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European Plant Invasions

7

Petr Pyšek, Jan Pergl, Wayne Dawson, Franz Essl, Holger Kreft, Patrick Weigelt, Marten Winter, and Mark van Kleunen

Abstract

Using the Global Naturalized Alien Flora (GloNAF) database, this chapter describes the patterns in regional diversity of naturalized alien plants in Europe. GloNAF registered 4139 naturalized plant taxa, which makes Europe the second richest continent after North America, and represents an increase by 390 taxa (or 9.6%) compared to the inventory conducted during the 2000s by the DAISIE (Delivering Alien Invasive Species Inventories for Europe) project. Most naturalized species are recorded in England (1379), Sweden (874), Scotland (861), Wales (835), France (716), the European part of Russia (649), Ukraine (626) and Norway (595), indicating that the northern part of the continent, in particular the British and Irish Isles and Scandinavia, is most heavily invaded. The rate of new introductions of plants that have become naturalized has increased sharply throughout the two past centuries and is not showing any signs of slowing down. Biogeographical, socio-economic and ecological factors drive the variation in regional naturalized species richness – high human population density and national wealth, cold

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temperate and Mediterranean zonobiomes, and habitats such as arable land, coastal habitats and ruderal sites are associated with high numbers of naturalized aliens. Europe has exchanged many species with other continents. The main donor of naturalized plants to Europe is temperate Asia (1265 more species received than donated); in contrast, Australasia and North America harbour many more naturalized species of European origin than they have supplied to Europe, 1159 and 1080, respectively. The 1926 naturalized aliens from other continents represent a 14.9% contribution to the total plant diversity in Europe. The most widespread naturalized species is *Erigeron canadensis*, native to North America, occurring in 47 regions (76%). Fifty-four plants appear on the list of invasive alien species based on impact classification, and four (*Acacia dealbata*, *Lantana camara*, *Pueraria lobata* and *Eichhornia crassipes*) are among the highest ranking species with potentially the most serious impacts.

Keywords

Alien plants · Distribution · Donor regions · Europe · Habitat · Historical dynamics · Naturalization · Origin · Plant invasions · Regional hotspots · Taxonomy · Temporal trends

7.1 Introduction

Europe, especially its Mediterranean region, has traditionally been considered a donor of invasive alien species to other parts of the world rather than a recipient. This is most likely for historical reasons and due to the long association of plants and animals in Europe with humans since the beginning of agriculture some 10,000 years ago (di Castri 1990). Recent research, however, has shown that the past decades may have changed this long-held pattern – plants and animals of alien origin now form a substantial part of the continent's biodiversity (DAISIE 2009; Hulme et al. 2009b; van Kleunen et al. 2015) and exert large and diverse impacts on both the environment and the economy (Vilà et al. 2010; Kumschick et al. 2015; Rumlerová et al. 2016). Moreover, while Europe has been a net exporter of naturalized plants since the discovery of America (di Castri 1990), in the past 60 years, more naturalized plants are being imported to than exported from Europe (Seebens et al. 2015).

Although Europe has always been one of the most intensively researched continents from the perspective of plant invasions (Pyšek et al. 2008), until the mid-2000s, the information on the presence and distribution of alien plant species for most European countries was scattered in a variety of published and unpublished accounts and databases. Only few countries had sound information on the composition of their alien floras available in specialized checklists (e.g. Austria, Essl and Rabitsch 2002; the Czech Republic, Pyšek et al. 2002; Germany, Klotz et al. 2002; Ireland, Reynolds 2002; and the UK, Clement and Foster 1994; Preston et al. 2002, 2004). This situation has changed with the DAISIE (Delivering Alien Invasive Species Inventories for Europe) project which, for the first time, collated comprehensive data for the whole continent and dramatically improved the knowledge of the European alien flora (Lambdon et al. 2008; DAISIE 2009; Pyšek et al. 2009). The DAISIE database contained records of 3749 naturalized alien plant species (following the definition of Richardson et al. 2000) in Europe, of which 1780 were introduced to Europe from other continents, and the remaining were native in some parts of it and naturalized in others (Lambdon et al. 2008). Further knowledge on plant invasions in this continent came with the founding and development of the Global Naturalized Alien Flora (GloNAF) database. This resource contains information on the global distribution of naturalized alien plants in more than 1000 regions of the world and currently records ~14,000 taxa that are naturalized in at least one country, district, state or island (van Kleunen et al. 2019). For Europe, GloNAF updated, extended and standardized data from DAISIE so that our accumulated knowledge of Europe's naturalized flora is now enriched by global information on the distribution of naturalized alien plants (van Kleunen et al. 2015, 2019; Pyšek et al. 2017). The data in GloNAF are restricted to naturalized neophytes (i.e. species introduced after the year 1500; Holub and Jirásek 1967; Pyšek et al. 2004).

In this chapter, we use the data from GloNAF to describe the patterns in diversity and geographic distribution of naturalized plants in Europe and the taxonomic and life history structure of the European naturalized flora. This approach represents a major update of the previous detailed account, based on DAISIE, published more than a decade ago (Lambdon et al. 2008; Pyšek et al. 2009). Here we (i) highlight regions with the highest numbers of naturalized and invasive aliens and review factors underlying the variation in richness of regional alien floras, including the role of habitats, (ii) by focusing on the taxonomic composition of the naturalized alien flora of Europe, we identify the most successful species, genera and families, as well as the role played by species with different life histories, (iii) we also compare the situation in Europe with other continents and describe the rate of exchange with major donor regions of alien plants to Europe and vice versa, and (iv) finally, available data on impacts of invasive plants are summarized, and an overview of the currently most important legislation related to plant invasions is outlined.

7.2 Distribution of Naturalized and Invasive Alien Species Diversity Across European Regions

The analyses in this chapter are mainly based on the GloNAF database, which provided data across 81 European regions (e.g. countries, states, provinces, districts, islands). Version 1.1 of GloNAF registered 4139 naturalized alien plant taxa in Europe which makes this continent the second richest after Northern America, where 5958 naturalized taxa of alien origin are recorded (van Kleunen et al. 2015) – these figures include also taxa on the intraspecific levels; for simplicity they are further referred to as 'species'. This represents an increase by 390 species (almost 10%) compared to the DAISIE inventory a decade ago (see Lambdon et al. 2008), yet the total number of naturalized alien plants in Europe is likely to be still higher. While most European countries are well covered, lack of data on naturalized floras for some regions in the European part of Russia currently results in rather low coverage for Europe as a whole in GloNAF (63.8% of the continent area; Pyšek et al. 2017). Work is currently under way to close this data gap (see, e.g. Vinogradova et al. 2018), and more species are likely to be identified as naturalized aliens in Europe.

The distribution of naturalized and invasive alien species (as defined by Richardson et al. 2000) richness in European regions is fairly uneven (Fig. 7.1). The highest numbers of naturalized species are recorded in the following countries or regions: England 1379, Sweden 874, Scotland 861, Wales 835, France 716, European part of Russia 649, Ukraine 626, Norway 595, Bulgaria 593, Belgium 508, Italy 478, Spain 454 and Germany 451. Some of these countries are on top also in terms of the percentage of naturalized species among the total flora, as a measure of the levels of invasion (sensu Chytrý et al. 2008) in some of the regions in the northern part of the continent, in particular in the British and Irish Isles and Scandinavia (England 47.0% of the total flora of the country, Wales 43.6%, Scotland 41.8%, European part of Russia 36.7%, Sweden 34.8%, Norway 32.2%, Denmark 29.1%, Ireland 28.3%). The relationship between the number of naturalized species and latitudinal location of the country, however, is not significant. At the global scale, north-western Europe is one of the global hotspots of naturalized alien species richness, alongside regions such as the western and eastern coasts of North America, South Africa, the south-eastern part of Australia, New Zealand, several Indian states and tropical Pacific Islands as well as individual islands across all oceans. In contrast, none of the global hotspots of invasive alien species (i.e. South Africa, India, California, Cuba, Florida, Queensland and Japan) are located in Europe (Pyšek et al. 2017).

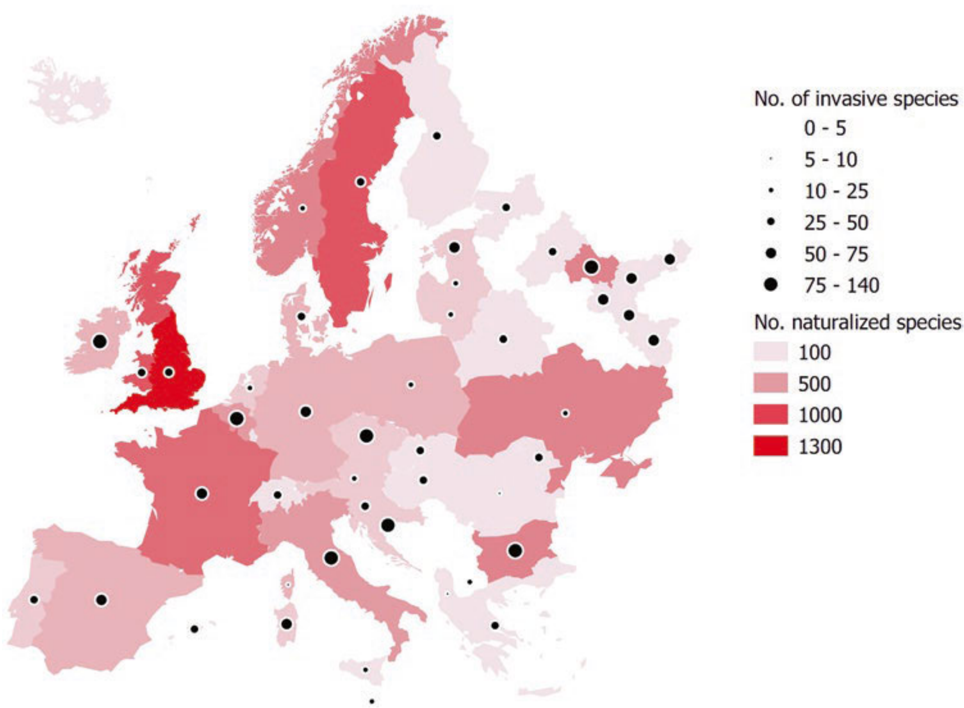

Fig. 7.1 The richness of naturalized and invasive alien plant species in European countries and regions. The numbers of naturalized species are shown by the shade of red and those of invasive alien species by the size of the black dot. Note that the colour scale is continuous and colours associated with the species numbers in the legend do not refer to discrete categories but to the thresholds of 100, 500, 1000 and 1300 species. The figure is based on data from Pyšek et al. (2017). Note that for European countries whose floras distinguish two groups based on residence times, archaeophytes (alien species that arrived before the year 1492) and neophytes (species that arrived after the year 1492; Pyšek et al. 2004), only the latter were considered. This is because the archaeophyte status of some species is unclear, the classification is not available for all European regions, and the distinction is not being used in other regions of the world. White areas indicate missing data

Although the numbers of naturalized and native species per region tend to be positively correlated with each other, this correlation was significant neither for islands nor for mainland regions (Fig. 7.2a). This is different from the pattern observed at the global scale where the numbers of naturalized species on islands increased significantly faster with increasing native species richness than for mainland regions, and both relationships were highly significant (Pyšek et al. 2017). Overall, a positive relationship between alien and native species at this regional level is expected based on null models of community invasibility. These models predict the relationship to be negative at small spatial scales and positive at larger scales (Fridley et al. 2004), when similar factors to those associated with the increase in native species with area, such as habitat heterogeneity, extensions of environmental gradients and increased probabilities of encountering disturbed habitats, are also responsible for establishment of more alien species (Stohlgren et al. 1999, 2003). Therefore, the lack of a significant correlation in the European data may indicate that some factors driving the richness of naturalized aliens differ from those determining the richness of native floras.

Those European mainland regions that are rich in naturalized aliens also harbour greater numbers of invasive alien species (Fig. 7.2b), but the relationship is only marginally significant ($p = 0.069$). It is interesting that for a given num-

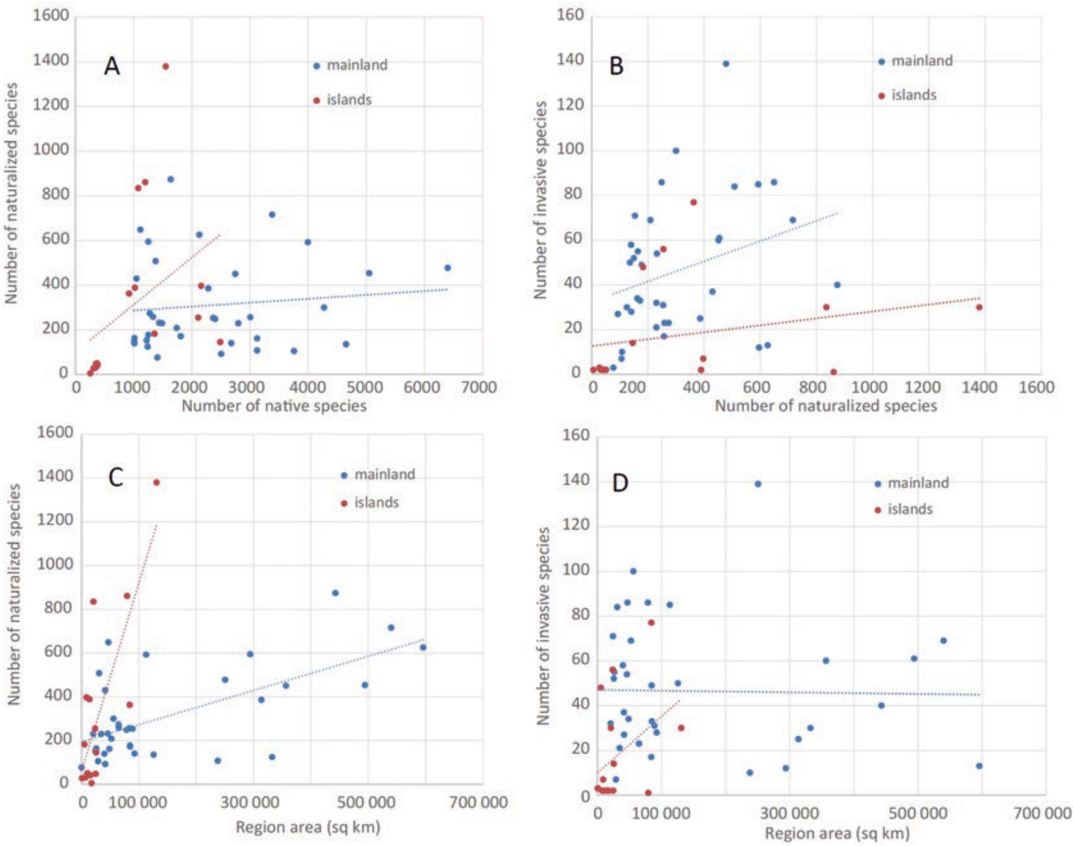

Fig. 7.2 Correlations of alien plant species numbers in European regions. (**a**) Number of naturalized species vs number of native species (mainland: r = 0.11, t = 0.6593, df = 34, p = 0.514, ns; islands: r = 0.40, t = 1.6306, df = 14, p = 0.125, ns). (**b**) Number of invasive alien species vs number of naturalized species (mainland: r = 0.307, df 34, p = 0.069, ns; islands: r = 0.26, t = 0.9863, df = 14, p = 0.341, ns). (**c**) Species-area relationship for naturalized species (mainland: r = 0.63, t = 4.724, df = 34, p < 0.001; islands: r = 0.79, t = 4.855, df = 14, p < 0.001) and (**d**) for invasive alien species (mainland: r = −0.02, t = −0.1152, df = 34, p = 0.909, ns; islands: r = 0.38, t = 1.5436, df = 14, p = 0.145, ns). The relationships are shown separately for mainland regions and islands. (Based on data in Pyšek et al. 2017)

ber of naturalized species, the number of invasive alien species is more than two times higher on the mainland than on islands (Fig. 7.2b). The species-area relationship for European regions is very steep for naturalized aliens on islands ($R^2 = 0.62$), but less so for mainland regions, where it still explains as much as 39% of variation (Fig. 7.2c). For invasive alien species, some increase with region area is only indicated on islands, but the relationship was non-significant (Fig. 7.2d). Although most of the relationships were not significant, the overall pattern is in line with the pattern observed for global alien floras (Pyšek et al. 2017).

7.3 Socio-Economic, Biogeographical and Ecological Factors Underlying the Variation in the Levels of Invasion in European Regions

Several studies analysing the determinants of naturalized species richness in Europe, including plants, have emphasized the importance of socio-economic drivers such as human population density and national wealth (Pyšek et al. 2010) and pointed to the phenomenon called invasion debt, i.e. that the consequences of the current economic activities will only fully manifest in the future (Essl et al. 2011a; Seebens et al. 2015). For biogeographic and environmental factors, the high levels of invasions in Europe are in accordance with one of the important correlates of naturalized alien richness, the distribution of zonobiomes. A global analysis of the effect of zonobiomes on naturalized plant richness in mainland regions revealed that regions located in colder temperate and Mediterranean climates, i.e. the two most widely represented climates in Europe, harboured on average twice as many naturalized aliens (19%) as those located in arid temperate, subtropical and tropical climates (10%; Pyšek et al. 2017). In a study looking at Europe separately, Lambdon et al. (2008) found that the numbers of naturalized plants were determined mainly by the interaction of mean annual temperature and mean precipitation – they increased in regions with higher precipitation but only in warmer areas.

As to ecological determinants, studies that evaluated invasions in individual European habitats, based on thousands of vegetation plots (with sizes of units to hundreds of square meters), yielded consistent results about the representation of alien species in the most invaded habitats (Chytrý et al. 2008). Chytrý et al. (2005) found that the six most invaded habitats in the Czech Republic harboured on average 4.4–9.6% of neophytes (the average across all vegetation types was 2.3%). Vilà et al. (2007) found similar mean numbers of neophytes per plot in Catalonia (~2.0% pooled across habitats, and ~ 9.0% in the most invaded habitats). The highest proportions were reported from Great Britain, with maxima of 10–25% neophytes per plot in the three most invaded habitat types (Chytrý et al. 2008). The figures reported for archaeophytes (species introduced since the Neolithic until the end of the Medieval, i.e. before the year 1492; Pyšek et al. 2004) were much higher, with 56%, 36% and 22% on arable land, ruderal vegetation and trampled habitats in the Czech Republic, respectively, and 16% on arable land in Great Britain. These results can be generalized – habitats associated with human- and water-induced disturbances, high fertility and high propagule pressure exhibit the highest levels of invasions. Pooled across regions, arable land, coastal sediments and ruderal habitats harbour the highest proportions of neophyte species in Europe (Pyšek et al. 2010). A regional study from the Czech Republic provides an evolutionary perspective on habitat invasibility, showing that alien species more strongly invade plant communities that are phylogenetically clustered, and because aliens tend to be related to native species, invaded communities become even more clustered (Lososová et al. 2015).

The data from the above studies of British, Catalonian and Czech habitats (Chytrý et al. 2008) were used to produce a European map of invasions by alien plants (Chytrý et al. 2009). This was done by translating habitat types to CORINE (Coordination of Information on the Environment) land cover classes (Moss and Wyatt 1994), which had been previously mapped across Europe from the interpretation of satellite images. The data from the three regions were extrapolated to other parts of Europe, using the framework of European biogeographical regions. The overall pattern indicates high levels of invasion in industrialized western Europe and in lowland agricultural regions in the east of the continent and lower levels of invasion in montane zones, oceanic areas in the north-west and the boreal zone (Chytrý et al. 2009). In a follow-up paper, Chytrý et al. (2012) projected the current levels of plant invasions in Europe under three different scenarios of economic development, based on changes in land use and climate (Spangenberg 2007) to project the future state of invasions by alien plants in Europe at three points of time (2020, 2050 and 2080). It revealed that invasions are likely to decrease in some areas and increase in others. Interestingly, the most environmentally friendly scenario, aiming at sustainability, will not result in the lowest levels of invasions. This is because this scenario was associated with the smallest increases in some regions, but also with the smallest decreases in invasions for other regions. The growth-oriented scenario would result in fewer invasions due to the more widespread abandonment of agricultural areas that are currently heavily invaded.

Overall, the polarization between more and less invaded regions is likely to increase if future policies are oriented toward economic deregulation, but an implementation of sustainability policies would not automatically restrict the spread of alien plants (Chytrý et al. 2012).

7.4 Sources of European Naturalized Flora and Exchange of Species With Other Continents

Besides 2213 naturalized species that resulted from introductions among regions within Europe (they are native to some part of the continent and naturalized in its other regions), there was an intense historical reciprocal exchange among Europe and other continents (defined by using the TDWG – Taxonomic Databases Working Group – biogeographical scheme; Brummit 2001), some of which were acting as major net donors of the European naturalized flora (Fig. 7.3). This was most pronounced for temperate Asia (1265 more species received than donated), with tropical Asia and Africa being the only two other continents that supplied more species to Europe than they received (277 and 161, respectively). All other continents harbour more naturalized species of European origin than they have supplied to Europe, the trend being most remarkable for Australasia (1159 more species donated) and Northern America (1080 species). Southern America has received 347 more species from Europe than it donated to Europe, and the corresponding figures for the Pacific Islands and Antarctica are 283 and 123 species, respectively.

These patterns of species exchange are reflected in the structure of the European naturalized flora by origin – European species are similarly frequent as species originating from temperate Asia (29.5% and 28.8% of all naturalized species with known area of origin, respectively), followed by Africa (15.0%, Northern America (10.1%), tropical Asia (8.5%) and Southern America (5.3%), with contributions from the Pacific Islands and Antarctica being negligible (Fig. 7.3). In addition, 35 taxa are of hybrid origin and 109 are only known from cultivation.

Subtracting the 2213 species of European origin yields 1926 naturalized aliens that were introduced from other continents and have become a permanent component of the European flora. These species add to the 10,928 native plant species (Winter et al. 2009) and thus represent 14.9% of the total plant diversity in Europe, less than the 20.3% reported previously (Lambdon et al. 2008; Pyšek and Hulme 2011). The main reason for this discrepancy, besides data coverage that improved over time, is that the previous estimate was based on all alien species in the DAISIE database many of which were only casual (i.e. species that do not form self-replacing populations; sensu Richardson et al. 2000).

7.5 Historical Dynamics of Alien Plant Arrivals to Europe

Over the last 200 years, there has been a steady increase in the number of alien plant species arriving and subsequently naturalizing in Europe. In the nineteenth century, numerous plants were brought to Europe for ornamental purposes, as a result of plant-hunting expeditions and increased interest in ornamental horticulture (Fry 2013; Seebens et al. 2017; van Kleunen et al. 2018). Transport of living plants was facilitated by inventions such as the Wardian Case mobile greenhouse in 1829 (Fry 2013). At the global scale, and also in Europe, the first record rates of vascular plants remained high in the twentieth century (Fig. 7.4a), most likely as a consequence of the intensification of global trade (Seebens et al. 2015) and the increasingly widespread cultivation of plants in agriculture and botanic and private gardens (Hulme 2015; van Kleunen et al. 2018).

Lambdon et al. (2008) presented another insight into the dynamics of plant invasions in Europe, by using the minimum residence times calculated from the first record dates for 1883 naturalized neophyte species of which 954 were of European origin and 929 originated from other continents. When the cumulative number of alien

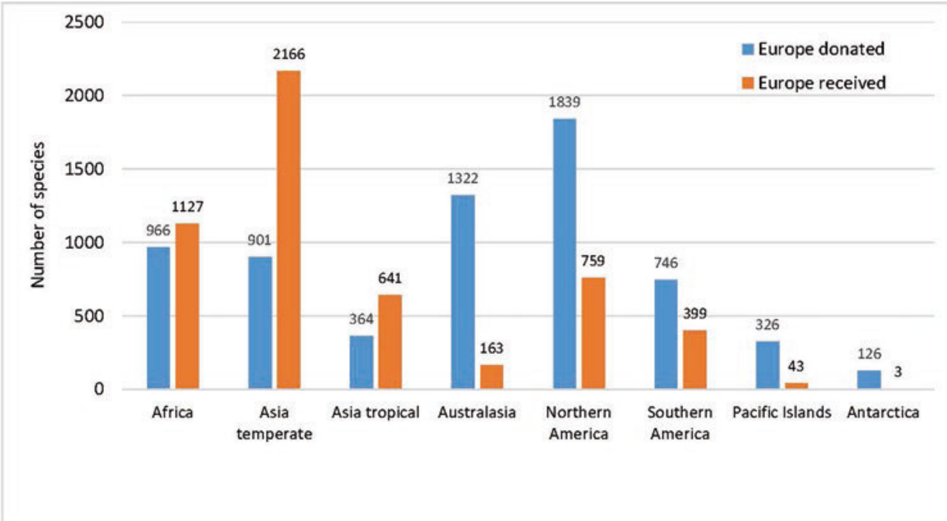

Fig. 7.3 Historical exchange of alien plant species among Europe and other continents (TDWG continents as recognized by the Biodiversity Information Standards Organization, originally Taxonomic Databases Working Group; Brummit 2001). The pairs of bars indicate the total number of native European species that have become naturalized in a given continent (Europe donated) vs the number of species native to that continent that are recorded as naturalized in Europe. The differences in numbers of donated vs received species among continents are significant (G-test, df 7, F = 354.9, p < 0.001). (Based on data in van Kleunen et al. 2015)

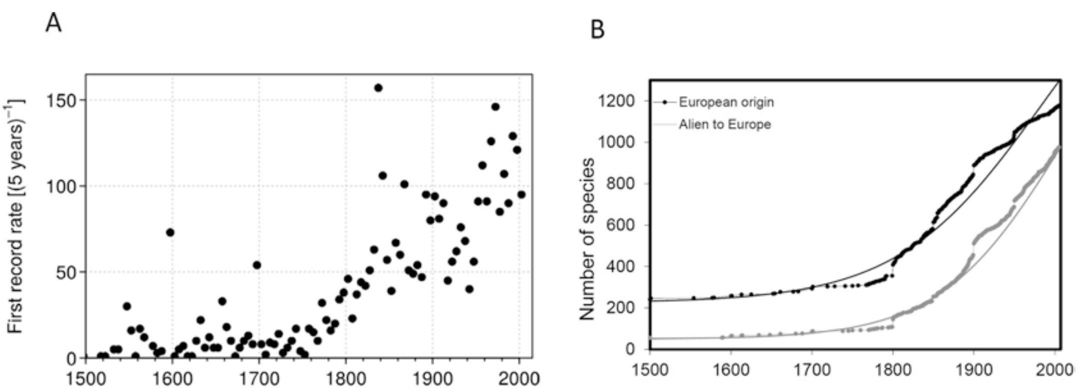

Fig. 7.4 Temporal trends in accumulation of alien plant species in Europe. (**a**) First records of alien species that have later become naturalized plotted for 5-year intervals. The plot is based on data from Seebens et al. (2017). (**b**) The number of species recorded as alien to at least one European country, in relation to their introduction date. Cumulative data are shown separately for species with native distribution area outside of Europe: T(p) = 0.0134y – 26.9, r^2 = 0.97, n = 929; and those of European origin, but occurring as alien in other parts of the continent: T(p) = 0.0113y – 22.40, r^2 = 0.95, n = 954. (This plot was taken from Lambdon et al. (2008), with the permission of the Czech Botanical Society)

arrivals was plotted against time, there was a strongly exponential increase in the rate at which species capable of naturalization were being imported (Fig. 7.4b) – of the naturalized neophytes of non-European origin, 50% arrived after 1899, 25% arrived after 1962 and 10% arrived after 1989. Aliens of European origin tended to start their spread earlier, but the overall slope was very similar. The rate of new introductions has increased sharply throughout the past two centuries and is showing little signs of slowing down (Lambdon et al. 2008).

Comparison of the current numbers of naturalized plants with the historical attempts to summarize European aliens can be used to estimate how quickly the naturalized flora of this continent has been increasing. In the first such study, Weber (1997) reported 1568 naturalized species in Europe, much less than recorded by DAISIE (2009) and recently by GloNAF (van Kleunen et al. 2015; Pyšek et al. 2017). The overview of Weber (1997) was based on the Flora Europaea, which relied on data from the 1960s to the 1970s (Tutin et al. 1964–1980), so one reason for the lower species number is simply time – since this period, there has been a continued influx of alien species to individual countries (Pyšek 2003). However, even then, many more alien species than included in that work must have been present in Europe. By taking into account residence times of naturalized species reported in the DAISIE database, Pyšek et al. (2009) estimated that there were 2175 naturalized aliens in Europe in 1980, when the publication of the first edition of Flora Europaea was completed, i.e. about 600 more than reported by Weber (1997).

7.6 The Most Widely Distributed Species

There are 35 species that have become naturalized in more than 30 regions, i.e. at least half of the European regions considered in the GloNAF database (n = 62, Table 7.1). The most widespread is *Erigeron canadensis*, occurring in 47 regions (i.e. 76% of the regions in Europe). Among the six most widely distributed naturalized species, there are another three in the Compositae family (*Matricaria matricarioides*, *Solidago canadensis*, *Galinsoga parviflora*), one representative each of the Hydrocharitaceae family (*Elodea canadensis*) and the Onagraceae family (*Oenothera biennis*). Among those 35 most successful naturalized species, the vast majority are perennial (15) and annual (14) herbs, with two additional shrubs (*Syringa vulgaris*, *Lycium barbarum*), two trees (*Robinia pseudoacacia*, *Acer negundo*), one aquatic (*Elodea canadensis*) and one biennial herb (*Oenothera biennis*). Almost all of the most widespread naturalized aliens are native to Northern America (20 species) or temperate Asia (15), with only two having their region of origin partly in Europe (*Syringa vulgaris*, *Hesperis matronalis*) and five in Southern America (Table 7.1). So, the most widespread invaders in Europe originate in the Northern Hemisphere.

Surprisingly, being widespread as a naturalized alien in Europe does not translate into a wide global distribution as naturalized (Fig. 7.5). There is no significant correlation between the number of regions a species occupies in Europe and the rest of the world (Pearson product-moment correlation, $t = 1.1897$, $df = 33$, $p = 0.2426$). Figure 7.5 highlights examples of species that are widespread everywhere (*Erigeron canadensis*), common globally but less frequent in Europe (*Datura stramonium*, *Medicago sativa*) or widely distributed only in Europe (*Elodea canadensis*, *Oenothera biennis*). A special group are species that are serious invaders wherever they occur, but their distribution is relatively restricted both in Europe and all over the world (*Heracleum mantegazzianum*, *Fallopia* sp. div.).

The ranking of the most widely distributed naturalized aliens made by Lambdon et al. (2008), also based on the number of regions occupied, allows for a rough indication of changes in distributions during the last decade. Bearing in mind that the delimitation of regions in the current GloNAF-based analysis is more detailed, yielding a higher number of regions (62 vs 49), there is a significant correlation between both periods (Pearson's product-moment correlation: $t = 4.121$, $df = 33$, $p < 0.001$), nevertheless with some remarkable outliers. For example, *Elodea canadensis*, *Matricaria matricarioides* and *Oxalis stricta* seem to have gained in distribution compared to other species, whereas *Robinia pseudoacacia* that ranked second in 2008 is an example of the opposite trend (Table 7.1).

Table 7.1 The most widespread naturalized alien plant species in Europe, ranked according to the number of regions in which they are recorded as naturalized (column Europe, n = 62)

Rank	Taxon	Family	Life history	Origin	Europe	RegTot	Rank 2008
1	*Erigeron canadensis*	Compositae	Annual	N Am, S Am	**47**	234	1
2	*Elodea canadensis*	Hydrocharitaceae	Aquatic	N Am	**46**	75	13
3	*Matricaria matricarioides*	Compositae	Annual	As-temp	**45**	109	23
4	*Oenothera biennis*	Onagraceae	Biennial	As-temp	**45**	97	6
5	*Solidago canadensis*	Compositae	Perennial	N Am	**44**	119	7
6	*Galinsoga parviflora*	Compositae	Annual	N Am, S Am	**43**	216	8
7	*Amaranthus retroflexus*	Amaranthaceae	Annual	N Am	**41**	193	3
8	*Reynoutria japonica*	Polygonaceae	Perennial	As-temp	**41**	98	5
9	*Veronica persica*	Plantaginaceae	Annual	As-temp	**40**	183	9
10	*Helianthus tuberosus*	Compositae	Perennial	N Am	**40**	140	11
11	*Oxalis stricta*	Oxalidaceae	Perennial	N Am	**40**	52	30
12	*Robinia pseudoacacia*	Leguminosae	Tree	N Am	**39**	154	2
13	*Galinsoga quadriradiata*	Compositae	Annual	N Am	**39**	145	16
14	*Impatiens glandulifera*	Balsaminaceae	Annual	As-temp	**39**	74	17
15	*Juncus tenuis*	Juncaceae	Perennial	N Am, S Am	**39**	69	14
16	*Epilobium ciliatum*	Onagraceae	Perennial	As-temp, N Am, S Am	**39**	67	34
17	*Erigeron annuus*	Compositae	Annual	N Am	**38**	69	10
18	*Solidago gigantea*	Compositae	Perennial	N Am	**38**	43	18
19	*Impatiens parviflora*	Balsaminaceae	Annual	As-temp	**37**	45	19
20	*Bidens frondosa*	Compositae	Annual	N Am	**36**	44	22
21	*Amaranthus albus*	Amaranthaceae	Annual	N Am	**35**	129	20
22	*Syringa vulgaris*	Oleaceae	Shrub	Eur, A-temp	**33**	83	54
23	*Acer negundo*	Sapindaceae	Tree	N Am	**33**	82	12
24	*Symphyotrichum novi-belgii*	Compositae	Perennial	N Am	**33**	58	40
25	*Heracleum mantegazzianum*	Apiaceae	Perennial	As-temp	**33**	53	41
26	*Datura stramonium*	Solanaceae	Annual	N Am	**32**	272	15
27	*Hesperis matronalis*	Brassicaceae	Perennial	Eur, As-temp	**32**	97	94
28	*Reynoutria sachalinensis*	Polygonaceae	Perennial	As-temp	**32**	71	27
29	*Bunias orientalis*	Brassicaceae	Perennial	As-temp	**32**	53	56
30	*Medicago sativa*	Leguminosae	Perennial	As-temp	**31**	242	24
31	*Cuscuta campestris*	Convolvulaceae	Annual	N Am, S Am	**31**	116	37
32	*Lycium barbarum*	Solanaceae	Shrub	As-tem	**31**	105	26
33	*Amaranthus blitoides*	Amaranthaceae	Annual	N Am	**31**	87	21
34	*Lupinus polyphyllus*	Leguminosae	Perennial	N Am	**31**	63	48
35	*Veronica filiformis*	Plantaginaceae	Perennial	As-temp	**31**	50	31

Species naturalized in at least half of the regions (31) are shown with information on their life history and native range (N Am, Northern America; S Am, Southern America; As-temp, temperate Asia; Eur, Europe). RegTot, total number of regions where the species has naturalized globally. Based on data from GloNAF database (van Kleunen et al. 2015, 2019; Pyšek et al. 2017). Rank 2008 – species' rank according to the number of regions from which it has been reported as naturalized in 2008, based on data from Lambdon et al. (2008)

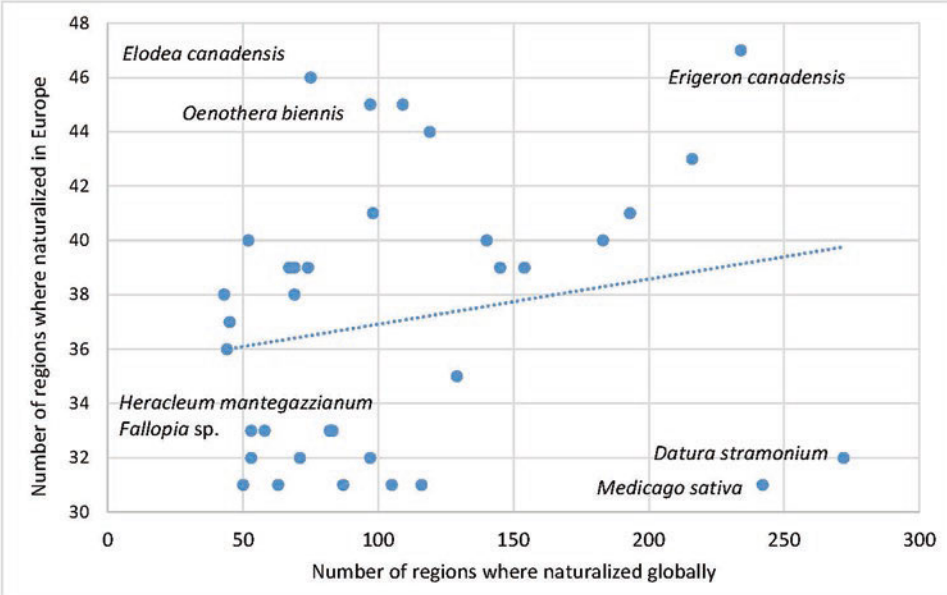

Fig. 7.5 The most widely distributed naturalized plant species in Europe in relation to their global distribution as naturalized. (Based on data from GloNAF. Pyšek et al. 2017; see Table 7.1)

7.7 Taxonomic and Life History Structure of the Naturalized Alien Flora of Europe

The following genera are most represented, measured by the number of naturalized species in Europe: *Cotoneaster* (73 species), *Oenothera* (55), *Euphorbia* (42), *Geranium* (35), *Salix* (33), *Sedum*, *Solanum* (both 31), *Rosa*, *Silene*, *Trifolium* (29), *Artemisia* (28), *Rumex*, *Allium* (27), *Narcissus*, *Crataegus* (26), *Rubus*, *Vicia* (25), *Prunus*, *Veronica*, *Bromus* (24), *Amaranthus*, *Centaurea* (23), *Iris* (22), *Populus*, *Senecio*, *Chenopodium*, *Campanula* (21), *Mentha*, *Medicago* and *Cyperus* (20). A genus whose naturalized species are most widely distributed in Europe, measured as the sum of regions where all its representatives are naturalized, is *Amaranthus* (275 species × region records), followed by *Cotoneaster* (220), *Oenothera* (220) and *Euphorbia* (214).

Nine families have more than 100 naturalized representatives in Europe. Compositae with 483 species built up 11.7% of the whole naturalized alien flora; corresponding figures for Gramineae are 334 species (8.1%), Rosaceae 321 (7.8%), Leguminosae 237 (5.7%), Brassicaceae 179 (4.3%), Lamiaceae 117 (2.8%), Caryophyllaceae 106 (2.6%), Apiaceae 104 (2.5%) and Amaranthaceae 103 species (2.5%). The first three families are also most widely distributed with 2440, 1413 and 1400 species × region records, respectively. Largely these patterns reflect that some of those families are among the largest families worldwide.

As to the life histories, the European naturalized flora is dominated by herbaceous perennials (36.2%), annuals (21.5%) and biennials (7.5%), followed by grasses (5.9%), climbers (3.3%), aquatic plants (0.9%), succulents (0.9%) and epiphytes (0.1%). Shrubs and trees contribute 15.5% and 8.2% to the total number of species, respectively.

7.8 Impacts of Alien Plant Species in Europe

Europe was the first continent producing a continental-wide inventory of the magnitude and variety of ecological and economic impacts of invasive alien species (Vilà et al. 2010). This assessment concerned negative impacts of alien plants, vertebrates and invertebrates on ecosystem services in terrestrial, freshwater and marine environments and revealed that there were 326 plant species with documented ecological impacts and 315 with economic impacts in Europe, representing 5.6% and 5.4% of the total number of alien plants recorded (Vilà et al. 2010). However, the real numbers are likely higher because for the vast majority of alien plants in Europe, the impacts are still unknown (Pyšek and Hulme 2011).

The assessment of impacts was put on a more quantitative basis with the development of standardized scoring tools (Nentwig et al. 2010, 2016; Blackburn et al. 2014). Kumschick et al. (2015) used the semi-quantitative generic impact scoring system (GISS), which describes environmental and socio-economic impacts using six categories of each. Their assessment was based on 128 species that are naturalized in Europe. Plants had a moderate total impact across categories compared to other taxonomic groups (with mammals having the highest and fish the lowest impact scores), and their environmental impacts were on average higher than their socio-economic impacts. The categories where most naturalized plants are reported in the literature to have an impact were competition with native taxa (84 out of 128 species evaluated) and ecosystem functioning (59 species), and in these two categories, the scores averaged across species were highest, indicating the strongest impacts. Compared to other groups, the impacts of alien plants in Europe are very broad, together with mammals; plants were the only taxon to exert impact on all 12 categories (see Kumschick et al. 2015; Nentwig et al. 2016 for details of the GISS classification).

Nentwig et al. (2018) integrated several scoring systems classifying the impacts of European aliens and proposed a list of 149 alien species with highest impacts, on which plants were the most numerous group, represented by 54 taxa. Four plants were included among the highest ranking species with the most serious potential impacts: *Acacia dealbata*, *Lantana camara*, *Pueraria lobata* and *Eichhornia crassipes* (Nentwig et al. 2018).

In another European-focused study, Winter et al. (2009) demonstrated the effects of alien plant invasions on the homogenization of European regional floras. Using data from 23 regions and considering both native species losses due to extinctions and additions to the flora by aliens in concert, these authors showed that plant invasions since the year 1500 exceeded extinctions and resulted in increased taxonomic alpha diversity (measured by species richness) but decreased phylogenetic alpha diversity within European regions and increased taxonomic and phylogenetic similarity among European regions (i.e. decreased beta diversity). This was so because extinct species were phylogenetically and taxonomically unique and typical of individual regions, and extinctions usually were not continent-wide and therefore led to differentiation, while many naturalized alien species were widespread, thereby contributing to homogenization. As a result, floras of many European regions now have more species, but have partly lost and will continue to lose their uniqueness (Winter et al. 2009). Moreover, the homogenization of European floras is increasing, as can be inferred from a comparison of these results with a study using older data on alien plants that found a greater dissimilarity (Winter et al. 2010).

7.9 Legislation

Although the rates of species introductions to Europe accelerated significantly during the second half of the twentieth century and still follow a steep curve at present (Hulme et al. 2009b), concerted efforts to understand biological invasions across the continent are relatively recent (Hulme et al. 2009a). The current knowledge base, nevertheless, provides an excellent foundation for integrated management action – Europe is nowadays a continent with the most comprehensive information on its alien biota particularly in terms of distribution patterns, invasion history and impacts. Even though

Europe is not the world leader in biosecurity policy, which is most developed on islands such as New Zealand (Hulme 2011), significant progress has been made during the last decade in implementation of research recommendations into policy. The single most important achievement was the implementation of EU Regulation No. 1143/2014 of the European Parliament and the EU Council from 22 October 2014 on the prevention and management of the introduction and spread of invasive alien species. This instrument aims at regulating invasive alien species in Europe using evidence-based risk assessment protocols and based on the cooperation between researchers and policymakers (Genovesi et al. 2014). The crucial component of the legislation is the list of invasive alien species of Union concern; after several updates there are now 66 species listed (https://ec.europa.eu/environment/nature/invasivealien/list/index_en.htm; as of 21 March 2021). Besides the EU legislation, there are national activities aimed at developing lists of aliens for management with varying legislative support (e.g. Essl et al. 2011b; Pergl et al. 2016; Sandvik et al. 2019). So, while Europe is still running behind with legislation on alien organisms, the first steps have been taken.

7.10 Conclusions

In this chapter, we summarize the most up-to-date information on the patterns in diversity and geographic distribution of naturalized plants in Europe and the taxonomic and life history structure of the European naturalized flora. This data, as accumulated during the last 2 years in a broad international cooperation in this continent, represents a solid basis for continuing scientific exploration of the mechanisms of plant invasions at the continental scale under ongoing global change, as well as for conservation efforts, management, policy and decision-making process.

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