Foreword

Alien invasive species are generally regarded as one of mankind's greatest ecological problems. Reports of species introductions and their myriad impacts have exploded since the early 1990s and include virtually all kingdoms and phyla. Included in this group is a small set of bivalve molluscs, including zebra (*Dreissena polymorpha*) and quagga (*D. rostriformis bugensis*) mussels. These two species have spread across much of Europe and North America, and were instrumental to efforts by managers in both the USA and Canada to develop better invasive species management strategies for preventing undesirable invasions and more effectively eradicate or limit dispersal of those that do succeed. British researchers recently identified the quagga mussel as the country's most high-risk potential invader, as spread of the species picks up across Europe.

A third member of the class Bivalvia and the topic of this volume—the golden mussel (*Limnoperna fortunei*)—has also been introduced abroad and is spreading quickly. Golden mussels are native to Southeast Asia, but have spread both in that region and throughout much of eastern and central South America. The latter invasions have occurred with lightning speed, with spread occurring over ~2000 km in ~20 years. Like the aforementioned dreissenid species, the golden mussel is an ecological engineer, radically altering many of the ecosystems it invades. Also like the dreissenid species, the golden mussel poses a significant biofouling problem to municipalities and industrial users of raw water. I became acutely aware of the pervasive nature of golden mussel biofouling while traveling in a remote section of the Pantanal and discovered mass colonization of native pictographs on rock walls lining the Paraguay River. The species also poses a very significant threat to man-made reservoirs and canals in China and elsewhere that were designed to move water from areas of abundance to those of greatest need.

Very clearly, a focused effort was required to assemble the most up-to-date and comprehensive information on this species. The book is edited by Demetrio Boltovskoy, a highly capable Argentinean researcher with more than 15 years' experience working with golden mussels. It covers virtually every aspect of golden mussels of interest to ecologists and managers. It is divided into sections, including those devoted to basic biology, environmental impact, behavior, comparisons to other biofouling molluscs, distribution and colonization, mitigation, and control.

The book's 40 authors are drawn from seven countries, with large contributions by researchers from Argentina, Brazil, and Japan. Individual chapters detail the anatomy, morphology, population genetics, population structure, reproductive cycles, interspecific interactions, and behavior of the species. Subsequent chapters focus on distribution and patterns of spread in South America, China, and Japan, and applied topics related to biofouling, control, and eradication.

This book will serve as the benchmark on the golden mussel as it continues its spread across Asia and South America, and more and more researchers and managers seek easily accessible and authoritative information on what to expect in their invaded system.

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Preface

Ever since it started spreading to other countries, *Limnoperna fortunei* has become an issue of growing concern. In his pioneering work, Morton (1977) pointed out that “The fouling potential of *L. fortunei* cannot, as yet, be accurately forecast, but it is felt expedient to warn against artificial introduction of this mollusc elsewhere.” This diagnosis proved correct shortly thereafter when *L. fortunei* was shown to have spread into Taiwan and Korea, and later into Japan and South America (see Part III in this volume). Introduction of the mussel in the latter two areas, which occurred at about the same time (around 1990), was clearly marked by a boom in the number of reports centered on this mussel (Fig. 1). Publications on *L. fortunei* soared from an average of <0.3 per year in 1950–1992, to over 20 per year in 1993–2012. By the end of 2013, there were ~ 500 works of various types devoted either solely or chiefly to the golden mussel. Journal articles made up around 60 % of this total, followed by conference reports, book chapters, theses, and miscellaneous works (web pages, internal reports, etc.) (Fig. 2).

Although such a volume of publications devoted to a single species may seem impressive, the number of works reporting new, peer-reviewed data in mainstream journals is much lower. Of the ca. 300 journal articles, only ~ 50 % have been published in widely available “white literature” (according to a recent survey by Barbosa 2014, for the period 1982–2012, the database of the Thomson Institute for Scientific Information—ISI contains 107 papers on *L. fortunei* published in 60 journals), whereas the other half corresponds to local or regional Asian or South American publications, largely in languages other than English (Fig. 3).

Significantly, much of this “grey literature” contains abundant useful information that is largely ignored by the international scientific community because of accessibility and language-related problems. Thus, one of the purposes of the present book is to critically summarize and disseminate a large amount of information that is not readily available. In order to ensure adequate coverage of widely dissimilar sources and languages, efforts were made to enlist authors from the different geographic areas occupied by *L. fortunei*.

This book centers specifically on *L. fortunei*, rather than on invasive aquatic bivalves in general. The latter have been profusely covered in several excellent

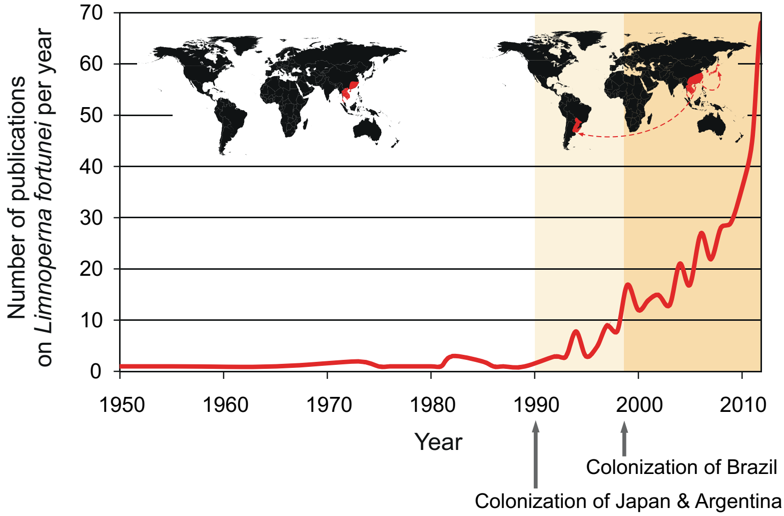

Fig. 1 Number of publications centered exclusively or chiefly on *Limnoperna fortunei*, published between 1950 and 2012

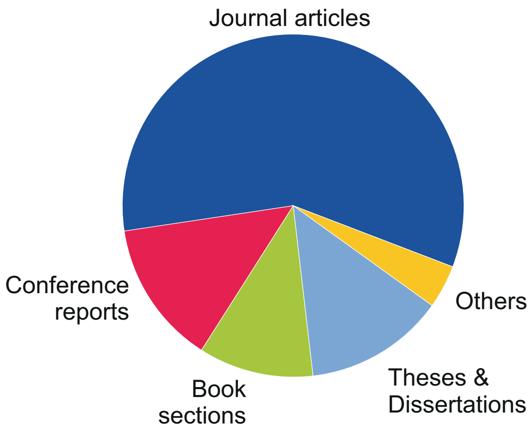

Fig. 2 Breakdown of publications shown in Fig. 1 according to source type

review works, so they are not discussed here, except in the context of direct comparisons with the golden mussel. Furthermore, the topics included herein are restricted to those for which data on *L. fortunei* are available, and these clearly do not cover all aspects of the biology and ecology of the mussel. Interestingly, however, even this limited volume of information contains disagreements. The reader will probably notice that different authors have different points of view and dissimilar outlooks on

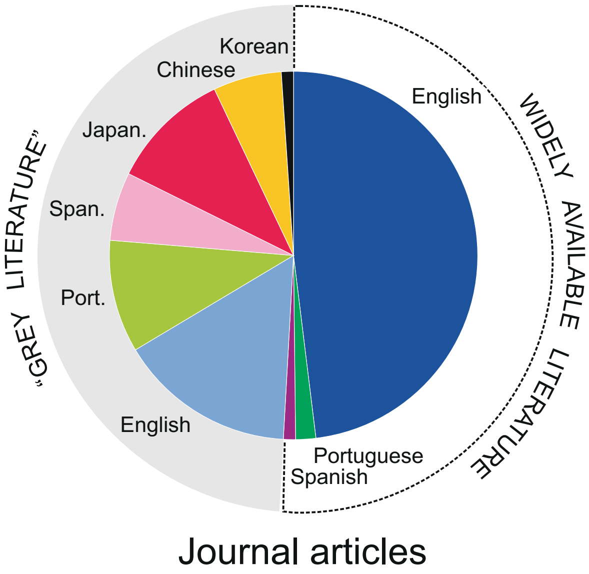

Fig. 3 Breakdown of journal articles published on *L. fortunei* up to 2013 according to source type and language. "Widely available literature" includes refereed journals indexed in most international databases (covered by SCOPUS). "Grey literature" includes refereed and un-refereed publications of limited distribution and not covered in most major international databases

the same issue. Aside from the fact that such discrepancies are unavoidable in most collective works, we deliberately avoided reconciling these disagreements in order to underscore the blanks and uncertainties in our current knowledge of this mussel.

Throughout the book, and particularly in the sections dealing with the impacts of *L. fortunei* on other organisms, care was taken to present a balanced overview of the effects that have effectively been investigated (rather than extrapolated from studies on other invasive mussels) in a dispassionate and nonjudgmental manner, avoiding repetition of general statements based on extrapolations from studies of other invasive species, in particular the zebra mussel. Much of the mainstream literature on alien species is focused on forcefully demonstrating that invasives are fundamentally different from indigenous species, and particularly that their effects are detrimental for the ecosystem (Davis et al. 2011). While this is clearly the case for many introduced species (Simberloff and signatories 2011; Simberloff et al. 2012; Paolucci et al. 2013), every introduction must be analyzed and weighed in its own right, rather than by extrapolation of knowledge from other invasives, or automatically labeled as harmful because the species involved is nonindigenous. Unfortunately, in the case of *L. fortunei* this has happened time and again. The following example illustrates this bias vividly. In a recent paper on the effects of climate variability on fisheries, Defeo et al. (2013) stated that "…NIS invasions have altered community structure and diversity in freshwater and estuarine ecosystems of Latin America, and negatively affected small scale fisheries. For example, the sustained increase of the Asiatic clams (*Corbicula fluminea* and *Limnoperna fortunei*) and the invasive whelk (*Rapana venosa*) in coastal/inshore ecosystems of South America generated drastic ecosystem effects that included the depletion of native species exploited by small scale fisheries, such as the blue mussel…." Aside from the fact that *Corbicula fluminea* and *L. fortunei* are typically freshwater organisms, practically absent in marine coastal/inshore ecosystems, the reference used by these authors to support their argument (Lercari and Bergamino 2011) does not mention *L. fortunei* at all, yet *L. fortunei* was included in the statement because, as is *C. fluminea* (whose negative influence on freshwater fisheries is debatable), it is an introduced species. Furthermore, the evidence available so far indicates that the presence of *L. fortunei* is probably beneficial, rather than harmful, for some exploited fish species (see "Trophic relationships of *Limnoperna fortunei* with larval fishes" and "Trophic relationships of *Limnoperna fortunei* with adult fishes" in this volume).

Numerous reports have shown that the same introduced species can have very dissimilar effects in different habitats, and even within the same habitat, with changing environmental conditions (Byers et al. 2002; D'Antonio and Hobbie 2005; Reise et al. 2006; Davis 2009; Ruokonen et al. 2014), let alone different (albeit functionally similar) species. Nevertheless, literature on *L. fortunei* is plagued with examples where results of studies showing the negative impacts of other species in vastly dissimilar environments (chiefly *D. polymorpha* in North America) are used as proof of a similar impact of *L. fortunei* in South America (Boltovskoy and Correa 2015). This approach hampers objective analyses and does little to advance our understanding of how this species interacts with its new environment.

Irrelevant, unoriginal, and unsubstantiated information is pervasive among all scientific fields, but "hot" topics seem to be particularly vulnerable. *L. fortunei* has become such a hot topic ever since it started interfering with the operation of power plants and its colonies became a salient feature of coastal freshwater areas. This has had a dual effect on published information on the golden mussel. On the one hand, it spurred a wealth of new data, particularly in the areas of population dynamics, geographic distribution, and ecology. On the other hand, however, it also stimulated the production of many reports with scarce—if any—original valuable information, centered on "crying wolf" and attributing to *L. fortunei*, without any supporting evidence, the environmental effects of *D. polymorpha* on European and North American waterbodies. Although some of these publications were careful to note that these effects were merely a possibility, they had a snowball effect whereby subsequent literature used them as proof of the putative impacts. This problem clearly reflects the fact that "… because positive results are more likely to be submitted and published, the invasion literature may be biased toward demonstrating that nonindigenous species have large ecological impacts" (Byers et al. 2002). Furthermore, the same bias seems to permeate grant submissions, conference reports, newspaper and magazine articles, consultant reports, thesis dissertations, book chapters, web pages, etc., where the importance of impacts is exaggerated in the hopes of getting funding or recognition. This phenomenon is likely also associated with the fact that the distinction between "pure" ecology and "applied" ecology, which prevailed in the 1950s and 1960s, has been blurring since the 1980s and ecologists have been increasingly concerned about justifying their research in a larger social context, particularly addressing the issue of how their work—funded by government money—benefits society at large (Davis 2006).

As noted by Davis (2006), during the last decade, invasion biology has developed along two distinct paths, vividly illustrated by the recent controversy of Davis et al. (2011) versus Simberloff and signatories (2011). The "Eltonian path" is characterized by the strongly conservation-oriented approach advocated by Elton (1958), while the "Asilomar path" is less focused on conservation/restoration issues. In their drive to prove their point, conservation-oriented researchers have often neglected an alternative approach whereby the introduced species, once established, is regarded as any native form, with both negative and positive effects on the colonized ecosystem. In addition to being inoperative on a practical level, the invasive vs. indigenous dichotomy can hamper objectivity and lead to nonsensical results (Valéry et al. 2013). Ignoring the fact that it is an alien form should most probably help us to assess its impacts more objectively (Thompson et al. 1995; Gurevitch and Padilla 2004; Davis et al. 2011). This should not imply a denial of the probability that nonnatives are more likely than natives to have strong impacts on local ecosystems (Simberloff et al. 2012; Paolucci et al. 2013), but the "invasive species approach" tends to lump all introduced species in the same bag thus focusing the assessment of their interactions on the traits that they share with other invasives (usually perceived as negative), rather than on those that characterize them best.

One of the most frequently marshaled arguments in association with the impact of introduced species is that their impact stems from the fact that they have no natural enemies in newly colonized areas (Van Driesche and Van Driesche 2000). While probably true for many nonnative species, this is probably not the case for *L. fortunei*, where >90% of the mussel's yearly production is lost to predation (Sylvester et al. 2007; Nakano et al. 2010). Admittedly, this assessment does not prove that *L. fortunei* is as vulnerable to predators in its invasive range as in its native range, yet it suggests that even some of the most deeply rooted tenets of invasion biology, such as the enemy release hypothesis (e.g., Colautti et al. 2004), cannot be applied indiscriminately to all invasives.

This discussion does not involve the pros and cons of deliberate species introductions, which mostly concern organisms directly used by man for food, shelter, medicine, ecosystem services, or aesthetic enjoyment (Ewel et al. 1999); it is hard to envision that *L. fortunei* will ever be the target of a deliberate introduction. Furthermore, basic precaution and the long list of introduced species that had devastating effects on native biota (Pimentel 2002; Simberloff 2003) clearly justify all possible efforts to keep biological invasions at bay or to eradicate them if feasible. However, once a nonnative species has been introduced and its eradication is out of the question (as is the case for *L. fortunei*), analyses of its interactions with the local biota should not be rooted in the notion that it is harmful.

As of 2014, in South America *L. fortunei*'s range seems still limited to the large Río de la Plata basin (Paraguay, Paraná, Uruguay rivers) and a few minor watersheds (Guaíba and Tramandaí, in Brazil, Mar Chiquita, in Argentina; see Chap. 19 in this volume). It has not been reported from the Amazon system, the next large South American watershed, but its colonization of this huge area is most probably inevitable. The proximity of the Amazon and the Río de la Plata basins makes the former very vulnerable to human transport of the golden mussel by watercraft, fishing, and fish culture gear, in particular fish cages, and any object that has been immersed in water and overgrown with mussels. Furthermore, the Amazon is navigable to ocean liners of virtually any tonnage, including ships with ballast water from infested ports along the Paraná-Uruguay-Río de la Plata waterways and the Guaíba basin, where compliance with international water ballast regulations is rather loosely enforced (Boltovskoy et al. 2011).

It is our intention that this book serves as a critical update and general reference for current knowledge on this important animal, and a guide to the many aspects that we still know almost nothing about. Indeed, after 30 years of relatively intensive research, the blanks are numerous and significant. Key aspects of the biology and ecology of *L. fortunei*, crucial for an appraisal of its impacts on the biota, have hardly been touched upon, such as its fertility, its metabolism and physiology, its natural enemies (other than fishes), its long-term effects on benthic communities, its direct and indirect impact on other filter-feeding organisms, etc. As detailed elsewhere in this book (see Chap. 7 in this volume), over two decades after *L. fortunei* started colonizing Japan and South America, only one attempt has been made at estimating its abundance across an entire water body. Density data available are almost invariably restricted to isolated, usually densely populated, spots, yielding little (if any) valuable information on the potential impact of these mussel beds. A significant void in our understanding of the impacts of the golden mussel is the absence of large-scale studies, both temporally and geographically. Almost all surveys on the relationships between *L. fortunei* and local organisms are laboratory or field studies of specific interactions that point at *possible* system-wide effects, but we do not know the extent to which these potential effects are actually changing preinvasion conditions. Difficulties in assessing the latter also stem from the paucity of background information, including long-term, comprehensive studies of the freshwater systems colonized by the mussel.

We hope that the critical update and summary of current knowledge contained in the following pages will help orient future research on *L. fortunei* as it spreads northwards.

Demetrio Boltovskoy

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