INVASIVE SPECIES

WHAT EVERYONE NEEDS TO KNOW

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FOREWORD

In the late 1970s, I became interested in biological invasions as a purely academic phenomenon. I was studying aspects of community ecology, particularly how different species fit together (or do not fit together!) to form biological communities. Introduced species seemed to me a useful subject, a test of various ideas about communities. After all, a biological invasion consists of a new species arriving in the midst of an existing community of native species. Will the new entry survive or not, and, if it does, how will it affect the natives? It seemed to me that answers to these questions would shed light on the forces structuring ecological communities. How similar can an introduced species be to an existing native species yet still persist? Conversely, will similarity to a native species aid an invasive species in displacing that species? How does the number of native species already present affect the likelihood that a new introduction will survive and spread? What happens when a totally new life form is introduced to a community (as when rats arrive on a formerly predator-free island)?

As I combed the literature on invasions seeking data that might help answer such questions, I found a problematic situation. Although many researchers had noted particular invasions and some had speculated on the reasons for them and the impacts they caused, relatively few had treated invasions in enough detail to help me answer the general questions I was asking. In fact, it seemed as if the majority of invasions were highly idiosyncratic, with the impacts resting on details that were very specific to the particular introduced species and to the biota of the particular region to which it was introduced. I wondered if perhaps there were no general answers. My own empirical research at the time, which included observation of both invasive and native insects attacking invasive and native plants, was too narrowly focused to suggest general patterns. Some of my observations were intriguing. For instance, Asian oaks widely planted in north Florida displayed remarkable resistance to native leaf-mining moths and beetles attacking them compared with native oak species. But how relevant were such findings to general patterns of biological invasions?

As I pondered my research results and delved into the literature on biological invasions in the mid-1980s, I participated in two projects almost simultaneously that greatly influenced my research career and definitively shifted my focus toward invasions. In 1982, the Scientific Committee on Problems of the Environment (SCOPE), an arm of the International Council of Scientific Unions, recognized a growing number of reports of environmental problems caused by biological invasions and an absence of any sort of synthetic, scientific overview of the phenomenon. In response, SCOPE organized a series of workshops in several nations to encourage study of the causes and consequences of biological invasions and to attempt to apply this research to solving the myriad problems invasions cause. These workshops engaged many of the world's leading ecologists, both those who had studied particular invasions intensively and those who were less familiar with the subject. I was fortunate enough to be invited to the North American workshop, held in California in 1984, and the final synthesis workshop in 1988 in Hawaii, which brought together participants from the regional and national workshops. These events featured many fascinating presentations on details of various invasions and highly stimulating discussions in both the daily sessions and informal conversations at dinner and into the night.

Coincidentally, in 1986 I was asked to join the national Board of Governors of the Nature Conservancy. I had long been engaged in conservation activities, both as a private citizen and as a scientist publishing papers on refuge design and causes of extinction. Among its many activities, the Nature Conservancy maintains an enormous network of refuges, and after joining the board I quickly learned from many of the land stewards who were managing those refuges that introduced species were a major problem—often the biggest problem—in a remarkable fraction of them. Invasive plants that overgrow the entire habitat were the most prevalent management challenge, but there were many others, including introduced predators that threaten rare animals, introduced herbivorous insects and mammals that imperil plants, and introduced plants that change the fire cycle to the disadvantage of native species. Juxtaposing this information from land stewards fighting invasions on the ground in the conservation trenches with the wealth of data and theory that scientists in the SCOPE project provided, I could not help but recognize that biological invasions were a subject of great practical urgency and limitless scientific opportunity. My research path was set.

The SCOPE project of the 1980s thus launched the science of modern invasion biology, bringing together ecologists, evolutionists, geneticists, earth scientists, and mathematical modelers in an explosion of research aimed at filling in the details of long-noted invasions as well as detecting impacts of new invasions and discerning previously unrecognized effects of older invasions. By the 1990s, land managers were intensively engaged in invasion biology, working with various technologies to eradicate invasive species or at least mitigate their harmful impacts. In the 2000s, economists and social scientists have increasingly interacted with invasion biologists to address the human side of invasion impacts and management of introduced species. However, it is not easy for the public and policymakers to understand the wealth of issues that biological invasions raise. Every week, newspapers and television shows feature reports of biological invasions, usually of local or regional interest: a new insect pest of regional forests or crops; an introduced fish that has made its way into local lakes; a new plant overrunning gardens or nature preserves; a new mosquito carrying a human pathogen. Occasionally, a particularly damaging invasion receives national coverage. However, media reports tend to sensationalize stories, presenting grim possible future scenarios but few details and often no context. Each of these reports is usually a one-off event, and none of them present the panorama of biological invasions and management options that people must understand if they are to form rational opinions about specific invasions.

In addition, many aspects of biological invasion management are controversial. Sometimes management costs are high, and, in some cases, the degree of invasion impact is debatable. Management procedures involving baits or herbicides can have nontarget impacts, or an eradication technique such as snaring wild boar or feral pigs can be inhumane. And, as with any large environmental problem (global warming and chemical pollution are examples), a small minority of scientists will argue that the problem is exaggerated or management actions unwarranted—or both. The popular media focus on controversy, so critics of invasion biology get a lot of press, again without the context that everyone needs to assess the criticisms intelligently.

The increasing number of damaging biological invasions, the rapid growth of a modern science to study them, the wealth of old and new management technologies (often unpublicized), and frequent controversies over policies and practice are all factors that combine to create a need for a comprehensive, nontechnical discussion of the full scope of biological invasions. This book aims to satisfy that need.

ACKNOWLEDGMENTS

My students and colleagues at the University of Tennessee have been a continuing source of information and insights on biological invasions. Every day I hear from them a new finding on one or more invaders or a new idea about how to study and understand them. In particular, my former students Martin Nuñez, Arijana Barun, Betsy Von Holle, Diego Vázquez, Tad Fukami, and Lara Souza all worked on biological invasions for their doctorates and taught me much about the systems they studied. They constantly bombarded me with challenging questions and readings of the invasion literature. My current students, Sara Kuebbing, Rafael Zenni, Noelia Barrios-Garcia, and Jessica Welch, have carried on this tradition and keep me from thinking I know too much about invasions. Sara and Rafael read an entire early draft of this manuscript and provided many suggestions that helped me improve it; for this service I am greatly indebted.

My wife, Mary Tebo, my daughter Ruth Simberloff, and my cousin Carol Bodian read and constructively criticized selected chapters. My daughter Tander Simberloff exhaustively edited an entire draft of the manuscript and kept hauling me down from the ivory tower—I will be forever appreciative.

Colleagues too numerous to list answered myriad questions on particular invasions discussed in this book, often providing substantial unpublished details. I am grateful for their assistance.

My editor at Oxford University Press, Hallie Stebbins, has been a constant source of encouragement and advice. The University of Tennessee granted me a year-long development leave (known elsewhere as a sabbatical), and a French hotbed of research on invasions, the Centre d' Écologie Fonctionnelle et Évolutive of the Centre National de la Recherche Scientifique in Montpellier, was a congenial host during this period. I wrote this book during this leave, and I thank both institutions for their assistance.

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GENERAL INTRODUCTION

1.1 What is a biological invasion?

On a sunny day in May 2002, two men went fishing at a small, shallow pond (originally a construction pit) behind a strip mall in Crofton, Maryland, 20 miles from the Capitol in Washington, D.C. Almost immediately, a large, strange fish snapped up a cast lure. This was unlike anything either man had seen before, resembling an obese, muscular eel, with fins running almost the entire length of the top and bottom of the 18-inch body and, clamped around the lure, a set of teeth like something out of a science fiction movie. Imbued with the catch-and-release philosophy, the fishermen released the fish, noting that it also looked pregnant. But, intrigued by this scary oddity, they photographed it before throwing it back in the water, though they did not develop the roll of film until June. None of their fishing buddies recognized the fish in the snapshot, so they took it to an office of the Maryland Department of Natural Resources. Even the fisheries scientists there could not identify it, but finally, through a website of nonnative fish species operated by the U.S. Geological Survey, they determined it to be a snakehead. The authors of the website then identified it as the northern snakehead, native to the Yangtze River in China north to the China–Russia border. This fish is a ferocious, aggressive predator that eats almost any other fish and can grow to 3 feet long. Worse, juveniles of this species can breathe air, survive awhile out of water, and move short distances overland—and the small Maryland pond is near the Little Patuxent River.

A month later, a fisherman caught a larger northern snakehead in the same Crofton pond. Soon after, he caught several baby snakeheads. Because of the proximity to Washington, the arrival of this fearsome fish made regional and then national headlines. Two horror movies were even loosely based on this event. It later turned out that this "invasion" had begun when a man purchased two individuals at an Asian food market and subsequently released them. The pond was drained, a hundred snakeheads of various sizes were destroyed, and none have been seen near the site since. However, a small breeding population was later discovered in the Potomac River (these individuals were determined by genetic means not to be related to those in Crofton), and individuals have cropped up in several distant states. Most ominously, they have been found in drainage ditches near the White River in Arkansas, from which they would have easy access to the Arkansas and Mississippi Rivers.

The arrival and spread of the northern snakehead is a classic biological invasion. The triggering event occurs when individuals of a species not native to a region arrive with human assistance and establish an ongoing population. If the population then spreads in its new home, the phenomenon is called a *biological invasion* and the species is termed *invasive,* at least in this region. Another example is the red imported fire ant, which arrived from South America in the port of Mobile, Alabama, in the 1930s and gradually spread throughout the southern United States, so that today it extends north to Tennessee and North Carolina and west to Texas. In the 1990s it jumped to southern California and began spreading there as well.

Several aspects of this definition require explanation. When we say "arrive with human assistance," this need not mean deliberate assistance. Many nonnative plant species are deliberately imported for horticultural use, and some, such as kudzu and Japanese knotweed, become invasive. Similarly, some deliberately introduced sport fish, such as the South American butterfly peacock bass in Florida, have become invasive. However, many invaders are inadvertently introduced as hitchhikers on goods carried or shipped by humans. The fire ant arrived in Mobile hidden in cargo and probably caught a ride to California in trucked plant material or soil. Additionally, the term *invader* is often used to describe all introduced species, but this is not quite accurate. An introduced species is any species that arrives somewhere with human help (deliberate or accidental), including even those species that do not establish populations or that establish populations but do not spread widely from the point of arrival. Biologists have generally restricted the term invasive to cases in which the species is found well beyond the arrival area.

By contrast with biologists' usage, policymakers sometimes use *invasive species* to describe only introduced species with negative impacts. For instance, President Bill Clinton's Executive Order 13112 of 1999 defines invasive species to be an "alien" species whose introduction does or is likely to harm the environment, the economy, or human health—a rather different definition from that traditionally used by biologists. Invasive species are sometimes referred to simply as "pests," but, in fact, not all invaders cause significant damage, and not all pests are introduced. In this book, invasive species will be used in the standard biological sense—species that arrive with human assistance, establish populations, and spread.

The word *native* also needs some explanation. Biologists say a species is native to a region if it evolved there or if it evolved elsewhere but arrived in the region by its own means, usually thousands if not millions of years ago and without human assistance. Species present in a region but not native have been termed *alien, exotic, nonindigenous,* and *nonnative,* but the various nonbiological uses, sometimes pejorative, of the terms *alien* and *exotic* have led biologists to use nonindigenous and especially nonnative for species not native to a region. For the great majority of biological invasions discussed in popular media and scientific literature, there is no question whether the species is in fact nonnative or might perhaps be native; its status is known. However, there are exceptions—some populations are suspected of having been introduced, but the evidence is simply insufficient to be conclusive. The common periwinkle snail of the northern United States and Canadian Atlantic coast is one such example that will be detailed in Chapter 11.3.

Populations whose status as native or nonnative is uncertain are termed *cryptogenic*, and for some regions or habitats the percentage of species that are cryptogenic is quite large. For instance, the native geographic range of many marine species is not known, and for widespread marine species it is often impossible to determine if they reached their current locations on their own or were carried in ballast water or on the hulls of ships, perhaps centuries ago before records were kept of which species were where. For some species, populations on the edge of what is believed to be the native range of a species may in fact be introduced. Among plants in the western Mediterranean region, several are ancient human imports from adjacent areas. For instance, the chasteberry, native to the eastern Mediterranean, was brought to Mediterranean France by monks for use as an anaphrodisiac to reduce libido. Among fishes in the United States, a surprising number of such "peripheral" populations were actually established by humans for sport fishing.

In much of the world, widespread human transport of species is a relatively recent phenomenon. Invasion biologists often focus on invasions that have occurred in the last 500 years, since the European discovery of America initiated what is known as the Columbian Exchange—the widespread movement of animals, plants, humans, and culture between the Old World and New World. Of course, humans moved