Preface

This collection of review articles is devoted to the modeling of ecological, epidemiological and evolutionary systems. Theoretical mathematical models are perhaps one of the most powerful approaches available for increasing our understanding of the complex population dynamics in these natural systems. Exciting new techniques are currently being developed to meet this challenge, such as generalized or structural modeling (Chapter 2), adaptive dynamics (Chapter 4) or multiplicative processes (Chapter 6). Many stem from the field of nonlinear dynamics and chaos theory, where even the simplest mathematical rules can generate a rich variety of dynamical behaviors that bear a strong analogy to biological populations (eg., Chapters 1, 2, 3, 4, 7).

One of the most interesting "cutting-edge" research areas today concerns the role of spatial structure in organizing biological systems. For example, in ecological models, spatial organization through aggregation and diffusion of individuals intimately controls the ultimate spread or extinction of an introduced invader. One of the goals of this book is to review how these basic processes give rise to the formation of beautiful spatial patterns (Chapters 2, 3) or the emergence of power laws (Chapter 5), that are frequently encountered in real and model systems. Furthermore, the effect of spatial scale may be decisive in resolving such questions as to which strain of a virus dominates in an evolutionary arms-race, whether or not plants can synchronize their reproduction (Chapter 4), and why unusual vegetation patterns arise in water limited desert systems (Chapter 5). Hence a key focus of interest in this collection centers on the dynamics of spatially structured interacting populations and communities.

Mathematical models also help to further our understanding of complex synchronization. The spontaneous onset of synchronization is one of the most remarkable phenomena found in biological systems and relies on the coordination and interaction among many scattered organisms.[1] Synchronization is a basic and efficient process which has the potential to shape the spatio-temporal dynamics of networks and extended systems. Synchronization arises in a large class of systems of various origins, ranging from physics and chemistry to biology and social sciences. In ecology, fluctuations of population numbers, such as the classical 10-year Canadian hare-lynx cycle, are known to synchronize to a collective rhythm that manifests over millions of square kilometers.[2] In the present collection, these issues are reviewed with a special emphasis on population dynamics, where synchrony depends on dispersal of individuals (Chapter 4, 5) and genetic oscillations (Chapter 9).

Another theme running through the chapters of this book concerns the ubiquitous appearance of power-law distributions that have been unexpectedly observed in numerous biological contexts. For example, in plant ecology, seed dispersal is characterized by power law distribution, with the great majority of seeds dispersing a short range, while some nevertheless manage to disperse surprisingly long distances. The distribution has a "long-tail" that differs greatly from the Gaussian expectation. Several chapters (5, 6) explain why power-law distributions are fundamental in many biological contexts. Levy flights in which movement or jumps occur across different spatial scales is one method for understanding power law distributions (Chapter 5). In Chapter 6, Zanette and Manrubia show how these distributions arise in the sizes of populations in satellite and core cities, the length of words in different languages (Zipf's Law), through to the musical compositions of Bach. In Chapter 7 the power law distributions associated with critical transitions in self-organized systems are shown to give insights into the oscillations and the control of persistent infectious diseases.

Finally, the book incorporates some of the very exciting developments surrounding the application of network theory for studying complex biological systems. The manner in which a population of individuals or agents are connected to each other may be summarised in the form of their particular network structure. The structure gives a great deal of information about the connectivity of the population and the way members are involved in interacting directly or indirectly with one another. Recently much interest has been devoted to the study of networks with complex topology including ecological food-webs (Chapter 1, 2), social networks for the spreading of information (Chapter 5) and diseases (Chapter 8), neural networks, the World-Wide-Web, or metabolic and genetic networks (Chapter 9). Inspired by empirical findings, there has been an attempt to classify networks into common generic types. Completely random networks sit at one side of the spectrum while regular lattices sit at the other end. In between these two extremes there are classes of networks which are hybrids having so-called small world properties (Chapter 8). Biologists often study other formations such as growing networks whose internal connectivities are extremely heterogeneous and exhibit so-called scale-free behaviour, characterized by a power-law in their degree distribution (Chapter 9). The dynamics of populations as they interact in different types of networks is a subject area currently receiving considerable interest and pervades many areas of the nonlinear sciences. It is therefore considered an important focus in this collection of research articles.

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References

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