post-modernist critique to be addressed here is regarding science's claim as the only way of knowing and further that knowing is impossible because knowledge is dependant upon the individual, their culture, their environment, etc. Certainly there has been a tendency for policy and decision makers to seek out scientific information and to diminish other types of information. This is understandable in a world which searches for and demands confident answers to problems. Jasanoff (1993) relates one post-modern position, that suggests that in a world where policy outcomes are largely determined by social relations, scientific knowledge serves only to underpin particular group or class interests, lending them the appearance of objectivity. This coincides well with a view that most citizens claim science has become an obstacle to the expression of concerns (Irwin, 1995).

Science as knowledge, is often used in conflicts to gain power. Science is portrayed as the only valid way of knowing and as such, alternatives lose credibility and standing in decision making. Popper (1994a) refutes this, arguing that ideas should be put forward as much as possible and should be able to operate freely against the narrowness of a 'scientists' perspective. Popper argues directly that science is only one way of knowing and operates within a certain finite realm. But, be prepared to defend other ways of knowing against critical discussion. The solution to 'science as power' is more difficult but lies in social uses of science and also in the critical discussion of the merits of each groups' particular scientific "facts". The application of post-normal science is perhaps one method for broaching the issue of multiple valid ways of knowing.

On the surface, there may be little that separates a post-normal critique from a post-modern critique. In fact it might be argued that post-normal critiques are a subset of post-modernist perspectives. Perhaps the two largest differences are that post-normal is mainly a critique of 'normal' science, and that post-normalists would not disallow a dominant use of science but rather frame the use of science more appropriately. More basically, I would argue that post-normal critics create a more explicit understanding of what science ought to be about and how science ought to influence decision-making. To that extent, post-normal science critiques are as follows: Funtowicz and Ravetz (1993) suggest that this emerging science attempts to manage uncertainty rather than eliminate it; make values more explicit; and creates scientific argument through interactive dialogues rather than formalized deduction. Further, they suggest that temporal and spatial characteristics are very important for discussing explanations and that historical perspectives and reflection of humanities past and future are relevant and necessary.

Normal science is claimed to be a science that in the modernist perspective has oversimplified the understanding of nature. What is often forgotten is that theories and scientific models are merely representations of reality and as such are inherently flawed. In this perspective any action taken will have errors and any actions that were based on previously accepted simple models, will have more errors and if adopted, create greater surprise (Holling, 1986). Ecology as depicted by Kay et al. (1999) requires understanding of complex systems, emergent properties, self-organization, spatial and scalar interactions, and self-organization (to name a few concepts) demanding a different paradigm than that of Newtonian objective and detached science (Norton, 1995).

Funtowicz and Ravetz, (1994) suggest that an appreciation of the diversity of knowledge systems can lead to a new practice of science in emergent complex systems. They suggest that as uncertainty increases and/or as decision stakes become higher, science, as it is traditionally practiced, loses some of its applicability and validity. There is no set boundary to indicate when science is appropriate or not, but rather the boundaries shift given different types of problems available knowledge, and conflicting interests among interest groups. In this form, post-normal science does not preclude the use of traditional science but rather places boundaries on it. Post-normal science does not appear to really be questioning how science is done (as does post-modernism) but rather questions the role that science plays in diminishing uncertainty, and gaining control over a given problem. Post-normal critiques address how science is used in the decision making process; a warning that scientific information can easily be taken out of its context and applied in ways that it was either not intended for, or applied where the information does not grasp the full complexity of a situation.

Post-normal science also speaks to the use of caution in high stake/uncertain situations. This is similar to the cautionary stance portrayed by the philosophy in science that knowledge is temporary, and will be replaced with new and hopefully better knowledge, from which actions may change. Decisions regarding ecological problems should be seen as relative merits or tradeoffs rather than based on solutions determining right and wrong. Thus, the role of ecology, according to Schneider and Kay (1994) should be about demonstrating the relative merits of different possible actions; ecology should provide explanations about tradeoffs.

The goals of ecology are frequently questioned. Many critics argue that the goal is to seek control over nature. Others claim that the goal of ecology is to gather information in an objective a manner as possible. Funtowicz and Ravetz (1993) suggest that science should have a more explicit goal in aiding decision-making and that definition of this goal should be discussed openly. The difficulty with complex systems and with deciding between tradeoffs is that it requires definition of values and thus the goal for the system. Schrader-Frechette and McCoy (1993) suggest that ecology has no clear norms for when a community is normal or healthy and, as a consequence positing a goal for ecological practice is quite difficult. There is considerable debate about whether an objectively defined state can be determined by science that can be used as the goal for ecological systems. This debate perhaps provides the greatest distinction between the modernist scientist and the post-normal scientist. Modernists would claim that such an objective goal could be determined from science whereas the post-normal scientist would suggest that describing a state where an ecosystem 'ought' to be is a value based question, one which requires discussion among groups interested in that particular ecosystem.

Summary

Schrader-Frechette and McCoy (1994) suggest that, if it can be established that protection from serious harm is more basic than providing or enhancing welfare, then the goal of ecology is one of precaution. Various historians and ecologists perceive that some parts of the ecological viewpoint are at odds with the modern scientific conceptualization of nature, so that ecology might well provide a framework which could override and require fundamental revision of some existing patterns of scientific thought. Thus their writings suggest that the emergence of ecology might herald the emergence of a "new science" (Biggins, 1978). If modern science is defined purely as Newtonian science (simplistic linear prediction) then ecology as a science moves us away from modern science. If modern science is defined as providing purely objective and unerring predictive capacities (in the empirical sense), then ecology creates an understanding that this view of modern science is not possible.

However, given the philosophy of modern science outlined briefly in this paper, ecology attempts to be and mostly is, a type of modern science. That is, ecology in many respects, represents the ideals of modern science philosophy, and yet challenges those ideals. Mirroring the philosophy of science, ecology has the capability to develop ideas (theories) about how the world functions. In ecology, that world often includes humans and multiple spatial and temporal scales of understanding. These theories need to include a conceptualization of the complexity of the natural world and provide predictive statements (narratives) about likely outcomes and limits or constraints of application of the theory under question (Kay & Schneider, 1994; Norton, 1995; Holling, 1986). These theories are held up for critical debate. Indeed, there is considerable debate regarding ecological theory and its application (Peters, 1993; Schneider & Kay, 1994, 1993; Bocking, 1978; Holling, 1986; Gunderson, Holling, & Light, 1995).

In addition to critiques, any number of environmental problems could be viewed as testing grounds for ecological theory (diversity-stability debate, genetically modified organisms, sustainability, global climate change, etc.). A science that recognizes that knowledge is changeable is a science of caution. Any actions that result from use of science should recognize that new and complex situations will likewise require cautious application of science. Concepts underlying adaptive management frameworks seek to institutionalize this debate allowing for action as opposed to the paralysis that is often felt in a purely political debate of uncertainty. And, it allows for alteration of theory when theories prove not to provide accurate explanations of ecological understanding. Last, ecology may be viewed as moving beyond the traditional modernist perspective as it evolves to include explicit definitions of values in order to help the science develop various narratives of policy outcomes.

When critiques of modern science are offered, there is a need to understand all that is being critiqued. Too often, a theory is used to critique practice, rather than another theory. The practice of science by scientists and its use by decision makers may have faults. Reasons for this are not merely a result of the science, but also representative of a societal evolution. Science has considerable sway in a society that looks to science for answers. This is both a phenomenon of science and of society. The theory of science may also be faulty but in its limitations it provides a more objective means of understanding the natural world than many other approaches to gathering information. It is not the only knowledge set that should be consulted but its predominant use in decision-making and policy creation suggests the need to improve the science that is influencing these domains.

Ecology is a science that recognizes the need for value identification, the need for a multi-scale and multi-perspective approach, and requires a multi-disciplinary systems approach. Solutions provided by ecology could stress relative merits instead of absolute answers. Rather than being viewed as a 'weak' science, ecology may be the most useful for dealing with environmental problems that are complex, multi-scale, and cannot necessarily be solved by reductionist measures alone. Ecology and the philosophy of science necessitates an adaptive precautionary approach given the complexity of social and bio-physical interactions. To continually improve our use of tools such as science, we need to consider its critiques, explore their validity, and incorporate them into application. Ecology as a key science and perspective in decision-making is well placed for this endeavour.

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