CHAPTER 6

Conclusion - Are Regime Shifts Real?

During a discussion with an ecologist, my colleague turned to me and asked with a twinkle in his eye whether I *believed regime shifts were real?*. In that question lies a deep seated skepticism that many field biologists have regarding the practical value of formal methods in the adaptive management of real-life ecosystems. There is no doubt that these systems exhibit large behavioral shifts. But one may argue that it is unclear whether those shifts occur because the system state has abruptly shifted between alternative stable states, or the variation reflects a periodic behavior with a very long fundamental period. To a great extent this is the same question asked of the bursting behavior in Fig. 9(c) of chapter 2. Does bursting represent a "real" shift between distinct regimes, or is it simply what we can expect of a complex system regime?

In my opinion, "is it real?" is probably not the right question to ask. The regime shift concept, popularized in Scheffer's paper [**97**], provides an easily understood explanation of the behavior using dynamical systems' concepts. But that explanation is rather imprecise and does not provide clear guidance with regard to the question posed regarding bursting phenomena. For such a mathematical concept to be "real", it should be "complete" within a well defined theory of dynamical systems. What is missing from Scheffers' popularized notion of regime shifts, in my opinion, is that careful identification of the theoretical framework in which the concept is embedded and a convincing assurance that the theoretical framework is sufficiently rich for living systems. This monograph answers the "is it real?" in the affirmative but only within the confines of theory for smooth dynamical systems.

But perhaps, what my colleague was really asking was whether the regime shift concept is a "real" depiction of the mechanisms driving the abrupt transitions seen in real-life systems. That question is difficult to answer without a lifetime of field work to establish the practical value of the concept in managing "real" systems. This monograph, of course, does not attempt to answer questions regarding the value of the method in real-life. All this monograph does is point to the utility regime shifts as a tool for understanding the ecological resilience of systems that can be modeled as smooth dynamical systems .

As was mentioned in chapter 1, the word *resilience* is used by many different communities. In urban planning it refers to communities that possess the capacity to rebuild after catastrophic disruption. In ecology, it means the system is able to restore ecosystem services after an externally triggered collapse. In engineering, it refers to a resistance or robustness of system function to faults and failures. To a great extent the underlying idea of "bouncing back" is still present in all of these applications. But without a formal framework that all applications can be mapped into, I have often seen colleagues argue over subtle differences that are driven by the shade that the application domain throws over the resilience concept. By discussing ecological resilience in terms of the regime transition systems, this monograph attempts to shine a light on the fundamental principles of resilience that are present in all application areas.

This monograph should be seen as an informal introduction to the use of computer algorithms in the formal analysis of dynamical systems. A great deal of work remains to be done. While this monograph outlined much of the mathematical theory for ecological resilience, the full scope of this theory has yet to be fully explored. As mentioned above, these ideas need to be applied to real-life systems to assess the practical value of this framework in enhancing the ecological resilience of real-life applications. This monograph focused on models for ecological systems for my original investigation of regime shifts and resilience was encouraged by colleagues in ecology. However the consumer-resource dynamics used in ecology are also used in modeling many networked engineering and socio-economic systems. Future work should examine how the concept of ecological resilience can be applied to these other application domains.