Preface

Dynamics has always been a core issue of all natural sciences. What are the driving forces and the "mechanisms" that result in motion of the system parts and/or lead to its evolution as a whole, whatever that system may be (particular cases range from a single rigid body to the human society)? What are the properties and scenarios of this motion and evolution? What can be the meaning or implication of this dynamics if considered in a wider context, e.g., through interaction with other systems or other sciences? These have been challenging and exciting problems for philosophers and scientists throughout at least 30 centuries.

The focus of interest has evolved, too. At the dawn of contemporary science, stationary processes were regarded as the essence of dynamics. Non-stationary motion was often either attributed to a specific cause (such as periodic forcing) or considered as a mere transient that was bound to die out after a relatively short relaxation time. The corresponding system's geometry was assumed to be smooth and regular. Those phenomena that did not fit into this philosophy, turbulent flow being the renowned example, were regarded as exotic and rare and, possibly, not self-sustained.

Although this mainstream thought of science has been challenged from time to time from as early as ancient Greece, it was not until the late twentieth century that it was widely realized that the dynamics of even very simple systems can be – and often is – completely different and much more complicated. Relaxation to steady states and periodic motion (with the limit cycle as its mathematical paradigm), which used to be the main elements of dynamics, were displaced by the concept of deterministic chaos. Smooth surfaces and simple curves gave way to objects with fractal properties. Moreover, chaos and fractals were eventually found (if not empirically, then at least theoretically) nearly everywhere, from lasers to animal behavior.

Even more importantly, it was realized that complex temporal dynamics and, especially, spatial structures do not just exist per se but can arise as a result of a system's self-organization. In an open system, i.e., a system with an inflow of mass and/or energy, the dynamics can become intrinsically unstable, resulting either in the formation of periodic spatial patterns or in a complicated turbulence-like spatiotemporal behaviour.

A similar evolution of concepts and ideas occurred in ecology and population biology. Ecologists have long been aware that population distribution in a natural environment is normally distinctly heterogeneous; however, that was usually regarded as a separate phenomenon that was not directly related to the main properties of population dynamics in time such as its persistence, reproductive success, etc. Correspondingly, earlier studies tended to focus mainly on the dynamics of "nonspatial" systems (i.e., systems where the spatial distribution of all factors and agents was regarded to be homogeneous under any circumstances). The results of the last two decades, however, proved that the impact of spatial dimensions can be crucial. The dynamics of a spatially extended system can be qualitatively different from the dynamics of its nonspatial counterpart due to self-organized, "spontaneous" pattern formation.

It should be mentioned that recent progress in theoretical ecology would unlikely have become possible without extensive use of mathematical modeling. There are several reasons why a complete and thorough study of ecosystem dynamics is hardly possible if based only on field data collection. Field observations are often very expensive and field experiments can sometimes be dangerous for the environment. Moreover, a regular experimental study implies replicated experiments; however, this is hardly possible in ecology because of the virtual impossibility of reproducing the same initial and environmental conditions. Note that mathematical models have been used in ecology from as early as the nineteenth century (cf. the work by Malthus) but they became a really powerful research tool after the development of numerical simulation approaches and modern computers.

Importantly, although the spatial dimension of ecosystems dynamics is nowadays widely recognized, the specific mechanisms behind species patterning in space are still poorly understood and the corresponding theoretical framework is underdeveloped. In particular, existing textbooks and research monographs on theoretical/mathematical ecology, when addressing its spatial aspect, practically never go beyond the classical Turing scenario of pattern formation. This book is designed to fill this gap, in particular, by giving an account of the significant progress made recently (and published in periodic scientific literature) in understanding these issues through mathematical modeling and numerical simulations using some basic, conceptual models of population dynamics.

A special remark should be made regarding terminology. Apparently, the term "pattern" has originally appeared in application to spatial processes where some kind of heterogeneity is observed. In the context of this book, however, we use this term somewhat more broadly, embracing also the purely temporal dynamics of spatially homogeneous systems; cf. "patterns of temporal behaviour."

Another tendency in scientific periodics over the last decade has been convergence between ecology and epidemiology. Although it seems to be common knowledge that a disease can change population dynamics essentially, mathematical approaches to these issues remained distinctly different until recently. Remarkably, both population dynamics and disease dynamics exhibit many similar properties, especially with regards to pattern formation in space and time. This book provides a first attempt at a unified approach to population dynamics and epidemiology by means of considering a few "ecoepidemiological" models where both the basic interspecies interactions of population dynamics and the impact of an infectious disease are considered explicitly.

The book is organized as follows. Part I starts with a general overview of relevant phenomena in ecology and epidemiology, giving also a few examples of pattern formation in natural systems, and then proceeds to a brief synopsis of existing modeling approaches.

Part II deals with nonspatial models of population dynamics and epidemiology. We have already mentioned that the dynamics of spatial and corresponding nonspatial systems can be essentially different and the results of nonspatial analysis may, in some cases, be misleading. Nevertheless, it is also clear that the properties of nonspatial dynamics provide a certain "skeleton" important for a thorough understanding of spatiotemporal dynamics. Correspondingly, Part II gives a wide panorama of existing nonspatial approaches, starting from basic ideas and elementary models and eventually bringing the reader to the state-of-the-art in this area.

In Part III, we introduce space by means of including "diffusion" of the individuals and consider the main scenarios of spatial and spatiotemporal pattern formation in deterministic models of population dynamics.

Finally, in Part IV, we address the issue of interaction between deterministic and stochastic processes in ecosystem/epidemics dynamics and consider how noise and stochasticity may affect pattern formation.

When writing this book, we were primarily thinking about experienced researchers in theoretical and mathematical ecology and/or in relevant areas of applied mathematics as the "target audience," and that affected its structure and style. In particular, from the beginning of Part I we use some advanced terminology from applied dynamical systems, mathematical modelling, and differential equations, which requires the reader to have at least some basic education in these topics (even in spite of the fact that much of that terminology is actually explained later in the text). However, we do hope that many researchers from neighboring fields and also postgraduate students will find this book useful as well; in order to encourage them to read it, we give enough calculation details. For the same purpose, the presentation of some introductory items is, at times, made on a rather elementary level.

A considerable part of the results included into this book was obtained in numerical simulations. Therefore, although numerical results by no means can be regarded as an adequate substitute to rigorous analysis, we think that it will be only fair if the reader is given an opportunity to reproduce the main results and (which is probably even more important) to make a deeper look into the system's dynamics in his/her own numerical experiments. For that purpose, a CD is attached to this book that contains many of the computer programs that we have used in our work. The programs are written in MATLAB; it must be mentioned here that MATLAB® and Simulink® are trademarks of The MathWorks, Inc., and are used with permission. The MathWorks does not warrant the accuracy of the programs on the CD. This

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Importantly, although the spatial dimension of ecosystems dynamics is nowadays widely recognized, the specific mechanisms behind species patterning in space are still poorly understood and the corresponding theoretical framework is underdeveloped. In particular, existing textbooks and research monographs on theoretical/mathematical ecology, when addressing its spatial aspect, practically never go beyond the classical Turing scenario of pattern formation. This book is designed to fill this gap, in particular, by giving an account of the significant progress made recently (and published in periodic scientific literature) in understanding these issues through mathematical modeling and numerical simulations using some basic, conceptual models of population dynamics.

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