Part 3

New Takes on Invasion Patterns

Chapter 7

BIOLOGICAL INVASIONS IN EUROPE 50 YEARS AFTER ELTON: TIME TO SOUND THE ALARM

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Fifty Years of Invasion Ecology: The Legacy of Charles Elton, 1st edition. Edited by David M. Richardson

7.1 INTRODUCTION

Although the rates of species' introductions to Europe accelerated significantly during the second half of the 20th century (Hulme et al. 2009c), concerted efforts to understand biological invasions across the continent are relatively recent (Hulme et al. 2009b). Earlier efforts focused mainly on floristic and faunal inventories that led to deliberations on the origins and alien status of species (Chew 2006; Davis 2006). Although such inventories were an important first step, alien species were often viewed as biogeographical curiosities. It was not until the dynamic nature of biological invasions was recognized and awareness of potential impacts increased that the study of alien species began to be incorporated into the field of population ecology. In this respect Europe lagged behind many other continents. For example, concerns about impacts of alien plants in New Zealand were expressed much earlier than in Europe (Allen 1936) but major plant invasions in natural environments in Europe only started being observed in the 1950s in increasingly disturbed landscapes (Williamson et al. 2005).

Invasion ecology has grown enormously in the 50 years since Charles Elton's *The Ecology of Invasions by Animals and Plants* (hereafter 'Elton's book') was published in 1958 (Davis 2006; Pyšek et al. 2006; Richardson & Pyšek 2007, 2008; Ricciardi & MacIsaac 2008; MacIsaac et al., this volume). This chapter reviews the current state of knowledge about biological invasions in Europe and evaluates the dramatic changes that have occurred since Elton's book. Europe, especially its Mediterranean region, has traditionally been considered a donor of invasive species to other parts of the world for historical reasons and the long association of plants and animals with humans since the beginning of agriculture some 10,000 years ago (di Castri 1989). This chapter aims to show that recent systematic research efforts in the past decade in Europe may have changed this long held view: plants and animals of alien origin now form a substantial part of the continent's biodiversity (DAISIE 2009), especially in the Mediterranean (Hulme et al. 2008), and exert huge and diverse impacts on both environment and economy (Vilà et al. 2009). To put the current situation into historical context, we first review how informative Elton's book is in terms of providing an accurate picture of biological invasions in Europe 50 years ago. We then use this as a baseline to explore how the situation and perspectives have changed in the present day.

7.2 STARTING WITH EXAMPLES: ELTON'S ANIMAL-BIASED PERSPECTIVE

Elton's book is very much about changes in species' distributions; biogeography was at the heart of his thinking. He was also a zoologist and, though he dealt with plant invasions in his book, they received far less attention than animals. Of the 195 organisms listed in the book's index, 169 (87%) are animals; of these 51% are arthropods, 27% vertebrates and the rest molluscs (Richardson & Pyšek 2007).

Therefore, for animals, comparison of the distribution maps in his book with current situation provides revealing histories. For example, the Colorado beetle, *Leptinotarsa decemlineata*, has increased its range eastwards and in Scandinavia (compare Fig. 7.1a with b); this species was introduced from South America to France in 1922 and until 1950s expanded throughout the European continent and parts of Asia (Lopez-Vaamonde 2009). The muskrat, *Ondatra zibethicus*, has also expanded its range, having now colonized most of the area encompassed by Elton's maps (compare Fig. 7.1c with d). However, Elton would probably be surprised at the speed and scale of invasions by more recent animal arrivals in Europe: the horse chestnut leaf-miner, *Cameraria ohridella* (Fig. 7.1e), currently a major problem in Europe (see, for example, Girardoz et al. 2006), rose-ringed parakeet, *Psittacula krameri* (Fig. 7.1f), invasion of which in Europe started as late as in the 1960s and 1970s through trading and escape from aviaries (Shwartz & Shirley 2009), or the comb jelly *Mnemiopsis leydii*, first found in Europe in the Black Sea in 1982 (Shiganova & Panov 2009). These species clearly illustrate that the dimensions and complexities of the problem have changed radically since Elton's time.

Only 21 plant taxa feature in Elton's book. A closer look reveals that stories of plant invasions are even less represented in support for the conclusions he drew. For example, the 21 plants mentioned account for 11% of all organisms dealt with in the book, but only 11 refer to invasive plants (others mostly mention plants in their native ranges and/or in relation to animals, mostly invading insects). Only six refer to invasions in

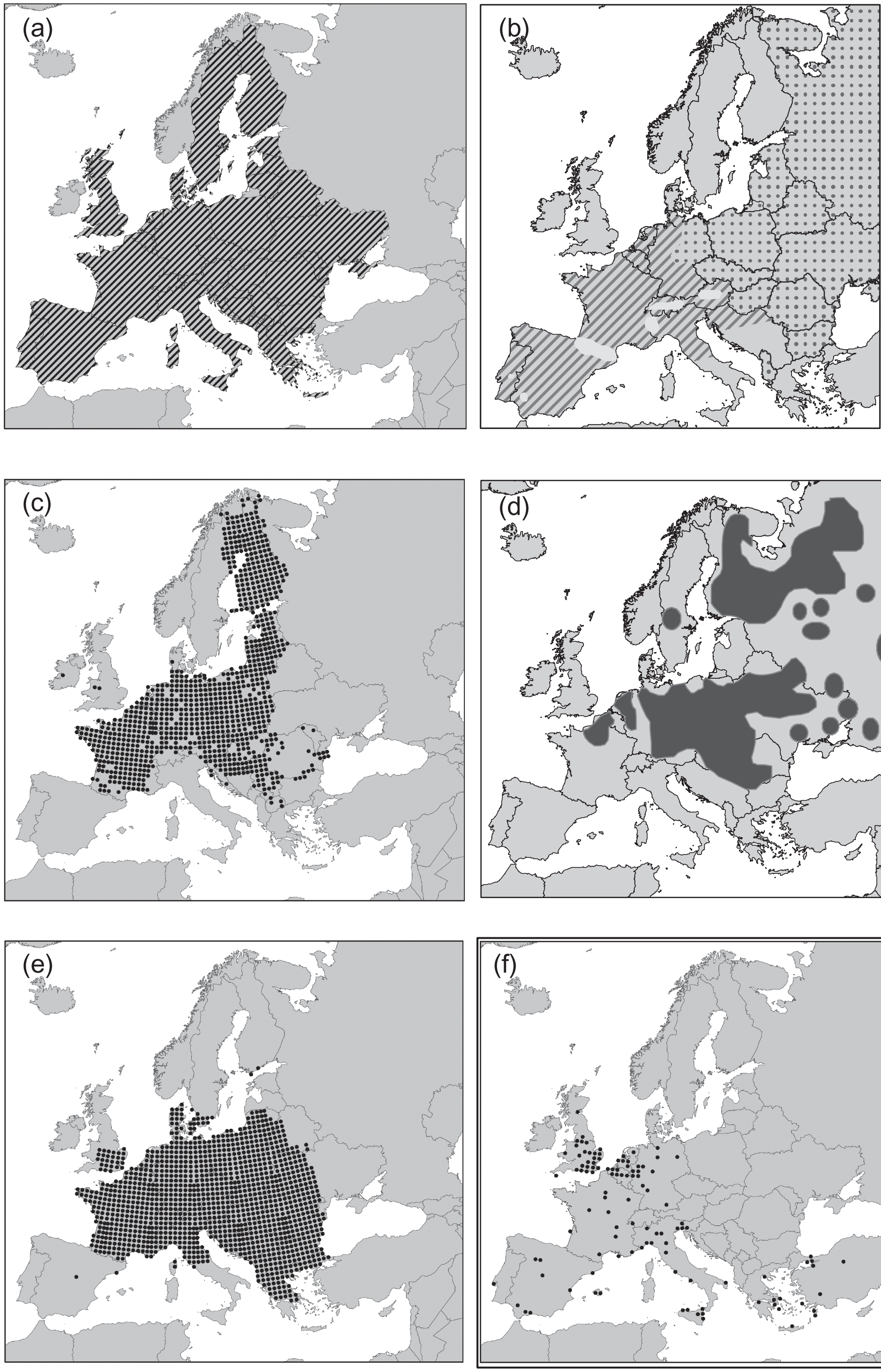

Fig. 7.1 Current distribution of animals mentioned by Elton as invasive in Europe (a, *Leptinotarsa decemlineata*; c, *Ondatra zibethicum*), compared with that given in his book (b, *Leptinotarsa decemlineata*: dots indicate no data; d, *Ondatra zibethicum*), and current distribution of recent invaders (e, *Cameraria ohridella*; f, *Psittacula krameri*). Species' distributions are mapped in 50 km × 50 km grid cells; hatching indicates that the species is reported from the given country, but does not necessarily occur over the whole area. Taken from DAISIE (2009); (b) and (d) redrawn from Elton (1958).

Europe, and only three of these species had by the 1950s undergone dramatic changes in distributions. Not surprisingly, the three primary examples were all from the UK (*Acer pseudoplatanus*, *Rhododendron ponticum* and *Spartina townsendii*) and only these three species are accorded as much detail as some of the animal examples Elton used. Yet, none of the plant species he dealt with was depicted on a map. Of the invasive plants he considered, *Spartina townsendii* (Fig. 7.2a) remains restricted to the UK and western coast of Europe but *Rhododendron ponticum* is now naturalized not only in the British Isles, but also in Belgium, France, the Netherlands and Austria (Fig. 7.2b). Within Britain and Ireland, it has spread substantially since 1958. It was reported from only 125 hectads ($10\,km^2$ grid cells) in 1970, but in 2248 hectads by 1999 (Preston et al. 2002). A similarly massive increase in Britain and Ireland occurred for sycamore, *Acer pseudoplatanus*, within this period (from 109 to 3400 hectads); the species is nowadays also naturalized in Scandinavia (Fig. 7.2c). *Rosa multiflora*, however, exemplifies a plant species about which Elton was obviously wrong; he considered it beneficial and admired it planted in hedgerows, but this species increased in distribution in the British Isles from 5 hectads to 102 in the last three decades of the 20th

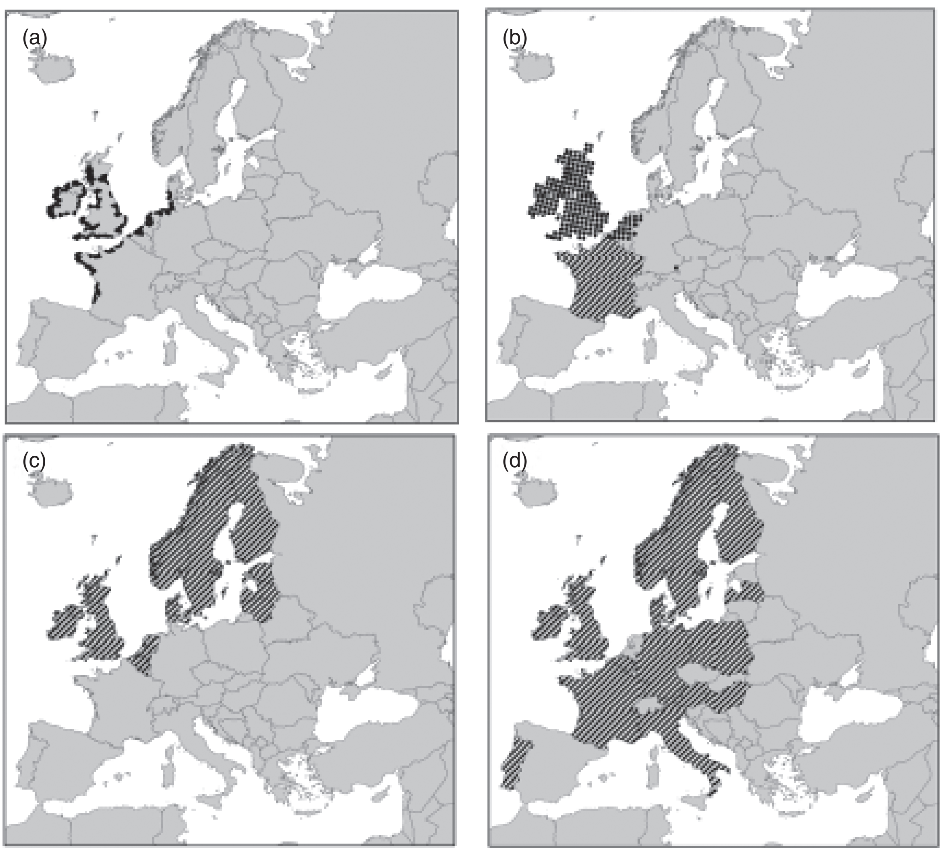

Fig. 7.2 Current distribution of plant species mentioned by Elton (1958) as invasive in Europe. (a) *Spartina townsendii*; (b) *Rhododendron ponticum*; (c) *Acer pseudoplatanus*; (d) *Rosa multiflora*, which he considered harmless, but this species has invaded not only Europe but also the USA since then. Species' distributions are mapped in 50 km × 50 km grid cells; hatching indicates that the species is reported from the country, but does not necessarily occur over the whole area. Taken from DAISIE (2009).

century (Preston et al. 2002) and it is now naturalized over a large part of Europe (Fig. 7.2d). In the eastern United States too, it became a noxious invader and has been the subject of numerous control campaigns since the 1960s (Simberloff 2000).

However, Elton's book is about examples. It does not provide quantitative insights into continent-wide patterns half a century ago. To be more quantitative, we can use current knowledge on alien plants in Europe for which the information is probably the most complete. Of the total number of naturalized neophytes (species introduced after 1500 AD; Pyšek et al. 2004) now present in Europe, over a quarter arrived after 1962, with 10% being even more recent with introductions occurring after 1989 (Lambdon et al. 2008). Using the estimated dates of introduction of alien plants in Europe (Lambdon et al. 2008), three-quarters were probably naturalized somewhere in Europe by 1958. Thus, there were approximately 1300 naturalized neophytes from other continents in Europe when Elton wrote his book; we might therefore have expected more than six examples to be addressed. The main reason for the minor attention given to plant invasions by Elton may be their perceived minor impact since, as in other parts of the world (Allen 1936), most alien plant species (and certainly major 'invasions') were in disturbed habitats (Pyšek et al. 2010), a feature that is acknowledged in his book. Thus the high species numbers of neophytes might not have been automatically translated into a great impact. The publication in 1961 of Sir Edward Salisbury's *Weeds and Aliens*, the first overview of this topic in a single volume, suggests that there was a much wider appreciation of plant invasions than emerges from reading Elton's book. Indeed, Salisbury (1961) addresses some of the very same plant species, though in more detail. He too focuses largely on the British Isles, and hardly addressed patterns for the rest of Europe.

Importantly, the most likely explanation for the dearth of plant examples in Elton's book is that some spectacular plant invasions in Europe only started in the late 1950s or were yet to explode (e.g. *Heracleum mantegazzianum*, see Pyšek et al. (2007a); *Caulerpa taxifolia*, *Carpobrotus edulis*). The indication of the magnitude of changes in the status of plant invasions in Europe over the past four decades can be documented by using the UK as an example. For this country, mapping data systematically collected in several periods are available and show that before 1970 there were 887 neophytes recorded, which together occurred in 50,655 hectads. By 1999 the number of neophyte species increased to 1438 and number of species–hectad records to 283,469, representing an increase by 460% (calculated from data in Preston et al. (2002)). This is indicative of the huge changes in the status of plant invasions in Europe.

7.3 FROM EXAMPLES TO PATTERNS: NUMBERS OF ALIEN SPECIES IN EUROPE

Starting with the big picture, what introduced species are found in Europe? The solid current position of Europe on the global map of research in biological invasions is largely due to two pan-European projects performed under the European Union 6th Framework Programme. The Delivering Alien Invasive Species Inventories for Europe (DAISIE) project established the European Alien Species Database, the European Expertise Registry and the European Invasive Alien Species Information System (Hulme et al. 2009a). Together they provide an online 'one-stop-shop' (www.europe-aliens.org) for information on biological invasions in Europe (Hulme et al. 2009a,b).

Based on data from 71 terrestrial and nine marine regions, DAISIE revealed that 10,771 alien species are known to occur in Europe (see DAISIE 2009 for the checklist of all alien species recorded, ranked taxonomically, that can be used as a reference for future assessment of trends in biological invasions in Europe). The taxa belong to 4492 genera and 1267 families. Plants are best represented and account for 55% of taxa, which is 5789 species; of this number, about a half are invasions within the continent, but the 2846 species of extra-European origin (Lambdon et al. 2008) add to 10,928 native plant species (Winter et al. 2010) and represent thus 20.3% of the total plant diversity in Europe. Terrestrial invertebrates account for 23% (2477 species), followed by vertebrates (6%), fungi (5%; Desprez-Lousteau et al. 2007), molluscs (4%), annelids (1%) and red algae (1%). DAISIE produced the first ever checklists of alien biota for some countries and substantially improved the accuracy of estimates of alien species numbers derived from previous datasets (Hulme et al. 2009d). For example, from the dynamics of introduction of alien plants it can be inferred that approximately 38% of the species present in Europe in the 1980s were not captured by the then completed authoritative Flora Europaea (Tutin et al.

1964–1980). The increase in the numbers of species is thus partly due to the quality of data collated by DAISIE, partly it also reflects new introductions.

The data collated by DAISIE made it possible to assess regional levels of plant and animal invasions in European countries, with large industrialized countries in the western part of the continent harbouring the highest numbers of alien species (Pyšek et al. 2011). There is a significant relationship between the total number of naturalized plant and animal species and the country GDP (Fig. 7.3; Hulme 2007). Of the marine basins, the Mediterranean is most species-rich in alien biota; of the total 737 alien multicellular alien species, 569 are recorded in this basin, whereas the Atlantic coast harbours 200 and Baltic Sea 69 alien species (Galil et al. 2009).

The detailed information about alien species from a wide range of groups makes it possible to evaluate the dynamics of introductions of alien species to Europe over the past century. The numbers of newly recorded naturalized taxa on the continent are generally increasing, in both terrestrial and aquatic environments, and this increase exhibits an accelerating trend (Fig. 7.4). In the past century, the number of naturalized plants increased from 4.1 per annum in 1900s–1920s to 6.5 in the past two decades. Per annum rates of introductions of amphibians and reptiles tripled (from 0.6 to 1.8 species) and birds exhibited similar dynamics over this period (from 1.4 to 4.8). The only exception to this trend is mammals, where it seems that most suitable introductions arrived in earlier decades, resulting in rather stable rates of introduction over time (Fig. 7.4). The same accelerating dynamics are found in marine environments, with more than 10 and four new species in the Mediterranean basin and Atlantic coast, respectively, recorded each year in the last decade of the 20th century, and one new species in the Baltic Sea (Galil et al. 2009; their figure 7.1). Overall, the rate of new introductions to Europe has increased sharply throughout the past century and is showing little sign of slowing down (Hulme et al. 2009c).

7.4 FROM PATTERNS TO MECHANISMS: WHAT DO WE KNOW?

Since 2000, the European Union has supported a variety of research initiatives that address different aspects of biological invasions (see Hulme et al. 2009b and their table 1). Yet, it was not until the completion of DAISIE that the accumulation of considerable data

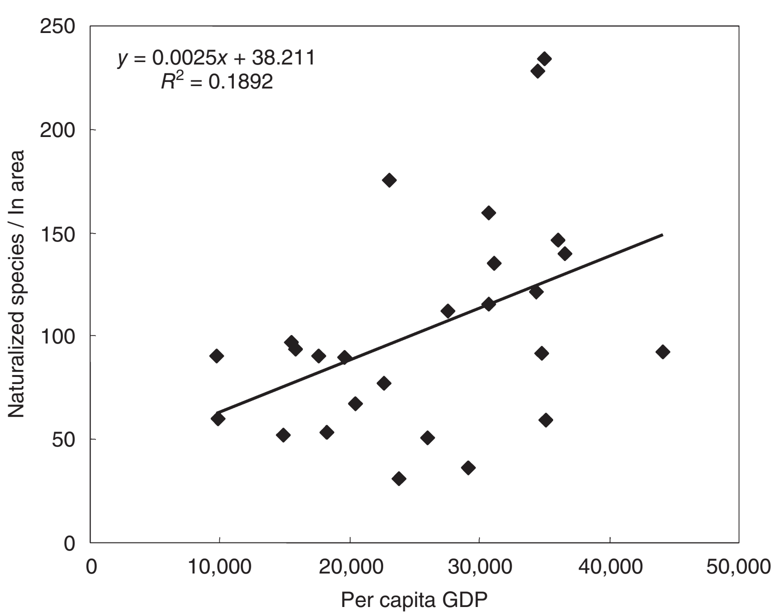

Fig. 7.3 Relationship between the number of naturalized alien species (fungi, bryophytes, plants, terrestrial invertebrates, fishes, amphibians, reptiles, birds and mammals) introduced after 1500 AD and per capita GDP (in US dollars) shown for European Union member countries (excluding one outlier: Luxembourg). $F = 5.60$, df = 1, 24, $P < 0.05$. Data taken from DAISIE database and Lambdon et al. (2008).

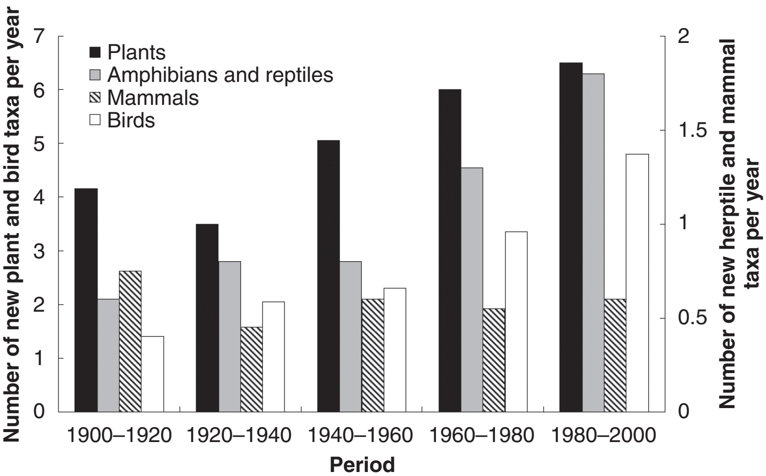

Fig. 7.4 Dynamics of introduction of alien plants and vertebrates in terrestrial environments to Europe. Alien taxa newly recorded as naturalized are shown per annum for the time periods indicated. Based on Hulme et al. (2009c) and reproduced with permission.

made it possible to aim at large-scale syntheses of biological invasions at the continental level, and search for general principles, some of them valid across a wide range of taxonomic groups and environments, as well as to assess the risk from invasions. This work was performed within the framework of the Assessing Large Scale Risks for Biodiversity using Tested Methods (ALARM) project (www.alarmproject.net; Settele et al. 2005). For the first time, it brought together many of the researchers who had previously worked on some of the European projects described above. At the end of 2009, at least 142 journal papers and book chapters dealing with biological invasions have appeared from ALARM (for references, see www.alarmproject.net).

Through DAISIE and ALARM, a conceptual approach emerged which addressed crucial steps or elements of the invasion process at the European-wide, continental scale. Table 7.1 summarizes Europe's most recent key contributions to the knowledge of invasion mechanism and patterns at a large, macroecological scale. The topics studied included pathways of invasion, the role of habitats, the role of species' traits in determining invasiveness, interaction of alien plants with local pollinators, drivers of invasion, ecological and economic impact of invasions, and risk-assessment. Some of these topics were discussed by Elton; for example, he could hardly have missed the crucial importance of how animals and plants are being introduced from one region to another by using various pathways, and he gave serious attention to this issue. Only recently have invasion pathways been conceptualized, described and parameterized based on European data (Hulme et al. 2008; Hulme this volume) Elton also recognized the key role of disturbed habitats in plant invasions and the great richness of aliens these habitats harbour. Thanks to current focus on habitat invasibility, these patterns have been recently described in detail and analysed (Vilà et al. 2007; Chytrý et al. 2008b; Hejda et al. 2009b; Pyšek et al. 2010). Distribution and spread, as basic features of biological invasions, were the focus of Elton's interest, although from comparison of his data with recent knowledge it clearly appears that periods of massive spread of most invaders were only about to come. It has been estimated that at present, 50 years after Elton, most European neophytes are still filling their potential ranges, a process that is estimated to take between 150 and 300 years after introduction (Williamson et al. 2009).

The substantial progress in creating inventories of invasions in Europe allows for detailed cross-taxonomic comparisons for many taxonomic groups from fungi, plants and invertebrates to vertebrates, in both terrestrial and aquatic environments; several studies aimed at cross-taxonomic analyses of patterns and identifying mechanisms valid for invasive biota in general. The data made it possible to perform these analyses at the continental scale, hence capturing a long-enough gradient of environmental settings, including climate,

Table 7.1 Key findings of recent studies on biological invasions in Europe, performed within the ALARM, DAISIE and other European projects. Only studies based on analyses of original data and addressing the continental or sufficiently large sub-continental scale, and/or a range of taxonomic groups are outlined. Environment: T, terrestrial; F, freshwater; M, marine.

Topic	Scale	Taxa and environment
Pathways of introduction	Continental	Plants, vertebrates, invertebrates, pathogens: T, F, M
Introduction dynamics	Continental	Plants, amphibians and reptiles, birds, mammals: T
Invasion dynamics	Regional	Plants: T
Evolution of invasiveness	Regional	Plants: T
Species' traits and invasiveness	Regional	Plants: T
Habitat affinities	Continental	Plants, insects, amphibians, reptiles, birds, mammals: T, F
Habitat affinities	Continental, regional	Plants: T
Drivers of invasion	Continental	Fungi, bryophytes, plants, invertebrates, fishes, amphibians, reptiles, birds, mammals: T, F
Pathways of introduction	Continental	Aquatic invaders: F
Drivers of invasion: propagule pressure	Continental, regional	Birds: T
Drivers of invasion: climate	Continental	Plants: T

Outcome	Reference
Alien species arrive using six principal pathways: release, escape, contaminant, stowaway, corridor and unaided. Vertebrate pathways tend to be characterized as deliberate releases, invertebrates as contaminants and plants as escapes. Pathogenic micro-organisms and fungi are generally introduced as contaminants of their hosts. The new framework enables these trends to be monitored and develop regulations to stem the number of future introductions.	Hulme et al. (2008)
Dynamics of invasion of alien species from all taxonomic groups and environments are increasing and show no sign of deceleration.	Hulme et al. (2009d)
Naturalized neophytes have smaller range sizes than natives. Historical dynamics indicates that it takes at least 150 years for an alien species to reach its full potential distribution. Most naturalized neophytes are still expanding their ranges in Europe.	Williamson et al. (2009)
Invasiveness does not appear to have a strong phylogenetic component. The presence or absence of native congeners therefore has limited influence on whether an introduced alien plant becomes naturalized.	Lambdon & Hulme (2006a); Lambdon (2008)
A range of traits may influence the likelihood of naturalization but it appears that species origin and the pathways of introduction are as important, if not more so, than the life-history traits of individual species.	Lloret et al. (2004, 2005); Lambdon & Hulme (2006b)
There are two ecologically distinct groups of alien species (plants and insects versus vertebrates) with strikingly different habitat affinities. Invasions by these two contrasting groups are complementary in terms of habitat use. Diversity of alien plants and insects concentrates in riparian and urban habitats, vertebrates are more evenly distributed and also invade aquatic habitats and woodland.	Pyšek et al. (2010)
Habitats are the more important predictors of the local level of invasion than climate and propagule pressure and the patterns of habitat invasions are consistent among biogeographical regions.	Chytrý et al. (2008a,b, 2009a,b); Vilà et al. (2007)
Macroeconomic factors are the most important predictors of the level of invasion in European regions, when analysed jointly with geographical and climatic variables.	Pyšek et al. (2010c)
The introduction and establishment transitions are independent of each other, and species that became widely established did so because their introduction was attempted in many countries, not because of a better establishment capability. The level of invasion of European countries is determined by their area and human population density, but not per capita GDP.	García-Berthou et al. (2005)
Community-level propagule pressure is the major driver shaping the distribution of alien birds in Europe.	Chiron et al. (2009)
Low precipitation constrains alien species richness in warm regions. A rather complex response of alien species to climate change in Europe may be expected, with drought becoming possibly important limiting factor in the future.	Lambdon et al. (2008)

Continued

Table 7.1 *Continued*

Topic	Scale	Taxa and environment
Ecological and economic impact	Continental	Plants, invertebrates, vertebrates: T, F, M
Impact on native pollinators	Continental	Plants: T
Homogenization	Continental	Plants: T
Prediction of future trends	Continental	Plants: T
Species' traits and impact	Continental	Birds, mammals: T

latitudinal and altitudinal trends, habitat heterogeneity and different levels of economies reflecting historical differences in the development of European nations (Table 7.1).

To summarize the most novel results from recent European studies, it appears that the six principal pathways used by alien species – release, escape, contaminant, stowaway, corridor and unaided – differ in importance according to the taxonomic group introduced and environment invaded (Hulme et al. 2008). The importance of propagule pressure associated with individual pathways differs with respect to the type of the pathways and organism in question; although it is of primary importance in, for example, fish and birds, where the pool of invasive species largely results from release (Garcia-Berthou et al. 2005; Chiron et al. 2009), it is less important in determining the level of invasion of plant communities, to which alien species arrive by other pathways, mostly escape from cultivation, contaminant and stowaway. For plants, the type of habitats in which the invasion occurs is a more important predictor of the local level of invasion than climate and propagule pressure (Chytrý et al. 2008a,b, 2009a,b; Vilà et al. 2007). Assessing the level of invasion of European habitats across taxonomic groups indicates that plants and insects have similarly close habitat affinities to riparian and urban habitat, which is strikingly different from vertebrates that invade in aquatic habitats and woodland; invasions by these two contrasting groups of biota are therefore complementary in terms of habitat use (Pyšek et al. 2010). Species invasiveness does not appear to have a strong phylogenetic component (Lambdon & Hulme 2006a; Lambdon 2008; Pyšek et al. 2009a); a range of traits affect the likelihood of invasion success but these traits interact with each other (Küster et al. 2008) and act in concert with other factors such as species origin, pathways of introduction (Lloret et al. 2004, 2005; Lambdon & Hulme 2006b) and propagule pressure and residence time (Pyšek et al. 2009b). These factors are generally more important than the life-history traits of individual species and the role of traits depends on the stage of invasion process, increasing as species reach more advanced stages of invasion (Pyšek et al.

Outcome	Reference
Ecological and economic impacts are only documented for approximately 10% of alien species in Europe, but many invaders cause multiple impacts over a large area in Europe. Terrestrial vertebrates and aquatic inland invaders are most efficient in causing negative ecological impacts, terrestrial invertebrates and vertebrates an economic impact. Ecological and economic impacts of alien organisms are correlated.	Vilà et al. (2010); Nentwig et al. (2010); Kenis et al. (2009)
Native pollinators depend upon alien plants more than on native plants, but the networks of native pollinators are very permeable and robust to the introduction of invasive alien species into the network.	Vilà et al. (2009)
Invasions of alien and extinctions of native species over the past centuries resulted in increased taxonomic and phylogenetic similarity among European regions that are losing part of their uniqueness due to this homogenization effect.	Winter et al. (2010)
European map of plant invasions based on land-use is a convenient tool for predicting future invasions under contrasting socioeconomic scenarios; the one focused on sustainability may not necessarily result in decreased level of plant invasions in the next 80 years.	Chytrý et al. (2010)
Habitat generalist birds and mammals have greater impact than habitat specialists.	Shirley & Kark (2009); Nentwig et al. (2010)

2009a,b). Since invasions are human-induced processes, macroeconomic factors, as a suitable surrogate of underlying factors, appear to be the most important predictors of the level of invasion in European regions, more so than geographical factors and climate (Pyšek et al. 2010c).

The macroecological analyses highlighted in Table 7.1 are being complemented by numerous studies at smaller scales, focused on individual taxonomic groups, and addressing specific topics, for example impact of invasive species on the diversity of invaded communities (Hejda & Pyšek 2006; Hulme & Bremner 2006; Truscott et al. 2008; Hejda et al. 2009a), competition between native and alien species (Fabre et al. 2004; Kohn et al. 2009) and biotic resistance (Paavola et al. 2005; Vilà et al. 2008), interaction across multiple trophic levels (Girardoz et al. 2006), invasibility of islands (Gimeno et al. 2006) or the role of climate in invasions (Truscott et al. 2006; Broenniman et al. 2007; Walther et al. 2007; Ross et al. 2008). Several case studies of individual invasive species addressing a wide array of methodological approaches were also produced in recent years, resulting from the above-mentioned European-Union-funded projects.

7.5 FROM UNDERSTANDING TO ACTION: WHERE TO NOW?

The field of invasion ecology suffers from the lack of effective translation of academically gratifying research results to management (Hulme 2003). Stakeholders feel disconnected from the science (Andreu et al. 2009) and theoretical advances need to be more effectively translated into improved management, including objective means for conflict resolution (Richardson & Pyšek 2008; Pyšek & Richardson 2010). We believe that European efforts in the past few years have forged some progress towards a more applied perspective and that a start is being made at adopting successful approaches for putting science into practice that were pioneered in Australia and New Zealand. European scientists have assisted managers by placing their results within a more applied framework such as the giant hogweed manual (Nielsen et al. 2005), have led attempt to raise awareness among the public (DAISIE 2009) and where possible have addressed policy gaps (Hulme et al. 2008).

Among the most important achievements of recent research efforts in Europe was a thorough evaluation of impact, leading to the first continental-wide inventory of the magnitude and variety of ecological and economic impacts of invasive alien species in global terms (Vilà et al. 2010). This assessment concerned negative impacts of alien plants, vertebrates and invertebrates on ecosystem services in terrestrial, freshwater and marine environments. There are currently 1094 species with documented ecological impacts and 1347 with economic impacts in Europe; this points to a serious gap in knowledge because the impact has not been assessed for 90% of the total number of alien species in Europe. Alien species from all taxonomic groups affect supporting, provisioning, regulating and cultural ecosystem services (Binimelis et al. 2007) and interfere with human well-being. Terrestrial vertebrates are responsible for the greatest range of impacts, and these are widely distributed across Europe. Terrestrial invertebrates lead to greater economic impacts than ecological impacts, while the reverse is true for terrestrial plants, where only a small proportion of the total number of species recorded in Europe have impact, and terrestrial vertebrates and aquatic inland invaders are most efficient in causing negative ecological impacts. In economic terms, it is terrestrial invertebrates and particularly terrestrial vertebrates where almost 40% of invaders have an economic impact. Based on this and other studies, the total annual costs of invasive alien species in Europe are estimated at €12.5 billion (Kettunen et al. 2009). Thanks to the study of Vilà et al. (2010), Europe has the most up-to-date information on numbers of aliens and their impacts but lags behind North America, a continent where biological invasions are studied most intensively (Pyšek et al. 2008), in the knowledge of mechanisms underlying impacts (Hulme et al. 2009b). This difference in focus and nature of information on impact is where the two continents can profit from each other's experiences and work towards reliable and comparable estimates of costs from alien species invasions (Vilà et al. 2010).

Remarkable progress has been made towards improving risk-assessment of biological invasions in Europe. For marine environments, an index has been developed that classifies the impacts of alien species on native species, communities, habitats and ecosystem functioning. The method can be used to evaluate impact at five different levels of 'biopollution' and is compatible within the existing schemes for water quality assessment (Olenin et al. 2007). A generic scoring system has been developed for invasive mammals that takes into account both environmental (competition, predation, hybridization, transmission of disease and herbivory) and economic (on agriculture, livestock, forestry, human health and infrastructure) impacts and distinguishes between 'actual' (determined by actual distribution of the invasive species assessed) and 'potential' impacts (Nentwig et al. 2010). For plants, existing risk-assessment schemes were tested to identify those most appropriate for Europe (Křivánek & Pyšek 2006) and the role of deliberate planting for forestry purposes on the invasion process evaluated (Křivánek et al. 2006). Consistent results on habitat invasibility by plants from different European biogeographical regions (Chytrý et al. 2008b) provided an excellent opportunity for mapping plant invasions not only at the regional level (Chytrý et al. 2009b) but for the whole of Europe (Chytrý et al. 2009a). Within the framework of linking the ecological research with socio-economic aspects (see, for example, Binimelis et al. 2007; Kobelt & Nentwig 2008; Andreu et al. 2009), the European map of plant invasions was used to project current levels of invasion under integrated scenarios of future socio-economic development in Europe, based on land-use patterns in Europe projected for 2020, 2050 and 2080 (Spangenberg 2007). This research indicates that an implementation of sustainability policies will not automatically restrict the spread of alien plants, but such policies might rather increase invasions by supporting agriculture and associated invasion-prone land use in less productive areas. This suggests that proactive strategies to manage invasive alien plants will be needed no matter how environmental friendly policies would be adopted in the future (Chytrý et al. 2010).

These examples illustrate that some progress towards developing tool of assessing risk from invasive species is being made, but where does Europe stand in terms of research and management of biological invasions? Recent efforts yielded results and data that will provide more results in the near future. These results represent a great potential to contribute to better understanding biological invasions by testing hypotheses and searching for general patterns valid across a range of taxa and environments. This knowledge can be used to improve scientific-based risk assessments; invasions are complex phenomena and the more key elements of the invasion process (pathways, habitats, species' traits, impact, etc.) are considered in an integrative risk-assessment scheme, the more effective such schemes would be. Last but not least, DAISIE and ALARM received much attention from the European Union administration and their results are used for developing the European strategy against invasive alien species (Kettunen et al. 2009; see http://ec.europa.eu/environment/nature/pdf/council_concl_0609.pdf).

For Europe to address biological invasions at a continental scale, there must be an end to the fragmented legislative and regulatory requirements addressing invasive species and the piecemeal approaches to tackling invasive species across Europe that fail to coordinate pre- and post-border actions (Hulme et al. 2009a). DAISIE established a database on expertise addressing biological invasions in Europe and it is clear that such expertise is heterogeneously distributed across the continent resulting in variable efficiencies in national monitoring and surveillance. As a result, Europe's borders can be easily penetrated by alien species. Furthermore, relative to understanding of the ecology, distribution and taxonomy of alien species in Europe, expertise in management and mitigation of impacts is the principal activity of little more than 10% of invasion scientists. The disparate nature of expertise in Europe also means that as assessing the risks of alien species has become increasingly complex specialist expertise and access to appropriate databases is required. At the same time, the current knowledge base provides an excellent foundation for concerted management action. Europe is nowadays a continent with the most integrated and comprehensive information on its alien biota particularly in terms of distribution patterns, invasion history and impacts. The comprehensiveness of the information is probably better than for any other continent that includes a clear picture of how fast species from other continents invade Europe, by which pathways, how they are distributed in habitats, what is their impact on biodiversity, ecosystems and economy and what can be expected in terms of future development. Although much remains to be done and the improving and completing the data is a never-ending process, the information needed for developing an effective strategy at the continental level is basically available. Our belief is that more than ever before, a single European coordinating centre with a specific remit to manage biological invasions is needed and should be developed with a mission to identify, assess and communicate current and emerging threats to the economy and environment posed by invasive species (Hulme et al. 2009c). A similar call for a single coordinating centre has been made for the USA (Lodge et al. 2006). Though invasive species can impose considerable impacts on economy and ecosystems, only 2% of Europeans feel that invasions are a significant threat to biodiversity. A single European coordinating body would build public awareness of the problem of invasions, involve the public in finding alternatives and solution, build long-term partnerships with concerned sectors and users, and encourage voluntary approaches and best practices where feasible.

ACKNOWLEDGEMENTS

We thank Mark Davis, David Richardson and an anonymous reviewer for helpful comments on the manuscript, members of DAISIE and ALARM consortia for cooperation, and Jan Pergl and Zuzana Sixtová for technical assistance. This work was supported by the European Union's FP6 projects ALARM (GOCE-CT-2003-506675; Settele et al. 2005), DAISIE (SSPICT-2003–511202), and FP7 project PRATIQUE (212459; Baker et al. 2009). P.P. was further supported by the Ministry of Education of the Czech Republic (MSM0021620828 and LC06073) and the Academy of Sciences of the Czech Republic (AV0Z60050516 and Praemium Academiae award).

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