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How Indeterminism Shapes Ecologists' Contributions to Managing Socio-Ecological Systems

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How Indeterminism Shapes Ecologists' Contributions to Managing Socio-Ecological Systems

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Abstract
To make a difference in policy making about socio-ecological systems, ecologists must grasp when decision makers are amenable to acting on ecological expertise and when they are not. To enable them to do so we present a matrix for classifying a socio-ecological system by the extent of what we don't know about its natural components and the sodal interactions that affects them. We use four examples, Midcontinent Mallards, Laysan Ducks, Pallid Sturgeon, and Rocky Mountain Grey Wolves to illustrate how the combination of natural and social source of indeterminism matters. Where social indeterminism is high, ecologists can expand the range of possible science-based options decision makers might consider even while recognizing societal-based concerns rather than science will dominate decision making. In contrast, where natural indeterminism is low, ecologists can offer reasonably accurate predictions that may well serve as inputs into decision making. Depending on the combination of natural and social indeterminism characterizing a particular circumstance, ecologists have different roles to play in informing socio-ecological system management.

Introduction

Writing in 1932, Pulitzer Prize winning political commentator, Walter Lippman (1932, p. 149) recognized that "the will of the people" was "a highly variable and incalculable factor... at the point where knowledge is to be applied to action." For example, the U.S. Congress, pressured by hunters, ranchers, and farmers, removed the Rocky Mountain Grey Wolf from the endangered species list in the states of Montana, Idaho, and parts of Washington and Oregon. Although there have been instances where the U.S. Fish and Wildlife Service has removed species from the list, May 2011 was the first time a U.S. Congressional Act eliminated a species from the endangered spedes list. What conservationists see are U.S. Congressional deliberations reflecting not the science but the political nature of the wolf controversy. As public policy, environmental policy decisions must consider what interested parties know, value and prefer because ultimately public policy is about impacts on what society values highly (National Research Council 2008).

In the policy realm, a good decision is defined as being logically consistent with what is known, induding uncertainties, what management alternatives can be under taken, and what the decision makers want for themselves or their constituencies (Howard 1966, 1968; Raiffa 1968). Ecologists can contribute to the first two components through technical analysis of socio-ecological systems (SES)-peer into the future, explain how systems work, identify which components are especially important, out line the consequences of alternative decisions and construct scenarios of possible preferred futures. Shrader-Frechette & McCoy (1993) argue bottom up approaches to ecological explanation infonned by knowledge of specific taxa and focusing on specific decisions, make a more helpful contribution to environmental problem solving than demonstrations of general ecological theory.

The third component of a good decision, being logically consistent with what the decision makers want for themselves or their constituencies, is often beyond the scope of ecology. To be able to apply science to resolving environmental ills requires recognizing the worth of the political arena for judging what underpins environmental debates-the value basis of disputes (Sarewitz 2004). This is particularly difficult for ecologists because ecology as a science is goal directed, and those goals are inherently normative because they involve specifying what constitutes "natural" or "healthy" (Shrader-Frechette & McCoy 1993).

Once we acknowledge values matter, the next step is to concede there are players in situations, such as managing the Rocky Mountain Grey Wolf, for whom no amount of information, no matter how persuasively presented, will sway their views. We know from psychological research into human decision making

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that especially when people are faced with uncertainty their thinking diverges markedly from what is assumed in normative decision theory (Tversky & Kahneman 1972; Kahneman et al. 1982). The ubiquity of strongly held views, substantial deviations from the assumptions in normative decision theory and the unpredictable nature of interactions among all players in SES mean the future cannot be known with certainty. What results is "socially generated indeterminism," a subset of indeterminism or "all forms of not knowing" (Tyre & Michaels 2011).

We argue ecologists need to put socially generated indeterminism on their radar screens if they are to be able to distinguish when the science they have to offer may or may not influence decision making. "Socially generated indeterminism" is not reducible by applying science. For any given task, analytical and heuristic processes may contribute independently to judgments (Stanovich & West 2000; Ferreira et al. 2006). In the following section, we consider key attributes of indeterminism. We then present a matrix based on the combination of natural and social indeterminism present in SES. Using this matrix we identify the different opportunities for how ecologists can contribute to decision making depending on the combination of indeterminism present, induding where providing more science is most likely to contribute to decision making. We conclude ecologists can contrtbute to environmental decision making, once they accept that how they do so, and what can be adlieved, depends on the political setting. As difficult as processing uncertain information is, addressing trade-offs and concerns over values is as challenging, if not more so (National Research Council 2008).

Indeterminism and its attributes

Rather than sorting through the many and varied definitions of uncertainty (e.g., Regan et al. 2002; Walker et al. 2003; Ascough et al. 2008; Mearns 2010 among others), we begin by returning to a concept about which there is little doubt—certainty. If one is certain about the future, this implies a particular outcome will happen. This condition of certainty is analogous to an older concept in philosophy, detenninism, which holds that if tlle current state of reality is known, so too are all future states of reality (Popper 1982). A determinist worldview implies present, past, and future are tied together as frames in a film. In contrast, indeterminism holds there is no certain future, even if the current state of nature is known exactly. There remains a deep philosophical divide between those who subscribe to a deterministic worldview and those who subscribe to an indeterministic one. The compromise position is the world is assumed deterministic, but our epistemic knowledge of reality is insufficient to ever be able to make perfect predictions. For our purposes, the consequences of this "weak indeterminism" and Popper's strong indeterminism are identical-we must make decisions in the absence of perfect information.

Tyre & Michaels (2011) divided indeterminism in SES into two dimensions: natural and social. Natural indeterminism is the fonn of indeterminism familiar to ecologists arising from, for example, changes in the environment, demographic stochasticity, and not knowing which of two or more hypotheses is more correct. Social indeterminism arises from at least three attributes associated with human activity: random process, shortsightedness and intentionality (Pielke 2007). Lee (1993) referred to this source of indeterminism as "management turbulence;" this is an attractive image because although the onset of turbulence in a fluid is relatively predictable, the outcomes are not. The following three attributes are features of natural indeterminism in the extreme and all forms of social indeterminism.

The future is not like the past

Although it is widely recognized that the dynamics of an SES often contain a random component, the analysis of an SES typically assumes that such stochastic variation is not changing over time—it is drawn from a stationary distribution. This assumption is so deeply embedded in how ecologists approach science that it can be difficult to recognize. It is relied upon implicitly every time ecologists use data from the past to make predictions about the future—something that we are being increasingly called upon to do (Carpenter 2002). As we accumulate longer time series, particularly on the climate system, it is increasingly clear that this assumption is untenable (e.g., Milly et al. 2008). The natural systems on which humans rely are not stationary, and never have been.

There are no limits

Every time ecologists fit a statistical model to data in an effort to understand variability, they implicitly assume the variability is bounded—there are upper limits to how much change ecologists can expect to see. This limit arises because the probability distributions decrease exponentially toward zero as the random variable gets farther from the central tendency. However, given both natural and social systems potentially adapt in an evolutionary manner to changed circumstances, bounding future dynamics in this way can grossly underestimate the potential magnitude of changes and perturbations. The presence of alternative stable states in SES (Scheffer 2009) also contributes to this problem; new dynamics, unlike those seen previously, may emerge after a critical threshold has been crossed.

Uncertainty will never be eliminated completely

Ecologists often feel strongly that one important reason for doing good science is to reduce uncertainty about the system being managed (e.g., Beven 2002). Even if we can reduce some sources of natural indeterminism via careful study, there will always remain a resistant nugget of unknowability about the future. For example, the size of the Pallid Sturgeon population on the Missouri River next year has some degree of variability, even beyond our imperfect ability to measure it. Demographic stochasticity in the nature of births and deaths coupled with variation in weather that affects growth and survival means that we can only ever predict a distribution of future population sizes. Similarly, it may be possible to reduce social indeterminism by changing the nature of the social system itself, but this would not be a direct result of scientific enquiry. No amount of studying the social component will reduce the potential for indeterminism in the system's future dynamics.

We have learned a lot from cognitive psychology about how people respond to indeterminism. Mostly from experimental research, we know trust and procedural fairness matter in decision making when uncertainty is perceived (Van den Bos 2001). At the same time individuals become acutely concerned with ascertaining how credible information sources are (Van den Bos 2001), more willing to question the reliability and adequacy of risk estimates, less inclined to be reassured (Rich et al. 1995), more likely to be steadfast in what they believe and what policies they prefer, and to terminate prematurely their quest for facts (Janis & Mann 1977; Klein 1996; Covello etal. 2001). We have learned how people make decisions in the absence of perfect infonnation from social science studies on risk. From the vantage point of the social sciences, risk involves an array of wanted and unwanted effects people attribute to a particular cause, resulting in consequences for something about which they care (Kasperson & Pijawka 1985), such as SES. We do know from Kahneman & Tversky's (1979) prospect theory people are risk averse when focusing on losses and risk prone when paying attention to gains. Rather than maximizing their benefits, many people balance their risk-taking behavior to avoid a major disaster and to achieve an acceptable payoff (Tversky 1972; Simon 1976).

Research is progressing on understanding how to promote human behavioral change impacting the environment. Particularly promising are frameworks linking values, norms, and behavior (Stern 2000). How decision makers respond to indeterminism in SESs shapes their uptake of ecologists' technical analysis in SES related decisions (Jaeger et al. 2001). Consequently, what an ecologist can contribute depends on relative levels of natural and social indeterminism and how tlley are perceived.

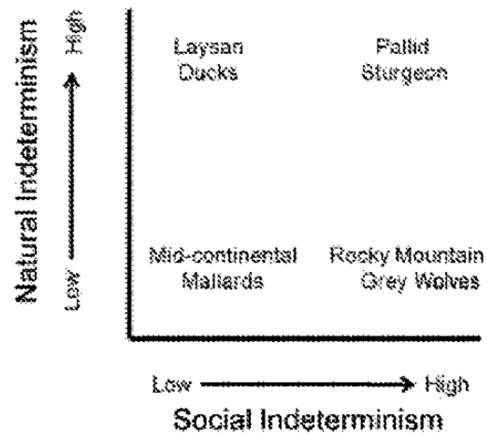

Figure 1. Characterizing socio-ecological systems in terms of the extent of their natural and social indeterminism

A typology of indeterminism

To aid ecologists in determining the different ways in which their science can make a difference in decision making, we developed a matrix in which a given SES can be characterized in tenns of the degree of its natural and social indeterminism (Figure 1). The natural indeterminism axis starts at the bottom with indeterminism that can be described by probability distributions (i.e. it is bounded), even if irreducible, and nonstationarity is either well understood, or short time frames make it less relevant. At the high end, natural indeterminism is not bounded by probability distributions and has substantial nonstationarity. On the left side of the social indeterminism axis, value conflicts are absent or muted. As one moves rightward on this axis the magnitude of social indeterminism increases, values diverge and with that risk tolerance deviates. Next, we provide examples to illustrate how the matrix can be used to characterize SES and to suggest how ecologists might profitably contribute to decision making within each of the four quadrants created by the two axes. How ecologists will be able to contribute to decision making about an SES is in large part a function of the constraints imposed by the combination of natural and social indeterminism associated with that SES and how other actors, notably decision makers respond to the combination.

The Adaptive Harvest Management (ARM) Program for Midcontinent Mallards (*Anas platyrhynchos*) in North America (Nichols et al. 2007) is in the lower left quadrant because it is characterized by relatively low levels of natural and sodal indeterminism. The legal authority to establish hunting regulations for North American waterfowl dates back to the 1918 Migratory Bird Treaty Act. Although winter surveys and banding data were employed to some extent between

1930 and 1950, the use of regularly collected scientific data in making harvest regulation decisions matured in the 1950s, when United States' and Canadian agencies began to survey systematically breeding populations of waterfowl on a continental scale. Since 1995, the first hunting season of ARM, the selection of regulatory "packages" has been based on sophisticated analysis of population data using optimal control theory, and careful accounting of many sources of natural indeterminism, including annual variation in the number of ponds available for breeding, and epistemic uncertainty about the structure of population dynamics. Although there are still many aspects of the natural system that are irreducibly variable, many key components of the system are characterized by well-bounded probability distributions. The social dynamics of the system have low levels of indeterminism because of a high degree of shared values amongst members of society who care greatly about waterfowl—mostly sportspeople who want to hunt and preserve the resource. The current form of resource governance has been in place for over half a century, and is accepted widely by participants. In addition, the legal mandate provided by the Migratory Bird Treaty Act places management responsibility with the federal U.S. Fish and Wildlife Service. These factors combine to produce a system of resource governance that is highly resistant to challenges. The potential for unbounded variation in social indeterminism is hinted at, however, by James D. Nichols, one of the architects of the optimal control approach. Although he has "not encountered much talk about AHM pladng the resource at risk," he contends, "the real test of the plan will come when the models and optimization lead to the recommendation to restrict regulations for the first time-will that be accepted by stakeholders?" (Nichols, personal communication, 2011).

In the example of The AHM of Midcontinent Mallards and other cases displaying low social and natural indeterminism, ecologists may be able to contribute (relatively) accurate predictions and system explanations with reasonable expectation that these will have a high likelihood of contributing constructively to the debate.

A system with low values of social indeterminism, but high levels of natural indeterminism, is managing the Laysan Duck (*Anas laysanensis*). In the first decade of the 21st century, the population on the 4.1 sq km Laysan Island fluctuated between 300 and 600 birds (Reynolds et al. 2008). Although the ducks were restricted to a single population on a remote atoll in the 20th century, there is evidence that the ducks had existed on other Hawaiian Archipelago islands. Perhaps because of the introduction of invasive species like rats, these other populations were extirpated. In addition to the usual concerns about a species with a single small population with limited translocation success, there is a substantial degree of unbounded, nonstationary natural indeterminism caused by not knowing the magnitude or rate of future sea level rise—the highest point on Laysan Island is 12 m above current sea level (Reynolds et al. 2008). In contrast, the degree of social indeterminism is negligible—there are no extant human settlements, and the birds live in the largest marine reserve in the world. Consequently managing risks for these birds can be done without having to make tradeoffs involving human activities, such as land development, that at times derail conservation.

The responses of species at risk, such as Laysan Ducks, to climate change (Conroy et al. 2011) is a good example of nonstationarity with lurking critical thresholds. Although there may be low social indeterminism, the high natural indeterminism means that we cannot (yet) place objective probability distributions on future dimate, nor do we know now how most species will respond to shifts in climate. Nonetheless we can still imagine ecologists will be able to generate a range of possible scenarios, each predicting the distribution of population sizes conditional on some degree of sea level rise. These scenarios could provide the sdentific basis for developing polides that will protect the ducks under a wide range of alternative futures.

In the matrix's top right quadrant are systems with high levels of natural and social indeterminism. The recovery of the Pallid Sturgeon (*Scaphirhynchus albus*) in the Missouri River basin in the upper Midwest of the United States exemplifies such a system. When this species was listed as endangered in the mid-1980s, the primary threats were thought to be the loss of shallow water habitats and high spring flows resulting from regulating the Missouri River discharge by dams, and channelizing the lower portions of the river for navigation (USFWS 2003). Although natural reproduction is very low, after three decades of increasingly intensive research, it is still not known what exactly must be changed about the current over system to enable this species to thrive. Although there are multiple hypotheses, testing these hypotheses requires either extensively modifying the river channel, restoong high spong flows, or both. Neither is popular with people living in the basin or working on the river, because of increased flood risk, loss of river navigability, or sacrificing hydropower potential Because some segment of human society cares passionately about each of these considerations, efforts to restore sturgeon habitat generate significant levels of social indeterminism.

As social indeterminism increases, the likelihood people agree to be bound by decisions decreases. The frequent legal challenges to the governance of the Missouri River in the late 1990s and early 2000s are a symptom of high social indeterminism. In the case of the population dynamics of Pallid Sturgeon this is coupled with high natural indeterminism. In particular, ecologists do not know what must be changed about the Missouri River ecosystem to allow successful natural recruitment. In addition, it will take decades for any biological response to habitat restoration to be detected; alterations to the hydrograph may show quicker responses under some hypotheses, but these are the very manipulations with the greatest value distinctions among the many stakeholders on the river. In the presence of indeterminism, we can expect stakeholders to be very critical of risk assessments for Pallid Sturgeon, and be unwilling to change their opinions about what matters and what actions should be taken. When working with decision makers to develop scenarios of long-term biological response to habitat restoration on the Missouri River, ecologists can use these insights to temper their expedations about tile immediate impad of their work. Instead they could focus on building credibility for risk assessments by validating predidions against independent data.

In the bottom right quadrant we find systems with low levels of natural indeterminism and high levels of social indeterminism. An example of this is managing the Rocky Mountain population of Grey Wolves. Ecologists know a lot about wolves; their behavior, physiology, evolutionary ecology, and population dynamics have been the subject of interest for over a century. The restored Rocky Mountains' population is monitored intensively (Smith & Ferguson 2005); the movements and reproduction of individual packs are tracked by a small army of biologists. Although there are scientific debates, for example about the extent to which wolf packs are affected by hunting over and above any immediate mortality impacts (Creel & Rotella 2010), these are at a much finer level of detail than those facing managers of Pallid Sturgeon and Laysan Ducks. The high volatility of social indeterminism is in evidence through the routine challenging in court of U.S. Fish and Wildlife service decisions and the recent groundbreaking Congressional decision to remove the Gray wolf from the endangered species list. As ecologists have learned in such circumstances science does not drive policy, even if natural indeterminism is low.

Where social indeterminism is high, regardless of the state of natural indeterminism, ecologists should be prepared to have their reasoning dismissed by some advocates and seized upon by others who see its potential to support their positions (Sarewitz 2000; Pielke 2007). Nonetheless they should strive to make predidions about future outcomes, and to test those predictions against real data. Such a process of alerting society to emerging and evolving challenges is time consuming, but by verifying the prediction skill of ecological models those predictions will be more acceptable once the social situation changes to enable their direct use. Another role for the ecologist in the face of high social indeterminism is to expand the range of possible outcomes for decision makers to consider, thus enabling the possibility for robust science-grounded decisions to be generated. In addition, some ecologists may choose to engage in the messy, democratic, political process where those with competing values and interests debate their perspectives in an attempt to achieve an operational consensus that will result in action (Sarewitz 2000). This may involve participating in the search for where consensus may be feasible, such as in component, linked, or smaller issues. Alternatively, ecologists may choose to openly associate science with possible courses of action—that is, to serve as Honest Brokers of Policy Alternatives." (Pielke 2007, p. 7). If political consensus is achieved, ecologists can monitor implemented policies and assess their performance. Where consensus does not result, ecologists still have an essential role to play. The need to advocate for full consideration of natural indeterminism does not diminish. As Rachel Carson demonstrated, there is value in educating those other than the primary players about a concern (Backing 2004).

Conclusion

In this brief note, we have argued that ecologists must be cognizant of two fonns of indeterminism: natural indeterminism, with which they have considerable familiarity, and social indeterminism, which constitutes frustrating, uncharted waters for many ecologists. Not to recognize how these two forms of indeterminism interact will lead to failure in managing expectations of ecologists as to how their expertise will be appreciated. It will be valued and employed differently depending on the mix of natural and social indeterminism present. To enable ecologists to identify the different ways in which their knowledge will be treated as inputs into decision making, we have presented a two by two matrix fom1ed by different combinations of natural and social indeterminism.

Although it would be tempting for ecologists to confine their efforts to circumstances where their work is influential in the near term, there is a powerful argument to be made, at a minimum, for ecologists to be alert to what is going on in situations on the right side of our matrix where social indeterminism is high. The right side of the matrix is the realm where collective values are forged that will underpin future policies and from where the next generation of pressing research questions will emerge. What ecologists can bring to the mix is making sure that concerns stemming from natural indeterminism are not ignored, undervalued, or misinterpreted where social indeterminism is high.

Ecologists do not have a single role to play in environmental decision making. Rather they have different roles to play depending on the combination of natural and social indeterminism characterizing a particular circumstance. In part, becoming a master action taking ecologist is about identifying situations conducive to incorporating ecological predictions into decision making and initiating problem-solving collaboration with colleagues from different disciplines, such as the social sciences (Palmer 2012). Equally, it is about using best available scientific practices to lay the groundwork for the next generation of research to aid an altered set of future decision-making possibilities.

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