CONSERVATION ISSUES

Biological Monitoring and Bridging the Gap Between Land Management and Science

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ABSTRACT: Traditional monitoring approaches may have the objective of gathering data to estimate population size for a given species, but often lack the context of hypothesis testing. As such, many natural areas managers (responsible for ecological monitoring) and scientists have shared little common ground. The goal of monitoring should be to inform managers so that they can insure that the species, communities, and ecosystems under their charge are able to persist in the face of stressors, often from anthropogenic sources. The inherent complexity of natural systems makes this a daunting task, a task that requires a renewed partnership between managers and conservation biologists. The non-equilibrium paradigm of population dynamics establishes a theoretical framework for shifting monitoring objectives from only population estimates to understanding the processes that drive the dynamics of those populations. Using a hypothesis-driven scientific approach, monitoring designs can embrace the scientific method, provide insights into the ecological processes at work within natural systems, and importantly, point directly to if, when, and how active management may need to be employed in order to prevent the loss of biodiversity. This approach provides a common ground for conservation biologists and natural areas managers to forge partnerships to better understand the complexity of ecological systems and our ability to sustain those systems for future generations.

Index terms: conceptual models, ecological monitoring, management, non-equilibrium population dynamics, scientific method

A symposium convened in the late 1990s to discuss how ecological theory can be applied to the design of monitoring programs concluded that the ability of ecological theory to guide monitoring was limited (Woodward et al. 1999). To the extent that this conclusion has been true, managers of natural areas and conservation biologists have shared little common ground (Rogers 1997). What managers need from scientists are clear directions as to appropriate monitoring metrics, thresholds for employing active management strategies, and given a myriad of management tasks, how to conduct triage so as to have the largest positive impact on the viability of the populations under their charge.

In the absence of such direction, most managers have relied on more traditional monitoring strategies, such as counts of focal or charismatic species (Campbell et al. 2002). That approach results in data estimating population size or density of a species in a given year. There have been significant gains in developing both sampling designs and statistical data analysis to provide an increasingly precise relative or absolute estimate of population size (n) (e. g. Green 1984; Green and Young 1993; Urquhart and Kincaid 1999; Nichols et al. 2000; MacKenzie 2005; Manley et al. 2005; Schmidt and Pellet 2005; Stanley and Royle 2005). However, knowing n does not necessarily determine whether increases or decreases in n in subsequent years are signals of a population at risk of extinction or rather part of an expected dynamic exhibited by a species responding to typical fluctuations in resources. As Krebs (1991) stated so succinctly, such data (disconnected from specific hypotheses or context) are ecologically banal. These data may not serve the needs of land managers and, without the structure and context provided by a hypothetic-deductive approach, may not attract the interest of conservation biologists in monitoring or the data generated through monitoring activities.

Monitoring should provide land managers with the data necessary to anticipate a trajectory toward extinction and then to implement remedial management while there is still an opportunity for that management to be effective. One suggestion for meeting this need is to identify management objectives, or thresholds for management action, as a component of monitoring strategies (Krebs 1991; Yoccuz et al. 2001). Yet identifying thresholds that are not arbitrary has proved to be a difficult problem. Natural population fluctuations, especially in arid environments, challenge the existence of a static threshold, indicating a population on a trajectory to extinction. Population levels of a threatened sand dune lizard (*Uma inornata* Cope) can change 10-fold up or down in just a few years, even approaching nearly non-detectable levels, before rebounding when limiting resources are again plentiful (Barrows 2006). If a population approaching non-detection is not a threshold for management action, what is?

Managers and ecologists have long operated under a "balance of nature" equilibrium-based paradigm (Rogers 1997). Using this paradigm, wildlife managers identified a carrying capacity (k), which was maintained for focal or charismatic species by employing active intervention to maintain resources and populations at near constant levels. Kruger National Park in South Africa (Rogers 1997) and, until recently, Yellowstone National Park in the United States (Wagner and Kay 1993) are often cited examples of this approach. Whenever populations exceeded or dipped below a perceived carrying capacity, managers employed strategies to bring those populations back to targeted levels. The need to actively manage populations so that they are maintained within a perceived equilibrium or carrying capacity brings into question the premise that such equilibria are, in fact, characteristic of natural populations.

Natural environments are exceedingly complex. One of the goals for ecologists is to discern patterns within the complexity that enable predictions as to how components of those environments assemble and persist through time. From a conservation perspective, predicting what conditions lead to a lack of persistence, or extinction, is the focus. The theoretical framework for addressing these issues has undergone an important shift in recent years. That shift has moved to one in which the non-equilibrium character of those populations is recognized as the norm (Pickett et al. 1992; Fiedler et al. 1997). Research questions under this new paradigm now focus on identifying the processes that drive population dynamics rather than just population estimates, a shift that provides a platform for a new way to address biological monitoring. Under this view, spatial and temporal heterogeneity and complexity are viewed as critical elements in the function of ecosystems (Christensen 1997; Fischer et al. 2004). If stochastic resource flux and population dynamics are embraced, management goals cannot be static values. This realization presents a challenge for conservation biologists and wildlife managers to work together to identify appropriate monitoring metrics and gather monitoring data that provide management direction to allow populations to persist in an increasingly compromised environment.

Putting these concepts into practice, conservation biologists and managers need to work in concert to develop conceptual models that define hypotheses about the important drivers of population dynamics, not just for focal species, but for species guilds and natural communities as well (Barrows et al. 2005). Monitoring strategies should be designed not just to estimate *n* (although that may be an outcome) but to test the hypotheses defined in the conceptual models. With a growing understanding of what drives the "natural" dynamics of populations, the importance of stressors can be assessed. When data regarding the incidence and importance of potential stressors are collected simultaneously with population data for multiple species within the same community, the relative influence of those stressors can be evaluated. Once models are evaluated and found to adequately predict the behavior of populations under varying resource levels and the occurrence of population stressors, thresholds for management action can be objectively defined as significant departures from predicted population dynamics. Not only is a threshold identified, but the target of management action (the stressor) is identified as well.

An example of how this framework has been employed starts with a conceptual model of a desert sand dune community in southern California's Coachella Valley described by Barrows et al. (2005). The model describes hypothesized relationships between a subset of sand dune species that are part of that community and various processes, both anthropogenic and not, that likely drive the dynamics of those species. One group of processes posited as stressors were urbanization, habitat fragmentation, and suburban-natural landscape edge effects (each arguably different scales of the same process). As natural preserve boundaries were largely fixed, managers were concerned that processes at the suburban-natural landscape interface could erode habitat quality and further reduce total habitat available to species restricted to the sand dunes. To test the hypothesis that edge effects were stressing the sand dune species, a monitoring strategy was designed that included a series of plots placed along the preserve edge and plots placed well within the core of the preserve. Rather than focus on a single or a few focal species, the sampling spanned soils, vegetation, arthropods, reptiles, mammals, and birds, enabling a community-level analysis.

That analysis found just two species' distributions that were negatively associated with the edge, the desert kangaroo rat (*Dipodomys deserti* Stephens) and the flat-tailed horned lizard (*Phrynosoma mcallii* Hallowell) (Barrows et al. 2006). Additionally one species, the loggerhead shrike (*Lanius ludovicianus* Linnaeus), was found to have a positive association with the preserve edge. The sampling design identified soil characteristics (for the kangaroo rat), increased predation pressure from shrikes and kestrels (*Falco sparverius* Linnaeus) (for the horned lizard), and the availability of perches and nest sites (for the shrike) as causal links to the observed distributions. For the horned lizard, there was a region along the preserve edge extending into the interior as much as 100-150 m where this species was absent, and thus as much as 10% of the lizard's habitat in this otherwise protected preserve became unoccupied (Barrows et al. 2006).

With this cause and effect information, land managers can employ adaptive management (Holling 1978), creating management experiments to evaluate the efficacy of a management strategy. For example, a management action to experimentally reduce artificial shrike and kestrel perches (such as overhead power lines) could be used to determine if habitat re-occupation by the horned lizards would result. The original conceptual model that posited a negative suburban-natural habitat edge effect provided a framework to design a monitoring approach to evaluate that hypothesis. Through an iterative process of correlative and experimental analyses, the inherent complexity of the species-habitat interactions was partitioned by the monitoring design to test a specific hypothesis that could then lead to a management response.

Under a more traditional monitoring approach, one or a few focal species would have been selected for population monitoring. Despite having a narrow distribution with increasingly fragmented habitat, the flat-tailed horned lizard has no special state or federal protection status and so there was no a priori reason to select the horned lizards as a focal species. Several state and federally protected species were present and would have received priority-monitoring attention. The listed threatened and endangered species did not show any edge aversion; had we not taken a community level approach, this boundary process and effects may have been overlooked. Even if the horned lizard had been selected for monitoring, a reasonable sampling design aimed at describing the lizard's population size and distribution would have involved establishing numerous random plots throughout potential habitat areas. While this approach would have yielded an estimate of *n*, the random distribution of survey plots may not have been able to elucidate the negative edge association. Instead, the plots had a stratified-random distribution (edge versus core) aimed at answering a specific hypothesis, which provided essential context to the data, as well as providing direction for management action. It is not by accident that the sampling design blurred the distinction between monitoring and answering a scientific question. To meet the needs of both scientists and managers, monitoring must overtly embrace the scientific process. A hypothetic-deductive approach results in heuristic data, providing clear direction for management actions, and so meets managers' needs.

Our objective is to present a science-driven process as the means for providing accurate and defensible direction for wildlife managers. Beginning with conceptual models, hypotheses identifying the critical drivers and threats to a species or community are developed and analyzed. Those hypotheses are evaluated, rejected, or accepted, with the result of a quantitative model from which to evaluate future data. As data are accumulated, analyzed, and patterns discerned, there may be a shift to monitoring the drivers of and threats to population dynamics within a community. Population metrics will always be addressed as part of a monitoring framework, but a focus on what drives population change will serve managers and species far better. Rarely do managers manage species; rather they manage the environmental characteristics that drive change in the species' populations. This approach is aimed at providing those managers with the tools to know if, when, and how to employ management to support the persistence of species and communities. Using a multiple species-community approach to data collection and analyses allows both scientists and managers to project the ecological costs and benefits of management to target and non-target species simultaneously, allowing for informed management triage. This approach also provides baseline data for ecologists to address otherwise elusive environmental complexity and spatial and temporal questions.

Monitoring not only can – but must – be guided by ecological theory and the scientific method in order to make the data relevant to scientists and ultimately useful to managers. The non-equilibrium paradigm of population dynamics (Pickett et al. 1992; Fiedler et al. 1997) creates a structure from which to frame questions regarding the nature of population dynamics that also meet the land manager's needs. From that structure, the monitoring focus becomes the processes that drive population and ecosystem dynamics, rather than on estimating *n*.

Conservation biologists have previously focused on developing theory and empirical data to guide preserve design. While those efforts have yielded invaluable insights, preserve design is only the first step in a long effort to insure that species, populations, and communities are able to persist through time. Due to economic, legal, and political constraints, preserve designs are nearly always short of ideal. Ultimately, sophisticated land management strategies guided by sound science will be necessary to successfully meet a preserve's conservation objectives. Employing monitoring approaches that meet the needs of both the scientists and the land managers will be key to sustaining that partnership through time.

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