(whereas the tradition of theoretical population genetics would make more sense). She characterizes G. Evelyn Hutchinson as affected by "the Popperian mood of the 1950s and 60s," but does not notice that his reply to criticisms of his style of logico-mathematical reasoning was distinctly anti-Popperian (Hutchinson, G. E. 1978. An introduction to population ecology. Yale University Press, New Haven). It is hard to know what to make of comments that new ideas or methods (such as laboratory experiments) were adopted because they had become "fashionable." Such problems do not detract from the main idea that this group of scientists was important for the development of modern ecology. But it suggests that readers should approach many interpretative statements with caution.

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Multiple stable states in theory and reality

Petraitis, Peter. 2013. **Multiple stable states in natural ecosystems.** Oxford University Press, Oxford, United Kingdom. xii + 188 p. $74.95, ISBN: 978-0-19-956934-2.

Key words: alternative stable states; experimental design; mathematical model; theory.

Less frequently than the occurrence of a blue moon, a monograph comes along that not only crystallizes an entire field of research but also is such a good read that once one picks it up, s/he won't put it down until every page has been absorbed. Peter Petraitis' *Multiple stable states in natural ecosystems* is just such a book. In 160 well-written pages, Petraitis (1) summarizes and encapsulates over a century of research (the earliest citation is to a 1911 paper on passenger pigeons); (2) provides graphical and mathematical details of the theory of alternative stable states; (3) illustrates how previous narrow readings of the literature, combined with patterns of self- and in-group citation, has led to repeated reinventions and rediscovery of this selfsame theory; and (4) lays out, critiques, and refines a set of experimental design principles for reliably documenting the existence of multiple stable states (MSS) in the field. This book should be read and kept close at hand not only by anyone working on MSS, thresholds, and regime shifts, but also by anyone interested in clear writing, the linkages between theory and empiricism, and the evolution of scientific fields of study.

The primary focus of *Multiple stable states* is to strengthen the links between existing theories, observations, and experimental demonstrations of MSS in ecological systems. Experimental demonstration of MSS has proven to be remarkably difficult: despite theory dating back to Alfred J. Lotka (1956. Elements of mathematical biology. Dover Publications, New York) and reified by Robert M. May (1977. Thresholds and breakpoints in ecosystems with a multiplicity of stable states. Nature 269:471–477) there are fewer than 10 field studies that provide evidence consistent with a model of MSS. The bar is high. Petraitis' prescription for a convincing demonstration of MSS includes four requirements: (1) the experiment must be done in a single environment, ideally at the same site; (2) the site can be shown to have the potential to be occupied by two or more distinct communities; (3) these communities are self-replicating; and (4) the manipulation must be a single, "pulse" perturbation that mimics a "natural" event in extent, duration, and effect (after Peterson, Charles H. 1984. Does a rigorous criterion for environmental identity preclude the existence of multiple stable points? American Naturalist 124:127–133).

Throughout the book, Petraitis elaborates on these criteria, pointing out both obvious and subtle difficulties in their implementation. These include: (1) using the "same" site; (2) differentiating self-replicating communities of interacting species from haphazard assemblages of co-occurring ones; (3) determining appropriate scales of disturbance, especially when using long-lived sentinel species or ecosystem engineers; and (4) defining stability. Appropriate compromises, including clever use of before-after-impact-control (BACI) designs are suggested (Chapter 10), but always accompanied by rigorous attention to analytical treatment data, caution in interpreting possible results, and transparency of presentation (through open access to primary data and negative results). At the same time, Petraitis is strongly critical of conclusions about MSS that depend on misconceptions about ecological systems and rely on misuse of theory.

In the first category, Petraitis discusses four common misconceptions in great detail (Chapter 8): (1) thresholds (a.k.a. regime shifts or tipping points) are always associated with systems exhibiting MSS (contradicted by theory); (2) MSS are a central component of state-and-transition models of environmental management (these management tools were developed explicitly for non-equilibrium rangelands); (3) the ecological "landscape" of the visual "ball-and-cup" model of MSS is defined by parameters whereas the position of the ball is defined by state variables (rather, it depends on the definitions of thresholds, as well as the relationships between parameters and state-variables, and where the higher-dimensional phase space was "sliced" to yield the observed landscape); and (4) particular characteristics—ecosystem engineers, positive feedback loops, stressful environments—are required for, or at least predispose, ecosystems to have MSS (contradicted both by theory and data). Three other misconceptions are dealt with more quickly: (1) systems with MSS are out of equilibrium (an obvious oxymoron); (2) the occurrence of MSS must involve stochasticity (contradicted by theory); and (3) hysteresis occurs in all systems with MSS (ditto). The entire discussion of misconceptions highlights the distinction between, on the one hand, studies of tipping points, regime shifts, and thresholds, in which slow environmental changes (hence, violation of experimental criterion 1, that MSS must occur *in the same environment*) lead to fast changes in ecological characteristics, and, on the other hand, studies of MSS. The conflation of these two ideas has arisen, in Petraitis' view, because of sloppy and inconsistent use of key concepts—thresholds, basins of attraction, the separatrix—that are carefully specified in theoretical treatments.

This observation leads directly to perhaps the most intriguing and important part of the book: Petraitis' commentary on the state of scholarship in the field. He opens the preface with the comment that "the idea of multiple stable states in ecosystems has been discovered with near independence or invented anew by researchers studying lakes, coral reefs, and semi-arid rangelands. There has been some cross-fertilization, but not as much as we might hope." He goes on to illustrate in the preface that the three most highly cited papers that laid the theoretical groundwork for the theory of MSS in ecological systems—May (1977, op. cit.); Westoby et al. 1989 (Westoby, Mark, Brian Walker, and Imanuel Noy-Meir. 1989. Opportunistic management for rangelands not at equilibrium. Journal of Range Management 42:266–274); and Scheffer et al. 2001 (Scheffer, Marten, Steve Carpenter, Jonathan A. Foley, Carl Folke, and Brian Walker. 2001. Catastrophic shifts in ecosystems. Nature 413:591–596)—are rarely cited in the same paper. Of about 2300 papers citing at least one of these three papers, only 10 (0.4%) cite all three. It is indeed a sad state of affairs in ecology when limnologists read only the limnological literature, rangeland ecologists stick to grassland papers, and theoreticians operate in a vacuum (see also Scheiner, Samuel M. 2013. The ecological literature, an idea-free distribution. Ecology Letters 16:1421–1423).

Petraitis elaborates on this theme in his detailed exposition of catastrophe theory (Chapters 5 and 6). Catastrophe theory was developed by René Thom in the 1970s and broadly popularized in monographs and general-interest treatments within five years. Yet, "[e]cologists, by and large, have not benefited from these insights. . . . [and] have largely overlooked the relationship between catastrophe theory and modern presentations of multiple stable states." There are nonetheless remarkable (but predictably uncited) similarities between graphs in contemporary ecological reviews (e.g., the ball-and-cup model of ecological landscapes and MSS) and illustrations in 1970s texts on catastrophe theory.

A colleague once took me to task for critiquing the dust-covered piles of journals in his office, saying "I don't read the literature, I write it." Thirty years later, I still disagree. Petraitis (and Scheiner) are right that we would progress much faster—in ecology in general, and in understanding MSS in particular—if we took a little more time to read and place our work in broader, theoretical contexts and a little less time producing the next least-publishable unit in which we pay only lip-service to the existing literature. *Multiple stable states in natural ecosystems* illustrates this principle in spades.

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