Chapter 4
Alien Vascular Plants of Europe

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4.1 Introduction

In terms of invasion biology, vascular plants are the most intensively researched taxonomic group; at least 395 plant invaders have been addressed in detailed case studies globally, accounting for 44% of all invasive taxa studied; after North America, Europe is the continent enjoying the most intensive study with at least 80 invasive plant species having been addressed (Pyšek et al. 2008). However, although there is a considerable body of information on major plant invaders in Europe (see also Weber 2003), the situation is much less satisfactory as far as complete national inventories of alien plants are concerned. Prior to the DAISIE project (www.europe-aliens.org), only few countries had a sound information on the composition of their alien floras, available in specialised checklists, notably Austria (Essl and Rabitsch 2002), the Czech Republic (Pyšek et al. 2002), Germany (Klotz et al. 2002; Kühn and Klotz 2003), Ireland (Reynolds 2002) and the UK (Clement and Foster 1994; Preston et al. 2002, 2004). This situation directly translated into poor knowledge across the European continent. The only available continental analysis of plant invasion patterns in Europe (Weber 1997) was based on data from Flora Europaea (Tutin et al. 1964–1980), the only synthetic source of information on floras of particular countries, including alien species. This source is, however, nowadays outdated and contains numerous inaccuracies in data for individual countries (Pyšek 2003). In general, 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and distribution of alien plant species for most European countries was scattered in a variety of published and unpublished accounts and databases; this is the case in other continents too (Meyerson and Mooney 2007). On the plant side, DAISIE was thus a major challenge of collating and assessing existing data on the most numerous group of European aliens and concentrating this information in an authoritative continental inventory.

The European area covered (Fig. 4.1) by the plant team of DAISIE was partly determined by the geographical coverage of source floras, but it was broadly attempted to use the limits set by Flora Europaea (Tutin et al. 1964–1980) for the north and central continental boundaries (i.e., as far east as the Urals, to the border of the Black Sea but excluding the Caucasus). In the south-east, Cyprus was

DAISIE, *Handbook of Alien Species in Europe,*

the boundary of the area included, and Turkey was also considered. In total, 49 countries/regions were included (Fig. 4.1). For each national region, a data set was compiled from the most comprehensive literature sources available, and taxonomic treatment was standardised across all national checklists (see Lambdon et al. 2008 for data sources and details of the procedure). Naturalised and casual alien species were distinguished with respect to invasion status, and archaeophytes and neophytes with respect to the residence time, following criteria suggested by Richardson et al. (2000) and Pyšek et al. (2004). However, in some cases there was insufficient information to determine the exact category (archaeophyte vs. neophyte, naturalised vs. casual) and the taxon was recorded as alien without further specification. This designation occurs most commonly in poorly-recorded countries (e.g., Belarus, Bulgaria, Moldova), but such data sets generally only include prominent invaders which are mostly likely to be naturalised.

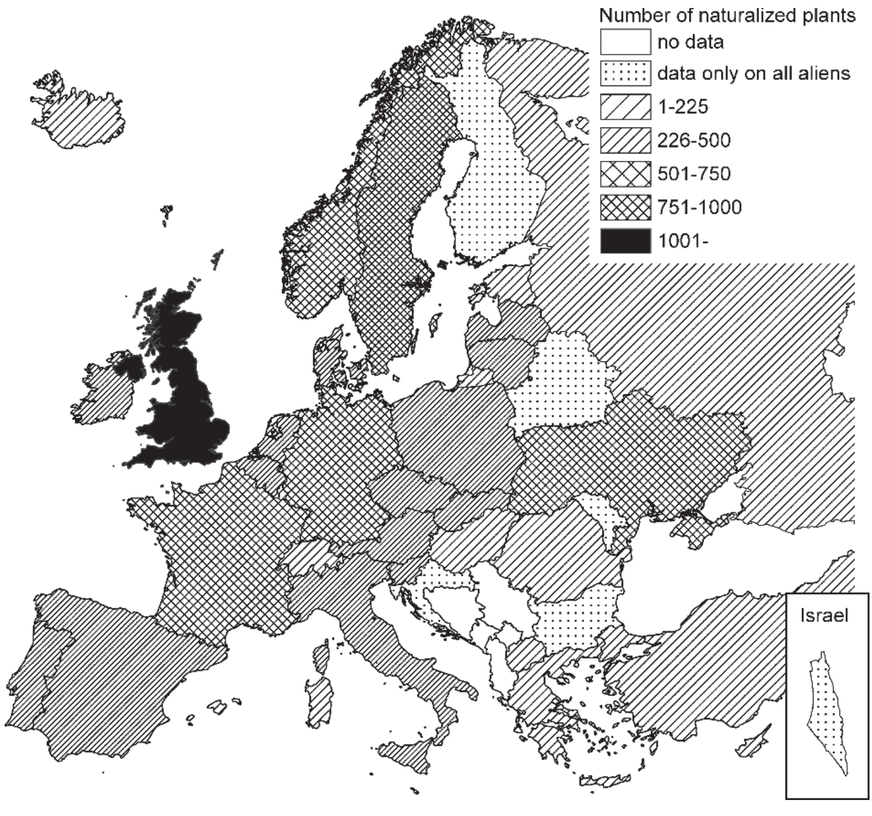

Fig. 4.1 Pattern of invasions by alien plants in Europe, expressed as numbers of naturalised alien plants in countries/regions; dotted areas indicate poorly researched regions for which only the information on the total number of aliens is available (Based on data from Lambdon et al. 2008); see this source for information on the numbers of species and assessment of the quality of data in particular countries/regions

Similarly, since the focus of DAISIE was primarily on neophytes, it may be safely assumed that the majority of all aliens, where reported, refer to naturalised neophytes. We distinguished between aliens in Europe, which group includes also species that are native in a part of Europe but alien to another part, and aliens to Europe, including species with native distribution area outside Europe; the latter is a subgroup of the former.

This chapter summarises the basic information on the structure of alien flora of Europe, presents the most common naturalised species, and describes robust large-scale geographical patterns in the level of invasion (in terms of Hierro et al. 2005; Chytrý et al. 2008b) across Europe and in the composition of regional alien floras. Finally, it points to current research gaps and outlines avenues for further research. Complete and more detailed information can be found in Lambdon et al. (2008).

4.2 Diversity of Alien Plants in Europe

The DAISIE database contains records of 5,789 alien plant species in Europe, of which 2,843 are alien to Europe, i.e. of extra-European origin (275 species were not assigned an origin status due to ambiguities over their native range). Of these aliens in and to Europe, 1,507 and 872, respectively, are casual in all regions where they occur. There are in total 3,749 naturalised alien plant species recorded in Europe, of which 1,780 are alien to Europe. We do not attempt to derive the total number of naturalised neophytes since it would have to be based on a limited subset of only 19 countries for which invasion and residence time status were designated, which would necessarily lead to an underestimation of the number of naturalised neophytes currently present in Europe (Lambdon et al. 2008).

The 11 years old overview of the alien flora of Europe (Weber 1997) reported 1568 naturalised species in Europe; this is much less than recorded by DAISIE and to explain this difference, two aspects need to be considered. The overview of Weber (1997) was based on Flora Europaea, which relied on data from 1960s–1970s (Tutin et al. 1964–1980). Since this period, there has been a continual influx of alien species to individual countries (Pyšek et al. 2003). When the publication of Flora of Europaea was completed, many more alien species than included in that work must have been present in Europe (Fig. 4.2). Taking into account that 65% of species in DAISIE database are naturalised, it can be estimated that there were 2,175 naturalised aliens in Europe in 1980, when the publication of the first edition of Flora Europaea was completed, i.e. much higher number of species than reported by Tutin et al. (1964–1980). Another principle reason for the low alien species number reported in Flora Europaea was rather low level of detail adopted for screening aliens. Raised awareness of the issue of alien species and increasing research intensity in the last decades (Pyšek et al. 2006), yielded dramatically higher numbers of species recorded in the DAISIE database, which is much closer to the reality.

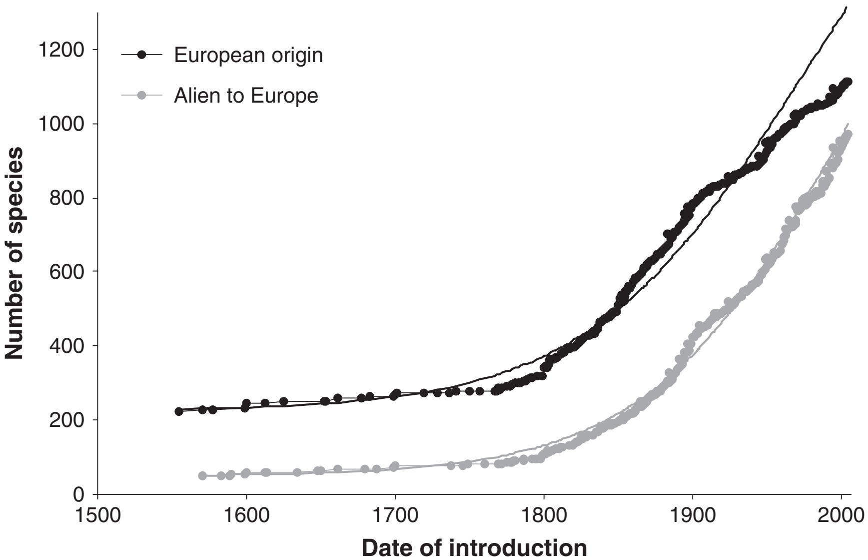

Fig. 4.2 Increase in numbers of alien neophytes introduced to Europe over the last 500 years. Cumulative data are shown separately for species with native distribution area outside Europe (n = 929) and those with European origin, but occurring as alien in other parts of the continent (n = 954); for these species introduction relates to their first record as alien outside their native range. Introduction dates are estimated from the minimum residence time, and species where this could not be evaluated with a reasonable degree of accuracy were excluded (Taken from Lambdon et al. 2008, published by courtesy of the Czech Botanical Society). Both relationships are approximately hyperbolic, and the following semi-logit transformation was most appropriate: $T(p) = -\ln(p/(2-p))$, where p is the proportion of the total number of species introduced, at a given time T, since AD 1500. Alien to Europe: $N = 0.0134p - 26.49$ ($r^2 = 0.97$); Aliens of European origin: $N = 0.0113p - 22.40$ ($r^2 = 0.95$)

4.3 Areas of Origin

For aliens in Europe, other parts of the continent are the main donor area. As much as 29% of all introductions (attributing species that originate from more than one region to each of these regions, Fig. 4.3) recruit from some European countries and invade in others. Combined with aliens of Asian origin (31%) illustrates the major contribution (60%) of the Eurasian super-continent to alien species richness in Europe. North and South America together account for 19% introduction of alien species in Europe. Considering species of extra-European origin separately yields a different picture (Fig. 4.3). Among aliens to Europe, 34% of introductions are of Asian origin (with temperate Asia providing more species than tropical), 23% and 22% originate from North and South America, respectively, and 17% from Africa. These figures are fairly consistent with distribution of origins in national floras (Kühn and Klotz 2003; Pyšek et al. 2002) and confirm patterns reported by Weber (1997) for Europe.

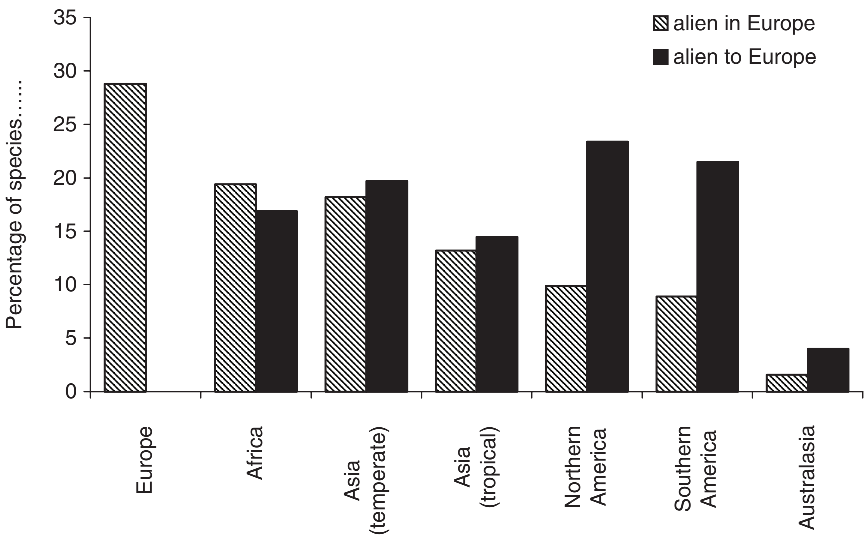

Fig. 4.3 Donor regions of the alien flora of Europe. Based on 2,094 naturalised aliens in Europe for which the region of origin was classified (hatched bars), 1,168 of these are alien to Europe, i.e. species that arrived to Europe from other continents (black bars). Note that the figure reflects the numbers of introductions from donor regions; species originating from more than one region were attributed to each of the regions of origins, so that the totals in both groups of aliens equal to 100% (Based on data from Lambdon et al. 2008)

4.4 Taxonomy

The European alien flora is dominated by large global plant families (Table 4.1); the highest numbers are found in the Asteraceae (692 alien representatives), Poaceae (597), Rosaceae (363), Fabaceae (subfamily Faboideae, 323) and Brassicaceae (247). These families have a weedy tendency (Daehler 1998; Pyšek 1998) and have undergone major radiations in temperate regions, with the exception of Rosaceae, where the majority of species introduced to Europe are boreo-temperate woody shrubs and trees. The only other predominantly woody, family highly represented is the Pinaceae (53 alien species). In total, alien species are from 213 families (Lambdon et al. 2008), almost twice as many as reported by Weber (1997). In some cases success may to be linked to the frequency of introductions, as some family characteristics make the species valuable for human uses (e.g., the Rosaceae as fruit crops, Pinaceae for timber and Lamiaceae as herbs and ornamental plants). Those families, which have diversified in Europe, sometimes have correspondingly greater numbers which are alien in Europe (Table 4.1). At higher taxonomic levels, families with a high representation of alien species cluster in the orders Asparagales, Ranunculales, Caryophyllales, Lamiales and Solanales (Lambdon et al. 2008). Obviously, the high diversity of European aliens in some families is largely determined by their high global species pools

Table 4.1 Most represented families in the alien flora of Europe (with at least 100 alien taxa), classified according to the Angiosperm Phylogeny Group (Stevens 2001 onwards) and Mabberley (1997). The total number of alien species recorded, the total number of naturalised aliens (Natur), and the number of naturalised neophytes (Neo) is given for aliens to Europe, aliens of European origin, and aliens in Europe. World species numbers were taken from Mabberley (1997). Species are ranked according to the total number of alien taxa in Europe (shown in bold) (See Lambdon et al. 2008 for a complete account on families)

	Aliens to Europe			Aliens of as in Table 4.2 European origin			Aliens in Europe			Total aliens in Europe as % of world number
	Total	Natur	Neo	Total	Natur	Neo	Total	Natur	Neo	
Asteraceae	334	193	138	334	225	144	**692**	424	283	3.0
Poaceae	340	136	93	257	159	99	**597**	295	192	6.3
Rosaceae	212	176	76	134	93	44	**363**	247	120	12.8
Fabaceae (Faboideae)	82	40	22	233	138	101	**323**	181	124	2.7
Brassicaceae	50	17	14	174	127	87	**247**	146	102	7.6
Amaranthaceae	128	51	45	56	40	27	**185**	91	72	9.0
Lamiaceae	55	29	17	97	69	34	**165**	102	52	2.5
Caryophyllaceae	13	5	2	141	74	37	**156**	80	39	6.8
Apiaceae	31	20	10	103	64	33	**143**	87	44	4.0
Plantaginaceae	38	21	7	82	58	23	**132**	84	31	2.4
Onagraceae	80	45	36	10	8	4	**112**	68	43	17.2
Solanaceae	88	53	39	12	11	6	**107**	66	45	3.6
Polygonaceae	45	30	18	46	28	16	**106**	63	36	9.6
Boraginaceae	26	18	10	63	47	30	**105**	69	41	4.6

(Asteraceae, Faboidae, Poaceae, Lamiaceae), but the proportions of the total numbers of world representatives present as aliens in Europe indicate that some families (notably Onagraceae with 17%, Salicaceae 15%, Rosaceae 13%, Geraniaceae 10%, Polygonaceae 10% and Amarathaceae 9% of the world species pool occurring as aliens in Europe) are more predisposed to invade than others (Daehler 1998; Pyšek 1998).

There are 1,567 genera with at least one alien representative in Europe (Table 4.2). The commonest genera are those with evolutionary centres in Europe or Eurasia, with a high native diversity (*Centaurea*, *Silene*, *Euphorbia*, *Rumex*) or those extensively used by humans (*Trifolium*, *Vicia*, *Rosa*). The pattern is very different for alien species with extra-European origin; the commonest genera among aliens to Europe are globally-diverse ones comprising mainly urban and agricultural weeds (*Amaranthus*, *Chenopodium* and *Solanum*), but also frequently cultivated (the largest *Cotoneaster* with 70 species alien to Europe comprises almost exclusively introductions for ornamental purposes, or other ornamentals such as those in genera *Sedum* or *Narcissus*). One special case is the genus *Oenothera*, where hybrid swarms tend to become true breeding after a few generations of isolation. Only a few large genera which have successfully invaded (e.g., *Oxalis*, *Panicum*, *Helianthus*) are predominantly extra-European.

Table 4.2 Most represented genera in the alien flora of Europe (with at least 35 alien taxa), classified according to the Angiosperm Phylogeny Group (Stevens 2001 onwards) and Mabberley (1997). The total number of alien species recorded, the total number of naturalised aliens (Natur), and the number of naturalised neophytes (Neo) is given for aliens to Europe, aliens of European origin, and aliens in Europe. Species are ranked according to the total number of alien taxa *in* Europe (shown in bold) (Adapted from Lambdon et al. 2008, where a more complete account on genera can be found)

Genus	Family	Aliens to Europe			Aliens of European origin			Aliens in Europe		
		Total	Natur	Neo	Total	Natur	Neo	Total	Natur	Neo
Cotoneater	Rosaceae	70	62	16	4	3	1	**75**	65	17
Oenothera	Onagraceae	43	32	28	3	2	2	**64**	49	33
Chenopodium	Amaranthaceae	29	10	10	22	17	9	**52**	27	19
Centaurea	Asteraceae	7	3	2	42	22	18	**51**	25	20
Rumex	Polygonaceae	11	3	2	26	16	12	**45**	20	14
Trifolium	Fabaceae	7	4	2	42	25	15	**49**	29	17
Euphorbia	Euphorbiaceae	10	7	2	29	23	14	**47**	33	17
Silene	Caryophyllaceae	5	2	1	40	18	18	**47**	21	9
Solanum	Solanaceae	35	25	19	3	2	1	**45**	29	20
Eragrostis	Poaceae	38	5	4	7	5	5	**45**	10	9
Senecio	Asteraceae	22	14	7	15	11	8	**44**	27	16
Amaranthus	Amaranthaceae	37	19	19	2	2	2	**39**	21	21
Bromus	Poaceae	13	7	3	24	15	18	**37**	22	11
Sedum	Crassulaceae	15	10	6	18	18	12	**36**	29	18
Veronica	Plantaginaceae	8	5	4	25	19	5	**35**	25	9
Rubus	Rosaceae	21	18	9	10	7	2	**35**	27	11
Cyperus	Cyperaceae	26	16	6	9	4	3	**35**	20	9

There are 128 species recorded from more than a half of the countries considered (Lambdon et al. 2008). The most common European alien species is Canadian fleabane *Conyza canadensis*, native to North America, occurring in 47 countries/regions (94%). Other species occurring in more than 80% of the regions studied include (Table 4.3): thorn-apple *Datura stramonium*, Jerusalem artichoke *Helianthus tuberosus*, black locust ***Robinia pseudoacacia*** (all native to North America), common amaranth *Amaranthus retroflexus*, least pepperwort *Lepidium virginicum* (North and Central America), shaggy-soldier *Galinsoga quadriradiata* (Central and South America), gallant-soldier *Galinsoga parviflora*, pineapple-weed *Matricaria discoidea* (South America), rough cocklebur *Xanthium strumarium* (Eurasia), common millet *Panicum miliaceum*, common field-speedwell *Veronica persica* (Asia) and common evening-primrose *Oenothera biennis* (this species probably originated in Europe but is considered alien in most countries). Since the widely distributed aliens are naturalised in the vast majority of regions from which the information on invasion status is available, it is reasonable to assume that the same is likely to be true for those where such assessment is missing (unspecified occurrences in Table 4.3). Notably, all of them are aliens to Europe, mostly originating from North America.

Table 4.3 The most widespread alien plant species in Europe. Their status as naturalised or casual is shown. Unspecified status refers to regions where the species is definitely alien but classification as to whether it is casual or naturalised is not available or it is impossible to decide about the status with certainty. Occurrence as neophyte or archaeophyte is not distinguished but given the focus of DAISIE, the majority of taxa are neophytes. Species are ranked according to the decreasing number of total occurrences in Europe as aliens (Adapted from Lambdon et al. 2008)

Species	Family	Naturalised	Casual	Unspecified	Total
Conyza canadensis	Asteraceae	33	1	13	47
Datura stramonium	Solanaceae	25	7	13	45
Amaranthus retroflexus	Amaranthaceae	30	4	10	44
Galinsoga parviflora	Asteraceae	27	2	15	44
Helianthus tuberosus	Asteraceae	26	5	12	43
Xanthium strumarium	Asteraceae	22	5	16	43
Lepidium virginicum	Brassicaceae	16	11	15	42
Oenothera biennis	Onagraceae	28	2	12	42
Robinia pseudoacacia	Fabaceae	32	2	8	42
Galinsoga quadriradiata	Asteraceae	25	1	15	41
Matricaria discoidea	Asteraceae	23	3	15	41
Panicum miliaceum	Poaceae	16	20	5	41
Veronica persica	Plantaginaceae	27	0	14	41
Ailanthus altissima	Simaroubaceae	30	1	9	40
Amaranthus albus	Amaranthaceae	24	5	11	40
Erigeron annuus	Asteraceae	27	3	10	40
Fallopia japonica	Polygonaceae	29	1	10	40
Medicago sativa	Fabaceae	23	4	13	40
Amaranthus blitoides	Amaranthaceae	24	6	9	39
Lepidium sativum	Brassicaceae	10	21	8	39
Papaver somniferum	Papaveraceae	12	17	10	39
Solidago canadensis	Asteraceae	28	0	11	39
Acer negundo	Sapindaceae	26	3	9	38
Chenopodium ambrosioides	Amaranthaceae	22	6	10	38
Elodea canadensis	Hydrocharitaceae	26	0	12	38
Juncus tenuis	Juncaceae	26	0	12	38
Panicum capillare	Poaceae	17	16	5	38
Phalaris canariensis	Poaceae	10	15	13	38
Vicia sativa	Fabaceae	15	13	10	38

However, the widely distributed species are not necessarily the most invasive in terms of impact and human perception. Many taxa listed in Table 4.3 are agricultural weeds or ruderal species of urban habitats; only few of the species included in the 100 worst alien species in this book are also among the most widely-distributed aliens, such as woody invaders black locust ***Robinia pseudoacacia*** (41 countries/regions) and tree of heaven ***Ailanthus altissima*** (39), or noxious weeds as Japanese knotweed ***Fallopia japonica*** (39), annual ragweed ***Ambrosia artemisiifolia*** (35), Himalayan balsam ***Impatiens glandulifera*** (34), Japanese rose ***Rosa rugosa*** (34), giant hogweed ***Heracleum mantegazzianum*** (27) and iceplant ***Carpobrotus edulis*** (24). Some of the serious invaders are actually quite localised to the regions concerned, e.g. wild ginger ***Hedychium gardnerianum*** (3) or giant rhubarb *Gunnera tinctoria* (4).

4.5 Temporal Trends of Invasion

There was a steady increase in the number of neophyte species over the last two centuries, both in terms of the rate at which new species were being imported to Europe and the rate of increase of the total number of neophytes in Europe (Fig. 4.2). Visual inspection of the figure suggests that arrivals from regions outside of Europe started to increase exponentially approximately at the middle of the 19th century. Of the nowadays naturalised neophytes alien to Europe, 50% arrived after 1899, 25% arrived after 1962 and 10% arrived after 1989. At present, 6.2 new alien species, capable of naturalisation, are arriving to Europe each year. The slope is marginally less steep for naturalised neophytes of European origin, which tended to start their spread historically earlier. In this case, 50% had first been detected as alien in a European country by 1876, and the most recent 10% had started to appear by 1969. Today, approximately 4.4 European species capable of naturalisation are newly found in parts of the continent outside their native range each year (Lambdon et al. 2008). Overall, it seems that the rate of new introductions has increased sharply throughout the two past centuries and is showing little sign of slowing down.

4.6 Main Pathways to Europe

Among 2,024 naturalised plant taxa alien to Europe with information on the pathway of introduction, intentional introductions account for 63% and unintentional for 37% (Fig. 4.4). Escapes of species cultivated for ornament and horticulture account for the highest number of species, 58% of the total. Only about 11 species can with certainty be attributed to intentional releases in the wild; this group is in many cases difficult to distinguish from "amenity" species (planted in semi-wild situations for practical purposes such as landscaping, e.g. iceplant ***Carpobrotus edulis*** or black locust ***Robinia pseudoacacia***, often used for stabilisation of soil). Examples of deliberate releases include purple pitcher plant *Sarracenia purpurea*, which was deliberately introduced to bogs in the UK and Ireland by botanists, and smooth cordgrass *Spartina alterniflora*, introduced to salt-marshes, although arguably the latter can be also considered rather an amenity use.

Contaminants of seed, mineral materials and other commodities are responsible for 403 introductions to Europe (17% of all species) and 235 species are assumed to have arrived as stowaways (directly associated with human transport but arriving independently of commodity, see Hulme et al. 2008a) (Fig. 4.4). However, the number of stowaways is almost certainly underestimated due to technically difficult systematic recording of this pathway, e.g. seed admixtures (Mack 2000). This underestimation is likely to be even more pronounced in unaided species, which are assumed to arrive by means independent of humans from a neighbouring region where they are not native (Hulme et al. 2008a). Forty one aliens of extra-European

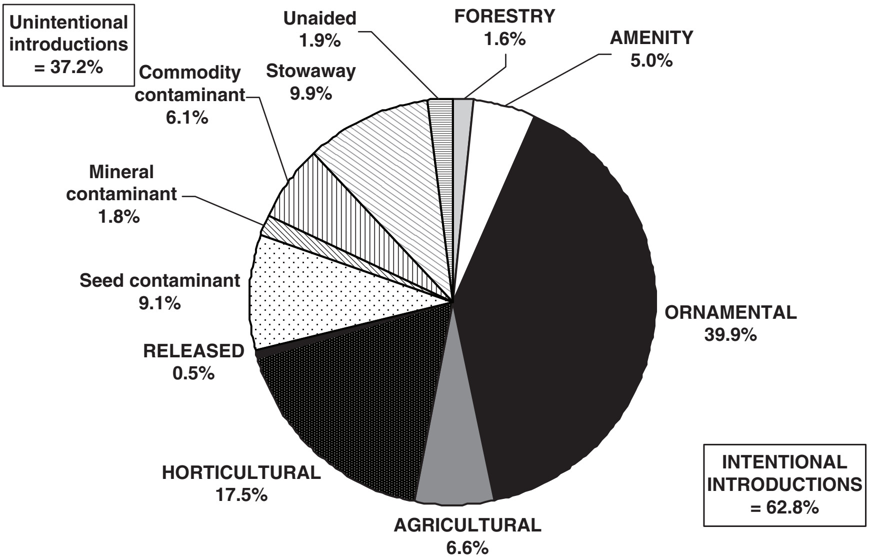

Fig. 4.4 Relative contribution of pathways of introduction shown for naturalised aliens to Europe, i.e. species with the area of origin outside Europe. Pathways of intentional introductions are in upper case letters, unintentional in lower case (Based on 1,983 naturalised aliens. Data from Lambdon et al. 2008)

origin (2% of species alien to Europe) are a product of spontaneous hybridisation involving one or both alien parents (Fig. 4.4). The spectrum of pathways is very similar for the complete European alien flora, as both groups of aliens, in Europe and to Europe, do not substantially differ in the proportional contribution of individual pathways (Lambdon et al. 2008).

4.7 Biogeographical Patterns

The pattern in the level of invasion of European regions by naturalised aliens (a measure based on species numbers, which does not necessarily reflect the invasibility of the region; Lonsdale 1999; Richardson and Pyšek 2006; Chytrý et al. 2008a) is summarised in Fig. 4.1. From the continental perspective, the highest richness of alien species is associated with large industrialised north-western countries with a tradition of good botanical recording or intensive recent research. The highest number of all alien species, regardless of status, is reported from Belgium (1,969), United Kingdom (1,779), Czech Republic (1,378), France (1,258), Sweden (1,201) and Austria (1,086); this is due to detailed inclusion of casuals. Surprisingly, only 371 alien species are reported from Russia, 149 of them naturalised (Lambdon et al. 2008). In terms of naturalised neophytes, United Kingdom (857), Germany

(450), Belgium (447), Italy (440), Ukraine (297), Austria (276), Poland (259), Lithuania (256), Portugal (250) and Czech Republic (229) harbour more than 200 species (Fig. 4.1).

The species-area relationship for naturalised alien plants in Europe indicates a diminishing increase of species numbers with increasing area (Fig. 4.5), the same as found for mammals. Plotting a subgroup of naturalised neophytes from countries where classification of species status was possible yields a steeper slope (Fig. 4.5).

Lambdon et al. (2008) used ordination analysis on assemblages of alien species in European countries/regions and identified five major distribution types: (1) north-western, comprising Scandinavia and the UK; (2) west-central, extending from Belgium and the Netherlands to Germany and Switzerland; (3) Baltic, including only the former Soviet Baltic states; (4) east-central, comprising the remainder of central and Eastern Europe; (5) southern, covering the entire Mediterranean region. Some prominent European alien invaders represent these biogeographical zones, e.g. ***Rhododendron ponticum*** the north-western, *Heracleum sosnowskyi* the Baltic, wild cucumber ***Echinocystis lobata*** the east-central and Indian fig ***Opuntia ficus-indica*** the southern distribution type (see the 100 worst alien species for distribution maps of these species, except for *H. sosnowskyi* see Lambdon et al. 2008).

Although it cannot be excluded that the pattern observed arises partly due to regional differences in the approach to botanical recording, there are almost certainly strong cultural and climatic influences. Gross Domestic Product, and mean annual rainfall and air

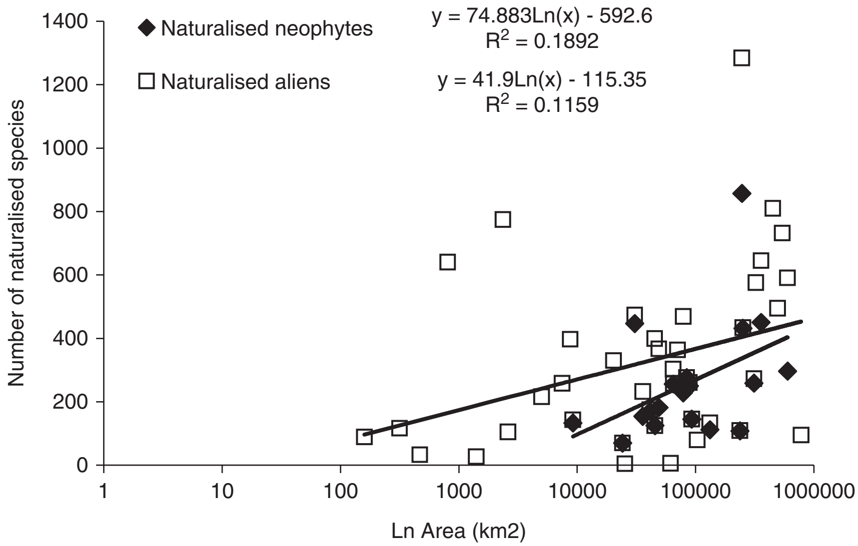

Fig. 4.5 Species-area relationship for alien plants in Europe. Based on the total number of naturalised aliens in 41 countries/regions. Trend is also shown for a subset of countries/regions where the information on the number of naturalised neophytes is available (n = 19). Note the semilog scale (Based on data from Lambdon et al. 2008)

temperature seem to play a role in the differentiation of alien floras, but are difficult to interpret since these factors are highly confounded with either latitudinal or longitudinal gradients. Country area and human population were poor explanatory variables, suggesting that factors associated with population density (e.g. urbanisation) are minor determinants of floristic composition. Therefore, it seems that bioclimatic constraints, dictating the suitability of species to the physical environment, are of primary importance and play major role in shaping the assemblages of alien species in Europe. Cultural factors such as regional trade links and traditional local preferences for crop, forestry and ornamental species, may also be important in influencing the introduced species pool (Lambdon et al. 2008). Kühn et al. (2003) showed that at least for Germany, alien species largely follow biogeographic patterns of native species.

Despite regional differences (Chytrý et al. 2008b), there is a high level of uniformity across the alien floras of the five biogeographical zones at the continent – there are only few distinctions between their alien species assemblages, as to be expected from the pattern reported for a continental scale elsewhere (e.g., McKinney 2004). For all five distribution types, the dominant families and geographical regions of origin were not substantially different from those displayed for the whole of Europe, and the dominant genera were also similar across the zones. However, the southern assemblage was most distinct, contained lower numbers of species in the temperate weedy genera such as *Chenopodium* and a stronger representation of genera with a tropical or New World bias (e.g., *Acacia*, *Opuntia*). That this assemblage coincides with the Mediterranean region, which has a particularly contrasting climate compared with the rest of Europe, confirms the important role of climate in shaping these alien species assemblages. Many of the common agricultural weeds alien in Europe are also native to the Mediterranean (Pyšek et al. 2004) and therefore excluded from the alien assemblage. In addition, countries in the Mediterranean region are positioned at the crossroads of three continents, which makes them accessible to biotic elements originating from a variety of sources; this may also contribute to the floristic distinctness of the southern alien assemblage. The east-central zone was most influenced by temperate genera (e.g., *Cotoneaster*, *Salix*), whilst the remaining three assemblages were very similar. The distribution patterns of alien species in Europe can be formally classified into four groups: (1) widespread: naturalised across much of the continent (448 species, with 76 occurring in all biogeographical zones); (2) regionally-common: naturalised consistently across a major biogeographical zone (196 species); (3) sporadic: occurring rarely and inconsistently across several biogeographic zones; (4) local: naturalised in only a small part of Europe; the latter two categories comprise the remaining vast majority of species (Lambdon et al. 2008).

4.8 Most Invaded Habitats

Since habitat descriptions in most floras are relatively coarse (Chytrý et al. 2008a, b), the recording in DAISIE database is only down to EUNIS Level 2 (Davies and Moss 2003), although in many cases only Level 1 was possible, either through low resolution or ambiguities in the source literature (Lambdon et al. 2008). Information on habitat affinities is available for 30 countries/regions. For Europe as a whole, 57% of recorded naturalised aliens in Europe (2,122 species) and 58% to Europe (1,059 species) were classified with respect to the occurrence in habitats (Table 4.4). Recent research on the representation of alien species in plant communities showed that habitat identity is the major determinant of not only the level of invasions (in the sense of Hierro et al. 2005) but also of invasibility and that it is more important than climate and factors related to propagule pressure (Chytrý et al. 2008a). The information on the level of invasions of individual habitats is therefore crucial to the management of alien species in Europe.

Human made habitats (industrial habitats and arable land, parks and gardens) harbour most alien species (Chytrý et al. 2005, 2008a, b). Of all naturalised aliens present in Europe, 64% occur in industrial habitats and 58% on arable land and in parks and gardens. Grasslands and woodlands are also highly invaded, with 37% and 32%, respectively, of all naturalised aliens in Europe present in these habitats. Mires, bogs and fens are least invaded of terrestrial habitats; approximately 10% of aliens in Europe occur there. In marine habitats, only 12 vascular plant species were recorded (7 of them alien to Europe), representing 0.6% of all species (Table 4.4).

Aliens in Europe on average occur in more habitat types than aliens to Europe, as indicated by a tendency to higher proportional values for the former group in Table 4.4 (see Lambdon et al. 2008 for statistical analysis). This can be interpreted in terms of better preadaptation of aliens originating in other parts of Europe to a

Table 4.4 Level of invasion of European EUNIS habitats by naturalised aliens, shown separately for aliens to Europe (n = 1,059) and aliens in Europe (n = 2,122) The sums of percentages across habitats do not equal 100% because many species occur in more than one habitat type. Habitat types were classified according to the EUNIS system (Davies and Moss 2003) (Based on data from Lambdon et al. 2008)

	Number of species		Percentage of the total number of classified species	
Category	Aliens in Europe	Aliens to Europe	Aliens in Europe	Aliens to Europe
Number of species classified	2,122	1,059	–	–
% classified of the total	56.6	57.7	–	–
A. Marine habitats	12	7	0.6	0.7
D. Mires, bogs and fens	220	118	10.4	11.1
B. Coastal habitats	343	170	16.2	16.1
C. Inland surface waters	444	260	20.9	24.6
F. Heathland and scrub	462	206	21.8	19.5
H. Inland sparsely vegetated habitats	497	211	23.4	19.9
G. Woodland and forest	668	310	31.5	29.3
E. Grasslands	793	276	37.4	26.1
I. Arable land, gardens and parks	1,240	533	58.4	50.3
J. Industrial habitats	1,360	658	64.1	62.1

wider range of European habitats – these species seem to profit from a better habitat match compared to extra-European aliens, which need to adapt to the character of European habitats during the invasion process (Lambdon et al. 2008). Another reason may be longer residence times of aliens with European native range (Pyšek et al. 2003), providing them with more time to colonise a wider range of habitats.

4.9 Ecological and Economic Impacts

Comprehensive data exist in the DAISIE database only for few countries (Latvia, Lithuania, and UK), where about 20% of naturalised species are considered to have an impact. The best data set, in terms of evaluation of the impact, refers to Switzerland; of 97 naturalised alien plant species, 50 are documented as having impact (see synthesis in Wittenberg 2006). However, some insights into a variety of impacts caused by alien plant species in Europe can be obtained from the inspection of species included in the 100 worst alien species; these taxa were selected so as to provide a representative sample of diverse impacts known to occur in Europe. Of the 18 plant taxa included, 17 are known to reduce the habitat of native species, and 8 are reported to cause disruption of the community assemblages. Iceplant ***Carpobrotus edulis*** (Vilà et al. 2006) and giant hogweed ***Heracleum mantegazzianum*** (Pyšek et al. 2007) are examples of alien species causing serious decrease in species richness of invaded communities. This is, however, not always the case as documented for Himalayan balsam ***Impatiens glandulifera***; under some circumstances the invasion of this species does not necessarily result in loss of the diversity of invaded communities, only in shifts in species composition towards ruderal, nitrogen demanding species (Hejda and Pyšek 2006, but see Hulme and Bremner 2006).

Alien plant species exert ecological and economic impacts, both direct and indirect, at multiple levels. Of the 22 impact types defined by Binimelis et al. (2007), plants included in the 100 worst alien species are attributed, on average, with more than four types of impacts per species, which makes them the group with the second most diverse impact, following terrestrial mammals. Regarding economic impacts, Bermuda buttercup ***Oxalis pes-caprae***, *Opuntia maxima*, knotgrass ***Paspalum paspalodes*** and ***Rhododendron ponticum*** are known to negatively affect commercial production and yield of agricultural and forest products. Black locust ***Robinia pseudoacacia***, tree of heaven ***Ailanthus altissima*** and pampas grass ***Cortaderia selloana*** are typical examples of aliens to Europe causing serious damage to infrastructures and utilities.

The unique genetic nature of native or even endemic species of special conservation value can be lost through introgression with widespread aliens (Vilà et al. 2000). In the Czech flora (Pyšek et al. 2002), hybrids contribute 13% to the total number of aliens, and the hybridisation is more frequent in archaeophytes (19%) than in neophytes (12%). Probably the best-known European example of the recent evolution of an invader relates to a North-American smooth cordgrass *Spartina alterniflora*, which hybridised with European *S. maritima* in England and France to produce a sterile *S.* × *townsendii*. The hybrid originated only at two places in

Europe and no invasion occurred until an allotetraploid form, common cordgrass *S. anglica* arose in 1890s. This form is able to grow in a wider range of conditions and became an aggressive invader in Europe and elsewhere (Williamson 1996). In Germany, the hybridisation of alien Austrian yellowcress *Rorippa austrica* with native *R. sylvestris* produces complex hybrid forms; those with ploidy levels 3x–5x reproduce sexually and spread to areas where parents do not grow (Bleeker 2003).

Alien plants are reported to reduce availability of pollinators to native species as documented for Himalayan balsam ***Impatiens glandulifera*** (Chittka and Schürkens 2001). In the Balearic Islands, native *Lotus cytisoides* receives less pollinator visits in communities invaded by the South African iceplant *Carpobrotus* spp. than in uninvaded communities (Traveset and Moragues 2004). Plant invaders can also modify community structure at higher trophic levels; the grass *Elymus athericus* was shown to affect spider population dynamics in salt marshes in France (Petillon et al. 2005).

That invading species alter ecosystem functioning (transformers sensu Richardson et al. 2000) was documented in Europe for example for black locust ***Robinia pseudoacacia***, which is reported to interfere with nitrogen cycle. Other species affect fire regimes; examples include pampas grass ***Cortaderia selloana*** and Mauritania vine reed *Ampelodesmos mauritanica*, which increase the risk of fire in Mediterranean scrub by higher fuel loads and slow decomposition resulting in formation of thick litter layers in invaded stands (Vilà et al. 2001; Grigulis et al. 2005). Finally, several alien terrestrial plants seem to affect cultural aspects of established human civilisations by altering their perception of natural landscapes (e.g., *Opuntia maxima*, Japanese rose ***Rosa rugosa***, Bermuda buttercup ***Oxalis pes-caprae***), reducing the area of recreational natural sites (e.g., giant hogweed ***Heracleum mantegazzianum***) or becoming abundant over ancient ruins (e.g., tree of heaven ***Ailanthus altissima***).

4.10 Expected Future Trends, Management Options and Their Feasibility

The data collated by DAISIE strongly suggests that up to now, the number of naturalised alien plant species in Europe tended to be underestimated and the outputs from DAISIE database represent the first European-wide detailed account of alien plant at this continent. The rate of import of new alien plant species to Europe shows very little signs of slowing down (Fig. 4.2). Moreover, even if introductions ceased, the number of naturalised plant species would increase due to the lag phase (Kowarik 1995; Richardson and Pyšek 2006). Since there is a close correlation between the total number of naturalised species and that of pests, more species mean more impact (Rejmánek and Randall 2004). As in other parts of the world, alien plant species are likely to increase in numbers (Levine and D'Antonio 2003), and the threat from plant invasions is unlikely to diminish in Europe in the near future.

Despite constant conservation efforts, biodiversity loss is estimated to be occurring at 100–10,000 times the background rate of the fossil record for the Cenozoic era (May et al. 1995) and alien species invasions are, along with loss of habitats through land-use change, direct exploitation, pollution and climate change, one of its major causes (Sala et al. 2000). In Europe, the Mediterranean region with highly diverse plant communities, is among the most endangered (Hulme et al. 2008b). This region is also likely to suffer from higher air temperatures and increasing drought, which are expected to change future fire regimes (Piñol et al. 1998; Lavorel et al. 1998). Increased fire frequencies have been reported to favour the establishment of alien species (Vilà et al. 2001). In northernly located regions, warmer conditions, likely to be brought about by climate changes, can be assumed to favour invasions by alien species as well (Walther et al. 2007), since many alien species originating from warmer regions are currently restricted from achieving wider distribution by not being able to complete their life cycle in cooler invaded areas (Pyšek et al. 2003).

The problem of alien plants needs to be addressed at the European scale. Dispersed and disconnected knowledge cannot easily be marshalled to deliver the information to politicians, but improving information exchange can build regional capacity to identify and manage invasive alien species threats. This implies that coordination of action against invasive species is crucial; a cross-European regulatory framework is needed. This holds true for plants in particular, as plants spread very easily and are more difficult to monitor and control, compared to some other taxa, such as vertebrates where substantial proportion of introductions is due to intentional releases. The spread of plants is highly correlated with human transport (Levine and D'Antonio 2003), which calls for cooperation between different sectors, including conservation agencies and transport companies with international scope (Meyerson and Mooney 2007).

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