Preface

All natural populations fluctuate in a substantially unpredictable, stochastic fashion. Stochasticity creates a risk of population extinction that does not exist in deterministic models, with important consequences for both pure and applied ecology. This book introduces biological concepts and mathematical methods that have proven useful in analyzing stochastic population dynamics in time and space. Assuming the reader has a background in basic ecology and a working knowledge of elementary calculus and statistics, we emphasize the insights that can be gained from relatively simple analytical models that incorporate stochasticity.

We make no attempt at a complete coverage of the field in terms of either taxa or the range of possible population models. For applications of single population models, we have a taxonomic preference for terrestrial vertebrates, particularly birds and large mammals, for two reasons. First, the most accurate data, with complete population censuses over decades, are available for birds and to a lesser extent for mammals. This facilitates our focus on biological processes in stochastic population dynamics without devoting inordinate space to statistical methods for estimating population sizes and handling large uncertainty that characterizes most population estimates. Second, many vertebrate populations reproduce annually at a certain breeding season each year, with small maximum rates of population growth. This greatly simplifies their analysis by avoiding complications of cyclic and chaotic dynamics that may apply to populations with short generations and high growth rates. Species diversity and community dynamics are illustrated using data on insects, especially tropical butterflies that are taxonomically well known and amenable to standardized collection of large samples, including numerous species over multiple generations.

In Chapter 1 we define and formulate demographic and environmental stochasticity, and illustrate statistical methods for estimating them from field data. The concept of long-run growth rate of a population in a stochastic environment is explained and, in Chapter 3, extended to age-structured populations. Chapters 2 and 4 develop diffusion approximations to analyze the extinction dynamics of single populations and metapopulations with local demographic and environmental stochasticity. Chapter 3 presents a new method of estimating the total density dependence in a life history from time series of populations with discrete annual reproduction. Applications to several data sets confirm that vertebrate population dynamics usually are undercompensated and not intrinsically cyclic or chaotic. Chapter 4 derives a model of small or moderate fluctuations in populations with a continuous spatial distribution to analyze the spatial scale of population fluctuations and local extinction risk. In Chapter 5, stochastic dynamics and statistical uncertainty are incorporated into population viability analysis using population prediction intervals. Chapter 6 demonstrates that stochasticity and uncertainty can strongly affect sustainable harvesting strategies. Statistics of species diversity measures and species abundance distributions are summarized in Chapter 7, with implications for the reliability of rapid assessments of biodiversity. Partitioning diversity into additive components associated with different factors, similar to the analysis of variance, provides a new approach to analyzing patterns of species diversity. In Chapter 8, we derive stochastic community models to analyze spatio-temporal data on community dynamics, revealing that the great majority of the variance of logarithmic species abundances can be attributed to deterministic and stochastic factors absent from neutral community models.

Although the conceptual simplicity and potential realism of simulation models appeals to many researchers, there are serious limitations and possible pitfalls that an analytically unsophisticated researcher is likely to encounter. Computer simulation of realistic models is not conducive to reaching general conclusions, and may also be time consuming, because each simulation must necessarily be based on particular values of various parameters. To paraphrase the eminent twentieth century British biologist J. B. S. Haldane, an ounce of analysis is worth a ton of simulation. Statistical theory has established that the best predictive power is achieved by relatively simple models with a small or intermediate number of parameters, rather than by complex models, because limited data do not permit accurate estimation of many parameters. A theme repeated throughout this book is that analytical modeling or insight derived from analysis, combined with simulation, often provides the most informative approach for understanding and interpreting population data.

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