Status and trends in the alien flora of Corsica

Jeanmonod, Daniel; Schlüssel, André; Gamisans, Jacques

Status and trends in the alien flora of Corsica

D. Jeanmonod[1], A. Schlüssel[2] and J. Gamisans[3]

[1]*Laboratoire de Systématique végétale et Biodiversité, Université de Genève et Conservatoire et Jardin botaniques de Genève, 1 ch. de l'impératrice, CH1292 Chambésy, Switzerland; e-mail: daniel.jeanmonod@ville-ge.ch*

[2]*Conservatoire et Jardin botaniques de Genève, 1 ch. de l'impératrice, CH1292 Chambésy, Switzerland*

[3]*11 rue Jean Bouyssou, F-31500 Toulouse, France*

This article summarizes and analyses some of the data published in *Flora Corsica* (Jeanmonod & Gamisans, 2007) in order to characterize the alien vascular plant flora of the island. The data analysed focus on different aspects of the alien flora such as diversity (species richness), abundance, lifeforms, vegetation belts, habitats and biogeographical origins. The results show that the alien species richness is currently high, representing 16.5% of the total flora, amongst which 37.5% are naturalized. The penetration of this flora occurs mainly at lower altitudes, and is still weak or absent in the higher altitude vegetation belts whereas it has increased over time within natural closed habitats. Over the last 11 years, the species richness of xenophytes has increased by 18.1%, which corresponds to an increase of 23.0% of the naturalized plants. Moreover, 24.8% of the alien taxa have increased in abundance. A scenario highlighting the trends of the introduced flora, and that includes issues of native biodiversity conservation, is proposed based on the results. The special case of invasive species is also considered, and their exponential increase on Corsica is highlighted. Other aspects of the alien flora, such as its taxonomic spectrum and biogeographical origins, are also analysed and are, whenever possible, compared with those of other geographical regions, particularly from the Mediterranean (Sardinia, Balearic Islands) and Continental Europe.

Introduction

Corsica is the fourth largest island in the Mediterranean Sea. It is situated in the western basin of this geographic area and is located about 82 km from continental Italy, and 160 km from the French mainland. It is the northernmost of the 6 major Mediterranean islands. This island is characterized by an especially marked topographic relief including more then 100 peaks over 2000 m above sea level.

From a geological perspective (Gauthier, 2001), the island is largely composed of mainly siliceous bedrock (67% of the surface), while schistaceous rocks cover about 15% of the surface. The limestone accounts for only about 2% of the island and it is divided into several isolated areas. The remaining parts of the island consist mainly of sedimentary areas that are distributed mostly in the eastern lowland part. The geological composition of Corsica is quite distinct from the nearby island of Sardinia, which has several important calcareous ranges and a much less marked topographic relief.

From a biogeograpical point of view, Corsica is part of the NW Mediterranean quadrant (Blondel & Aronson, 1999), with which it shares many species. However, it has been isolated from the continent for 30 million years, having separated at that time with an assembly formed by Sardinia, the Balearic Islands, Calabria and the Betic-Rif Massif. Over time this block disintegrated into different elements which subsequently drifted in several directions, leaving Corsica close to Sardinia. These two islands are now only 12 km apart and were connected by land during the last glaciations. Corsica forms a biogeographic entity with Sardinia, and shares a common, but old, history with the Balearics (400 km apart), Calabria (600 km apart), and even earlier with the Betic-Rif Arc. After Sardinia, its closest neighbours are Italy – specifically Toscana (including the Tuscan Archipelago) and Liguria – and Southern France.

Flora Corsica (Jeanmonod & Gamisans, 2007) was used to conduct an analysis of the flora based on the various features of each taxon identified within it. A first publication (Jeanmonod *et al.*, 2011) focused on the general characteristics of the whole flora. Here, a similar analysis focuses on the alien flora.

The study of the non-native flora has become increasingly important over recent years because of the environmental problems that have emerged following the establishment of some of these species. Regions with a Mediterranean climate appear to be particularly sensitive to biological invasions, according to the risk scenarios calculated by Sala *et al.* (2000). Moreover, the Convention on Biological Diversity (Anon, 1993), in Article 8h, states that 'Each contracting party shall, as far as possible, and as appropriate, prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species'. This implies a good understanding of the alien species and the threats they entail, but also of the evolution of the alien flora which can be extremely dynamic.

Within the alien flora on Corsica only a few species have proved to be problematic: these are the ones that have been

defined as 'invasive alien species'. As indicated by the IUCN (2000) 'One of the major threats to native biological diversity is now acknowledged by scientists and governments to be biological invasions caused by alien invasive species. The impacts of alien invasive species are immense, insidious, and usually irreversible. They may be as damaging to native species and ecosystems on a global scale as the loss and degradation of habitats'. As stated by Genovesi & Shine (2004), 'invasive alien species are the second leading cause of species extinction worldwide (after the degradation and loss of habitats), they particularly affect the biological diversity of islands and isolated ecosystems in terms of evolution'. It is therefore particularly important to: (1) monitor the evolution of the alien flora of Corsica, because it is an isolated ecosystem dating from the Messinian crisis (5 million years ago); and (2) understand the mechanisms involved, especially those that affect these species, and allow them to establish themselves permanently (naturalized taxa), or to penetrate and spread into the territory. Using this knowledge alien species that are likely to become invasive can be identified more effectively. Given the nature of the problem, the speed of diagnosis is crucial. The more territory that is colonized by a species, the higher the costs of eradication or control of the populations become. It follows that, above and beyond the analysis of the alien flora of Corsica, the aim was to identify factors that promote the establishment and spread of these species, to quantify their invasion rate, their ability to establish and to spread, in order to formulate invasion scenarios for the future.

The strategies to be implemented in order to lower the impact of the alien flora on the natural vegetation and biodiversity will largely depend upon these results.

Materials and methods

Treated taxa

All the data has been extracted from *Flora Corsica* (Jeanmonod & Gamisans, 2007). Data from more recent work (Jeanmonod & Schlüssel, 2008, 2010) has not been included to ensure that a consistent set of data from a specified time period, and based on a particular reference point, was used. *Flora Corsica* mentions 2781 taxa that could be found on the island in the wild. These taxa represent 2397 species of which 269 have additional infraspecific taxa (283 subspecies, 98 varieties and 3 forms). In order to make comparisons with other floras and other areas as accurate as possible, only species and subspecies were retained herein. The taxonomic concepts, for some taxa, vary from flora to flora, with subspecies (sometimes even some varieties) considered as full species, or vice versa. These differing taxonomic concepts influence the figures used in the analysis. However, using only the taxonomic ranks of species and subspecies means that the differences are reduced to a minimum, because it is these two ranks that are generally used in the biodiversity calculations inherent in the various floras. Thus, all the following analyses are based on a total of 2680 species and subspecies (2397 + 283) of vascular plants (corresponding to'taxa' in this study) that can be found in the wild on Corsica.

Introduced taxa

The alien (or introduced) flora includes all xenophytes, that is to say all taxa of foreign origin whose presence on Corsica is not natural, but results from either deliberate (termed subspontaneous taxa, which can become naturalized) or involuntary introduction (termed adventitious taxa, which can also become naturalized). In our study, only neophytes (taxa that colonized the island since 1492 AD) were selected. The archeophytes (taxa that occurred on Corsica before that date) are considered to be part of the native flora. The latter group is negligible, given the insular nature of Corsica that historically has created an efficient barrier to the entry of non-native plants. The alien flora, as treated here, does not include those cultivated taxa that have never been observed in the wild within the territory. For detailed discussion of the various classifications and terms used on the subject of xenophytes, as well as the methods used to define the categories and the options taken to overcome the difficulties inherent in this type of analysis, see Natali & Jeanmonod (1996). It should be noted that three broad categories of plants are distinguished according to their mode of introduction and naturalization:

- Adventitious plants[1]: plants of foreign origin, introduced by accident, not well-established and likely to disappear at any time.
- Subspontaneous plants: plants of foreign origin, escaped from cultivation (crops, ornamentals), not well-established and likely to disappear at any time.
- Naturalized plants: plants of foreign origin, well-established in the wild and able to survive without any human intervention (='established').

The first two categories together form the group known as 'casual plants' (poorly established plants that may disappear).

Invasive taxa

Within the naturalized plants, the invasive species (=exotic pest plants) group stands out. An invasive species is defined by the IUCN as 'an alien species which becomes established in natural or semi-natural ecosystems or habitat, is an agent of change, and threatens native biological diversity' (IUCN, 2000; MacNeely, 2001).

Comparisons over time

For the alien flora, the data extracted from *Flora Corsica* were compared with those of a study carried out 11 years earlier (Natali & Jeanmonod, 1996). However, the data given by these authors could not be used in its entirety because many corrections have been made since 1996. The authors of *Flora Corsica* rejected 30 taxa treated by Natali & Jeanmonod (1996), considering them to be erroneous. A further set of taxa were either placed

[1]The terms 'adventitious' and 'casual alien plants' are used in a restricted sense, as they define only plants introduced unintentionally by people. This does not correspond to the meaning of 'casual' given by several Anglo-Saxon authors such as Richardson *et al.* (2000).

in synonymy or were considered as hybrids (9), because several taxa considered as being 'perhaps' or 'probably introduced' were later considered as 'indigenous' (70) or cultivated (2). Conversely, 13 taxa not taken into account by Natali & Jeanmonod (1996) and considered to be 'indigenous' were treated as 'introduced' by *Flora Corsica*. Consequently, the number of neophytes was reduced from 473 to 375 (473−30−9−70−2 + 13) to ensure that comparisons were made between data defined on the same basis.

Abundance classes

All species were divided into seven major abundance classes (as in Gamisans & Jeanmonod, 1993) as follows (ranked by increasing order of rarity):

CC = very common;
C = common;
PF = infrequent or disseminated;
LOC = localised (only in small areas, where it can be abundant);
R = rare: only 6–10 known localities;
RR = very rare: only 1–5 known localities;
D = probably extinct in Corsica.

Life-forms

Flora Corsica indicates the life-form of each taxon. The life-forms used in this study correspond to the major groups defined by Raunkiaer (1934), based on the strategy developed by plants (location of the plant growth-point) to survive unfavourable seasons (dry season, cold season), and used in many other floras. These groups are as follows: therophytes, phanerophytes, chamaephytes, hemicryptophytes, geophytes and hydrophytes (including the helophytes). The relative importance of life-forms is relevant as they play a major role in the composition of functional groups (Brooks *et al.*, 1997; Médail *et al.*, 1998) and demonstrate an affinity with ecological and bioclimatic factors (Daget, 1980). The life-forms thus represent useful descriptors with good predictive powers for assessing the stability and conservation status of Mediterranean habitats (Verlaque *et al.*, 2001).

Vegetation belts

The characteristics of the vegetation belts and the vegetation belt boundaries of Corsica were defined by Gamisans (1978). These altitudinal zones include seven belts: thermomediterranean, mesomediterranean, supramediterranean, montane, oromediterranean, subalpine, and alpine. In addition to these belts, and because of its particularities, we also refer to the 'coastal zone' that is composed of specific habitat types (rocks, sand dunes, salty soils) subject to sea spray and strong winds. In the various analyses (see figures and tables below), these different belts are ranked in ascending order, corresponding to their natural altitudinal position. The oromediterranean belt was placed between the montane and the subalpine belts as its altitudinal position is the same as the latter, but it is strictly restricted to south facing slopes.

Habitats

The classification used by Jeanmonod & Gamisans (2007) is based on the major vegetation types. Here this system is simplified by reducing it to 12 habitat categories: (1) aquatic; (2) semi-aquatic; (3) wet herb; (4) riparian (woody vegetation along stream banks); (5) sandy; (6) rocky; (7) meadows and grasslands; (8) megaphorbs; (9) bushes and shrubs; (10) forests; (11) cultivated; and (12) ruderal.

Substrate

In *Flora Corsica*, the substrate indicated for each taxon is presented in a simplified form. The authors indicate it only when the taxa are associated with limestone, schists or serpentinite. Nothing is mentioned when a taxon is present on siliceous soils or when a taxon is indifferent to the substrate. Thus, the substrate assignment (silica or indifferent) is used by default in our analysis for all taxa where the other three substrates are not mentioned.

Biogeographical origin

The biogeographical origins of the introduced taxa were divided into 15 categories. Six were based on broad geographical divisions (continents or sub-continents): (1) Africa; (2) America; (3) Asia; (4) Oceania (incl. Australia); (5) Eurasia, but also taking into account some broad climatic characteristics; (6) tropical (including subtropical); and (7) circum-boreal (including Eurosiberian and Boreal/Austral taxa). The rest were based on more precise biogeographical areas (for the territories closer to Corsica): (8) Macaronesian; (9) Mediterranean touranian; (10) Mediterranean montane; (11) Atlantic (including the Mediterranean/Atlantic taxa); (12) Stenomediterranean; and (13) Eurymediterranean. Finally, we also distinguished (14) the cosmopolitan taxa (including the subcosmopolitan ones) and (15) those that are known to have an origin related to crops. For detailed explanations see Jeanmonod & Gamisans, 2007.

Statistical analysis

The correlation between several variables were tested using the Spearman rank correlation test [(rS); Zar, 1996], a non parametric linear correlation test, using the formula $rS = 1-\{(6 \times \Sigma di^2)/(n^3-n)\}$, where di is the difference between the ranks of the two variables, and n is the total number of ranks. There is a perfect linear correlation when rS = 1 or −1, and conversely no linear correlation when rS = 0. The critical value (threshold) was set at 0.05. The probability (P) of being wrong in rejecting the null hypothesis was also calculated.

Results and discussion

The species richness (alpha biodiversity) of the alien flora of Corsica is particularly high with 443 introduced taxa found on the island (Table 1), corresponding to 16.5% of the total flora or

Table 1 Comparison of the alpha biodiversity of the native and alien flora of various geographical areas, listed in ascending order of their surface area

Territory (surface in km^2)	Alien taxa	Native taxa	Total list of taxa	% alien taxa/total flora
Vaucluse/FR (3567)[1]	45	1730	1775	2.5%
Balearics/ES (4987)[2]	124	1729	1853	7.2%
Bouche-du-Rhône/FR (5087)[3]	1011	1887	2898	34.8%
Liguria/IT (5410)[4]	216	2915	3131	6.9%
Gard/FR (5863)*[,6]	72	2253	2325	3.1%
Crete/GR (8336)[7]	162	1839	2001	8.1%
Corsica/FR (8748)	443	2237	2680	16.5%
Cyprus/CY-TR (9520)*[,8]	62	1514	1576	3.9%
Tuscany /IT (22 992)[4]	318	3117	3435	10.2%
Sardinia/IT (24 000) [1995][4]	208	2199	2407	8.6%
Sardinia/IT (24 000) [2009][4]	482	2199	2681	18.0%
Piemonte/IT (25 400)[4]	372	3138	3510	10.6%
Sicily/IT (25 700)[4]	292	2718	3010	9.7%
Switzerland (41 285)[9]	467	2584	3051	15.3%
Italy (301 230)[4]	782	6852	7634	10.24%

After [1]Girerd (1978), [2]Larrucea & Coll (2006) and Vilà & Muñoz (1999), [3]Molinier (1981), [4]Conti *et al.* (2005), [5]Bacchetta *et al.* (2009); [6]Aubin (1999), [7]Jahn (2003), [8]Alziar (1995) and [9]Aeschimann & Heitz (2005). Floras marked with an * dealt only with species (infraspecific taxa were not taken into account).

19.8% of the native flora. The comparison of these figures (number of taxa and percentage of the alien flora versus the total flora) with those of other, mainly Mediterranean, geographical areas, shows that the values obtained for Corsica are higher than those in the other regions, with the exception of the Bouches-du-Rhône (SE France), which seems to be a very particular case.

The high species richness seen in the alien flora of Corsica may be explained in several ways. Insularity could be a primary cause, as islands are particularly sensitive and vulnerable to invasions of non-native plants, especially when they are remote and isolated, as seen in the Hawaiian Islands with 44% and New Zealand with 40% of alien species, respectively (Loope & Mueller-Dombois, 1989; Mac Donald & Cooper, 1995). However, Corsica is near the mainland and the other Mediterranean islands do not have a higher alien species richness value than those of neighbouring continental regions. When comparing the data from Corsica to that of Switzerland (used for comparative purposes because of its similar size and topographic relief, and because of the availability of recent and comprehensive floristic data; see Aeschimann & Heitz, 2005) similar rates were found, despite the fact that Switzerland is in the middle of the European continent.

Statistical analysis [Spearman rank test (rS)] demonstrated that, unlike native taxa whose number is strongly influenced by the size of the geographical area under consideration [(rS) 0.05, 14 = 0.538 < 0.631; with $0.01 < P < 0.02$ (see also Jeanmonod *et al.*, 2011)], the number of alien taxa showed no significant correlation with the size of the corresponding geographical area [(rS) 0.05, 14 = 0.538 > 0.503; with $0.05 < P < 0.1$]. The Spearman rank test showed that there was a significant linear correlation between the total number of taxa present per region and the proportion (but also the absolute number) of introduced taxa in these regions [(rS) 0.05, 14 = 0.538 < 0.609; with $0.002 < P < 0.005$]. However, Corsica (16.5%) and the Bouches-du-Rhône (34.8%) have a high number of introduced plants compared to other regions with a similar surface area. These results suggest that the number of alien plants per surface unit has not yet reached its saturation point, and that it should continue to increase in these territories. The proportion of alien taxa present on the various Mediterranean islands (Table 1), is not correlated with the distance of these islands from the nearest mainland coast [(rS) 0.05, 6 = 0.886 > 0.371; with $P = 0.5$]. This is likely to be linked to the fact that the colonization of islands by alien taxa is one that largely depends on trade and tourism transit between the mainland and the islands. The figures in Table 1 should be considered with some caution, however, as in older publications the alien flora has often been neglected, and because the alien flora of a given area evolves very quickly, which means that the year of the publication of the data affects the figures. For Sardinia, Conti *et al.* (2005) reported 208 alien taxa, while a more recent and complete study (Bacchetta *et al.*, 2009) reported 482 alien taxa. The study of Lambdon *et al.* (2008) for Europe as a whole showed the same phenomenon with 1568 alien taxa reported in *Flora Europaea* (Weber, 1997), and 5789 according to their more recent data. Because of the fast evolution of alien floras we focus mainly on the recent data published for Sardinia (Bacchetta *et al.*, 2009) and the Balearic Islands (Vilà & Muñoz, 1999).

Only some of the alien plants are able to naturalize. On Corsica the naturalized plants represent 166 taxa, which correspond to 37.5% of the non-native flora, 7.4% of the native flora or 6.2% of the whole Corsican flora. For the casual plants, more than two-thirds (187 taxa) are subspontaneous plants. These figures highlight the importance of the deliberate introduction of alien plants onto the island, mostly for commercial purposes (ornamental or crop plants) (Natali & Jeanmonod, 1996). The remaining casual plants consist of adventitious taxa, which also probably arrived on the island through commercial channels, but were introduced accidentally.

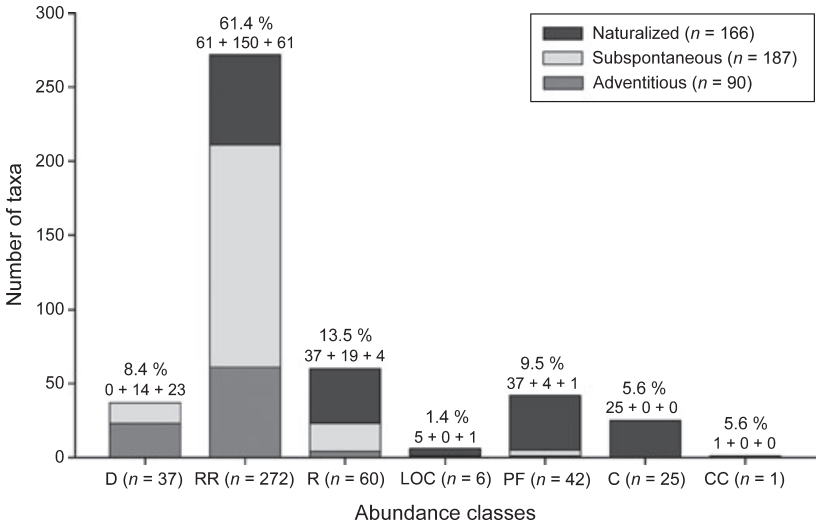

Fig. 1 Number of taxa in each of the three categories of alien plants for each abundance class (n = total in each category or class). CC, very common; C, common; PF, infrequent or dispersed; LOC, localised; R, rare; RR, very rare; D, probably extinct. For each class, the percentage of the total number of taxa is indicated above the corresponding column, as well as the absolute number of taxa for each category (from left to right: naturalized, subspontaneous, adventitious).

Abundance

The abundance spectrum of the alien flora (Fig. 1) is quite different from that of the native flora (see Jeanmonod *et al.*, 2011). The vast majority of the alien flora consists of very rare (RR) taxa (272 taxa, 61.4% of the alien flora). It is noteworthy that many of these alien taxa (37 taxa, 8.4% of the alien flora) have not been recorded again after their initial discovery, and thus failed to colonize the island. However, taxa that become well-established may also go on to colonize new areas. Thus, 15.4% (68 taxa) of the alien flora is now fairly widespread (abundance classes PF + C + CC) whereas 11 years ago only 11% was widespread (Natali & Jeanmonod, 1996).

Taxonomic spectrum

The alien flora is distributed across 94 families, among which 52 contain naturalized taxa. The ranking order for the three most important families (*Asteraceae, Poaceae, Fabaceae*) is identical to the ranking of the families in the native flora (Fig. 2). This ranking changes somewhat for the other families (to be compared with data analysed in Jeanmonod *et al.*, 2011). The *Caryophyllaceae*, *Apiaceae, Orchidaceae* and *Ranunculaceae*, which are important families for the native flora of Corsica, have no, or few, alien representatives. On the other hand, small families such as *Solanaceae, Chenopodiaceae* and *Amaranthaceae* have high numbers of alien representatives. The situation is quite different when focusing only on the naturalized or the casual plants: *Lamiaceae* and *Rosaceae* have no naturalized taxa and *Brassicaceae* falls to tenth place, far behind *Amaranthaceae*. Sardinia, with its similar number of families (98) within the alien flora, demonstrates a quite different taxonomic spectrum (Bacchetta *et al.*, 2009). On Sardinia, *Fabaceae* is the most species-rich family (46 taxa) followed by *Poaceae* (32), *Asteraceae* (30) and, surprisingly, *Rosaceae* (19). In the Balearic Islands the alien flora is represented by only 46 families. As seen on Corsica, *Asteraceae*

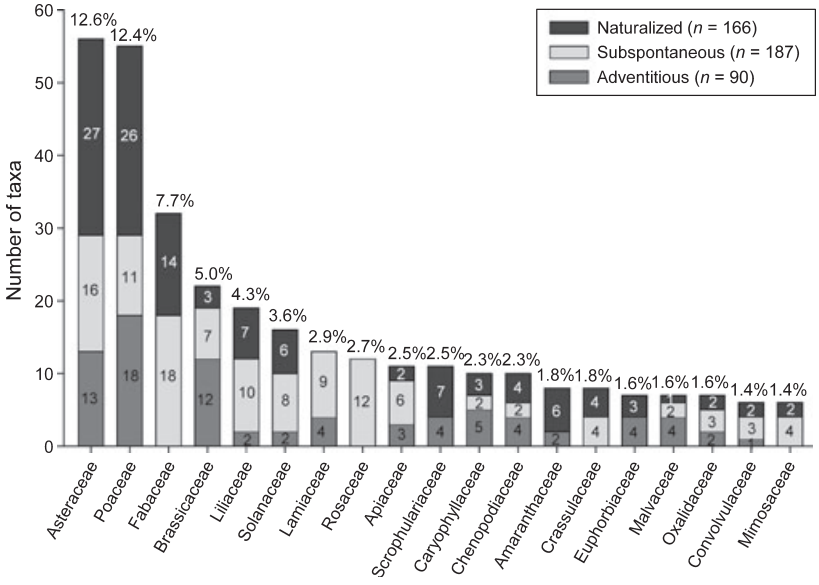

Fig. 2 Distribution of the alien flora of the 19 most species rich families (with at least 6 alien taxa reported on Corsica), arranged in order of family importance.

Table 2 Biological spectra of the three categories of alien plants and of the native flora of Corsica. For comparison, the biological spectra of alien taxa in Sardinia ([1]after Bacchetta *et al.*, 2009), and the Balearic Islands ([2]after Vilà & Muñoz, 1999) are also given

	Hydrophytes	Therophytes	Geophytes	Hemicryptophytes	Chamaephytes	Phanerophytes
Adventitious	2 (2.2%)	54 (60.0%)	3 (3.3%)	33 (36.7%)	5 (5.6%)	0 (0%)
Subspontaneous	2 (1.1%)	49 (26.2%)	22 (11.8%)	44 (23.5%)	25 (13.4%)	64 (34.2%)
Naturalized	3 (1.8%)	59 (35.5%)	19 (11.4%)	45 (27.1%)	16 (9.6%)	44 (26.5%)
Alien taxa	7 (1.6%)	162 (36.6%)	44 (9.9%)	122 (27.5%)	46 (10.4%)	108 (24.4%)
Native	4.0%	35.7%	13.8%	40.3%	7.7%	7.3%
[1]Sardinia	2%	31%	9%	12%	6%	40%
[2]Balearics	–	37.9%	9.7%	17.7%	12.1%	16.9%

and *Fabaceae* are the most important families, followed by *Solanaceae* and *Poaceae* (Vilà & Muñoz, 1999). For Europe as a whole (Lambdon *et al.*, 2008), the top five families are the same as for Corsica, with the exception of *Rosaceae* which is in third place in Europe. This can be attributed to the temperate climate that dominates on the European continent favouring this family. The genera *Amaranthus, Chenopodium* and *Solanum* are very well-represented in Europe (which is also the case on Corsica) whereas the genera *Cotoneaster* and *Oenothera*, are well-represented in Europe but not on Corsica. *Oenothera*, a genus of American origin, is a curious case as three species have been reported several times on the island, but none of them have been found again since. This genus has not managed to colonize Corsica but on the continent it has become relatively common.

Life forms

The biological spectrum of life-forms of the alien flora of Corsica is quite distinct from that of the native flora (Table 2). In particular, the proportion of woody plants (phanerophytes and chamaephytes) is much higher (34.8% compared to 15.0%). These values are close to those obtained 11 years earlier by Natali & Jeanmonod (1996), but with fewer therophytes (38.7% in 1996) and more phanerophytes (14.8% in 1996).[2]

The three categories of alien plants have quite different biological spectra. The therophytes represent 55.7% and the hemicryptophytes 34% of the adventitious taxa, which leaves very few taxa in the remaining life-form types within this category. In contrast, the subspontaneous and naturalized categories have a similar biological spectrum, with a high proportion of phanerophytes (31.1% and 23.6%, respectively), and a relatively high proportion of chamaephytes (12.1% and 8.6%, respectively) and geophytes (10.7% and 10.2%, respectively). On Corsica, the alien flora has a distribution mainly centred on the mesomediterranean belt (see next section). The inference that the biological spectrum is similar to the one shown by the flora of this belt might be made but it was found not to be the case. The biological spectrum of the mesomediterranean flora is as follows: hydrophytes, 26.1%; therophytes, 46.1%; geophytes, 14.8%; hemicryptophytes, 19.8%; chamaephytes, 5.8%; and phanerophytes, 8.3% (see Jeanmonod *et al.*, 2011). In other words, the alien flora has its own pattern of life-forms. Interestingly, the biological spectrum of the alien flora of Sardinia (Bacchetta *et al.*, 2009) and of the Balearic Islands (Vilà & Muñoz, 1999) are similar to that of Corsica, with the exception of the phanerophytes, which have a higher value on Sardinia (40%).

[2]The percentage is calculated based on the total number of taxa in each category. The sum slightly exceeds 100% because some taxa may have several life-forms.

Vegetation belts

The colonization and spread of the alien flora is restricted to the lower vegetation belts (Fig. 3) and does not reflect the altitudinal distribution of the whole Corsican flora (see Jeanmonod *et al.*, 2011). Thus, 83.1% of the alien flora is found in the mesomediterranean belt and < 20% in the other belts: coastal zone, 14.4%; thermomediterranean, 19.4%; supramediterranean, 17.4; montane, 5.4%, with none in the higher altitude belts. The various categories of alien plants (subspontaneous, adventitious and naturalized) show a similar pattern and the differences between these categories are not significant.

Habitats

The distribution of the alien flora in the various habitats (Fig. 4) shows, rather unsurprisingly, that a high proportion of the introduced plants are present in ruderal (67.9%) and cultivated habitats (17.8%). This corroborates the results obtained by Natali & Jeanmonod (1996) for Corsica, and it also confirms that the colonization of the island by non-native taxa occurs mainly via the anthropogenic, disturbed and sparsely vegetated habitats. Our results also show that a high proportion of alien taxa are present in the meadows and grasslands (14.7%, with a significant amount of subspontaneous taxa) and in the rocky habitats (10.2%, with a significant proportion of adventitious taxa). The proportion of alien plants in the forests (5.0%) remains low, but has increased significantly since 1996 when it was at 2.7%. The increase in alien taxa seen in these habitats collectively is 85.2%.

Figure 4 shows that naturalization of the alien flora occurs in most habitats (except those with no or only very low numbers of alien taxa such as the megaphorbs or aquatic and semi-aquatic habitats). However, in comparison with the whole alien flora, naturalization is more pronounced in relatively densely vegetated habitats such as meadows and grasslands, bushy and shrubby habitats, and riparian habitats, than in those that are sparsely vegetated such as the ruderal, cultivated and rocky habitats. Wet herb

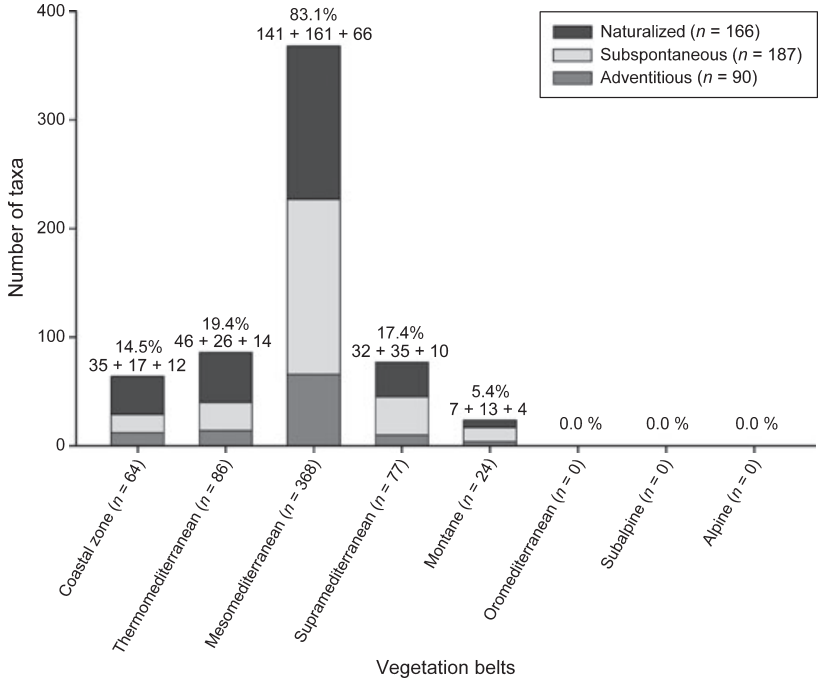

Fig. 3 Distribution of the alien flora in the various vegetation belts. For each belt, the percentage of the total number of alien taxa is indicated above the corresponding column, as well as the absolute number of taxa for each category (from left to right: naturalized, subspontaneous, adventitious).

habitats contain proportionally more naturalized than casual plants. Despite the fact that the types of habitats have been treated a little differently, this spectrum reflects the one highlighted by Lambdon *et al.* (2008) for the entire European continent, that is to say 60–70% of the alien taxa are found in the ruderal habitats. In contrast, a significantly higher proportion of alien taxa are represented in the forests (±30%) and in the meadows and grasslands (±35%) of Europe than in the same habitats on Corsica. On Sardinia (Bacchetta *et al.*, 2009) the proportions of alien plants in the various habitats are similar to those observed for Corsica (8% in forests, 7% in riparian habitats), but significantly higher proportions are found in the wet herb habitats (11%). On the Balearic Islands (Vilà & Muñoz, 1999), the colonization of densely vegetated habitats is much lower, with only 2% in forests and 3% in meadows and grasslands. These latter results may be somewhat biased by the fact that the information is almost 10 years old, and many alien taxa may have reached the archipelago since then, as has been the case for Corsica since 1996 (see the Evolution section below).

Substrate

The distribution of the alien flora according to the bedrock type (results not shown) demonstrates that the vast majority of these plants (97.7%) grow on siliceous substrates or are indifferent to this environmental factor. On Corsica, only nine alien species are associated with limestone [*Anemone coronaria* L., *Apera spica-venti* (L.) P. Beauv., *Artemisia arborescens* (Vaill.) L., *Capparis spinosa* L, *Cerastium comatum* Desv., *Lilium candidum* L., *Mantisalca salmantica* (L.) Briq. & Cavill., *Tulipa agenensis* DC., *Zantedeschia aethiopica* (L.) Spreng.]. Only two species are limited to schistaceous soils (*Capparis spinosa* L. and *Sedum mexicanum* Britton), and none are serpentinicolous (associated with ultrabasic rocks which include serpentine).

Biogeographical origin

The biogeographical origins of the alien flora (Fig. 5) are extremely diverse, as already shown by Natali & Jeanmonod (1996). The great majority of these taxa come from distant continents (Africa, Asia, Australia–Oceania, and the tropics: 49.2%) whereas alien plants of mesogean origin (Stenomediterranean, Eurymediterranean, Mediterranean montane) represent only 25.7%, and those with a Holarctic, non-Mediterranean origin (Circumboreal, Atlantic and Eurasian) represent 19.4%. This biogeographical spectrum is quite similar to that given for Sardinia (Bacchetta *et al.*, 2009), although the mesogean part is less important (17%), while the African (11%) and the American (30%) groups have higher values. In the Balearic Islands (Vilà & Muñoz, 1999), the spectrum is also similar to that of Corsica, with 54.5% of alien taxa with a very distant origin, and 23.1% with a mesogean origin. In contrast, the figures for the whole of Europe (Lambdon *et al.*, 2008) are quite different, with a much higher rate of African (36.1%) and Asian (34%) taxa seen. The geographic position and insularity of Corsica and the more temperate climate that predominates across the European continent may explain these differences, especially with respect to plants of Asian origin.

The three categories of alien plants (adventitious, subspontaneous and naturalized) have three very different biogeographical spectra. These results facilitate the identification of which group of alien plants contains taxa that are most likely to naturalize. The naturalized plants contain a majority of American taxa (out of which 48.7% originate from North America and 51.3% from

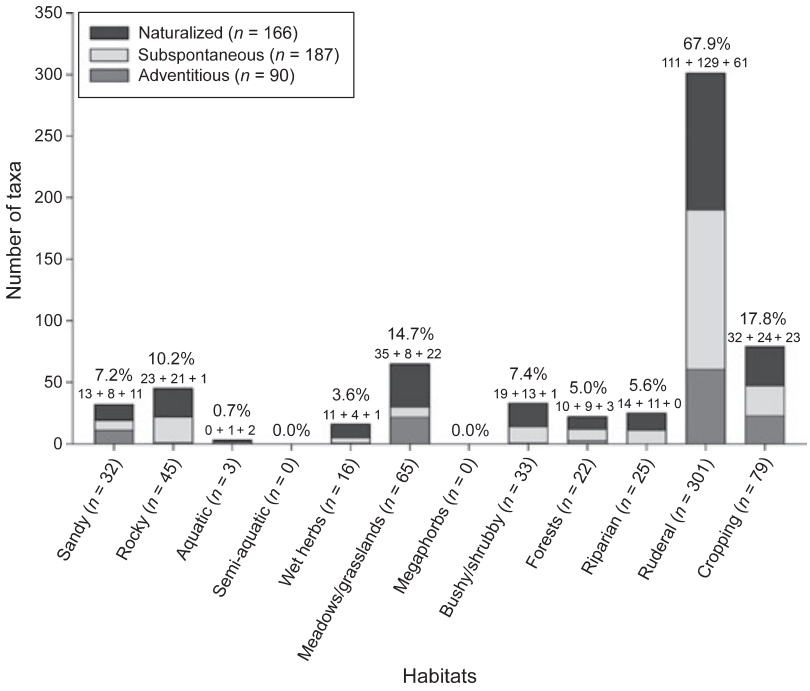

Fig. 4 Distribution of the alien flora in the various habitats. The number above each column indicates the percentage of the total alien flora. For each belt, the percentage of the total number of alien taxa is indicated above the corresponding column, as well as the absolute number of taxa for each category (from left to right: naturalized, subspontaneous, adventitious).

South America and/or Central America). The Asian taxa, although well-represented in the group of the subspontaneous plants, appear to have less capacity to naturalize. However, trade with America over the last 100 or so years has meant that the American taxa have been able to reach Europe for a longer period than the East Asian taxa. The intense commercial traffic between Europe and East Asia is relatively recent and consequently many Asian species may naturalize in the near future. This hypothesis is supported by the fact that the Asian naturalized plants accounted for 6% of all naturalized plants in 1996 (Natali & Jeanmonod, 1996), while in 2007 they represented 7.8%, an increase of 30%.

Evolution over time

The data extracted from *Flora Corsica* (Jeanmonod & Gamisans, 2007) were compared with those of Natali & Jeanmonod (1996), after an adjustment of the data, as explained in the chapter 'Materials and Methods'. The comparison of these data is shown in Table 3.

The increasing importance of the alien flora and the potential impact that it may have on the native flora of Corsica can be highlighted based on three main indicators:

- The increase in alien species richness: the arrival of 68 alien taxa in 11 years corresponds to an increase of 18.1% from the 1996 levels.
- The changing status of alien taxa, namely the evolution of the proportion of casual (=adventitious + subspontaneous) versus naturalized plants: from the 240 casual taxa recorded in 1996, 28 have become naturalized, which equates to an increase of 11.7% (among them 8 were previously adventitious and 20 were subspontaneous taxa). The naturalized group demonstrates a larger species richness increase (23.0%) than the casual group (15.4%), or all the xenophytes (18.1%).
- The variation in the abundance of alien taxa (Table 4): alien taxa showed a large increase in their abundance, with 56 (14.9% of the alien flora of 1996) changing to one or several higher abundance classes (some, for example, jump from RR to LOC or even PF). Only three taxa (0.8%) show a decrease in their abundance (*Galium verum* L., which changed from R to RR, *Genista tinctoria* L. and *Pyrola secunda* L., which changed from RR to D). A total of 316 taxa (84.3%) did not change their status. However, this does not necessarily mean that their abundance remained stable. For example, a taxon known from six or seven localities (classified as R) and recently recorded in two new localities, increases its abundance but remains in the same abundance class. According to floristic data published between 1996 and 2007 (Jeanmonod & Burdet, 1996–1999; Jeanmonod, 2000; Jeanmonod & Schlüssel, 2001–2006), new localities were recorded for 37 additional taxa that, nonetheless, remained in their original class. In all, a total of 98 (24.8%) of the alien taxa expanded their distribution on Corsica.

From these results, future trends can be extrapolated. Two scenarios are possible (Fig. 6). The first indicates a steady, more or less linear, increase in alien species richness, corresponding to an increase of 68 taxa every 11 years, or 6.2 taxa per year. The second indicates an exponential increase with the same percentages (corresponding to an increase of 18.1% every 11 years). Based on the observations made on Corsica, and elsewhere in Europe (Lambdon *et al.*, 2008), it appears that the second scenario is closer to the truth. Data from the past 30 years shows an accelerating increase in the arrival of alien taxa due to increased

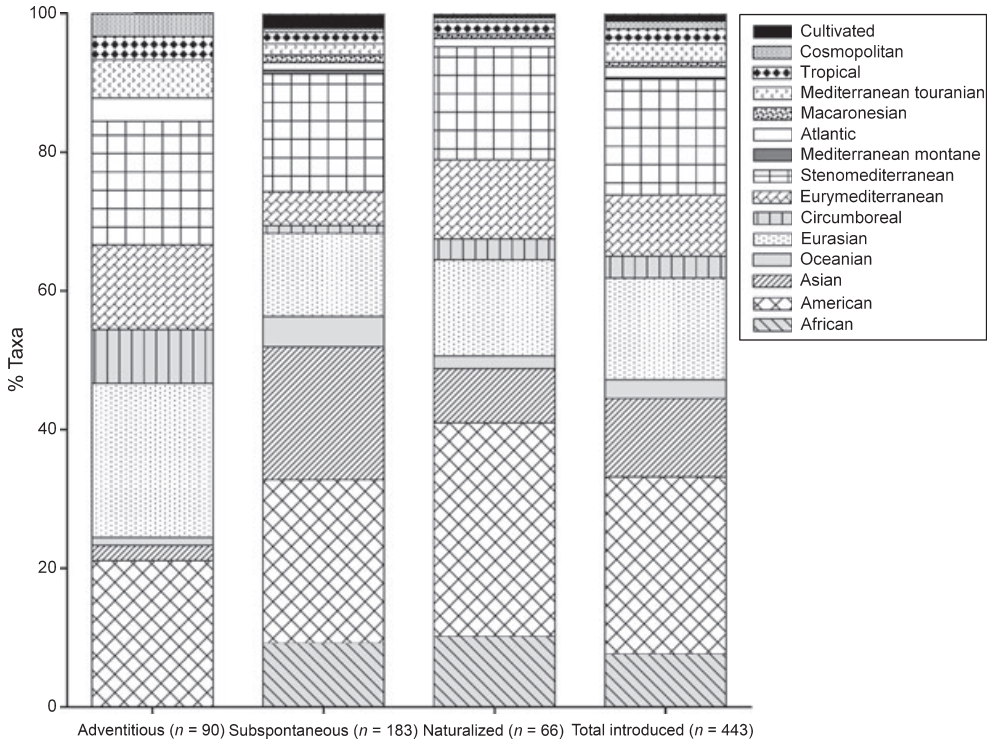

Fig. 5 Biogeographical origin of the alien flora found on Corsica, according to the categories to which they belong.

tourism and trade between the mainland and Corsica.[3] Moreover, this exponential trend is confirmed by the publication of 21 new alien taxa recorded for Corsica since 2007 (Jeanmonod & Schlüssel, 2008, 2010). This equates to a rate of 7 new taxa per year, instead of the predicted 6.2 per year in the first scenario.

The second scenario predicts that, in about a century, the number of alien taxa is expected to exceed the number of native taxa. It is noteworthy that the naturalized group has a faster growth rate in species richness than the casual group. The number of naturalized taxa is predicted to exceed the number of endemic taxa (including sub-endemics) around the year 2040 and to reach the same number as the native plants around the year 2140. The first scenario predicts that it would take 400 years for the number of alien taxa to reach the number of native taxa, and 50 years for the naturalized plants to reach the number of endemics. The reality will probably fall somewhere between the two scenarios, unless serious measures are taken to limit the introduction of new species that are likely to be able to naturalize.

Invasive species

Flora Corsica (Jeanmonod & Gamisans, 2007) highlights 18 taxa that are known to be invasive plants and that should be eradicated and a further 13 potentially invasive taxa that should be removed as a precaution. These 31 taxa represent 7.0% of the alien flora, 1.39% of the native flora, and 1.16% of the whole flora on the island. Among these 31 taxa (Table 5), 12 are already well-established (classified as PF, C or CC) and are therefore likely to pose serious environmental threats. This has already been seen with the Hottentot fig [*Carpobrotus edulis* (L.) N. E. Br.], which sometimes forms a low and very dense vegetation cover in littoral habitats, preventing the development of other species and becoming a direct threat to species such as the very rare, sub-endemic (endemic to Corsica and Sardinia) and endangered *Anchusa crispa* Viv. (Guyot & Muracciole, 1995). Another example is the tree of heaven (*Ailanthus altissima* (Mill.) Swingle) which competes vigorously with native species, especially in xeric ecosystems and disturbed habitats (Kowarik, 1983; Vilà *et al.*, 2006). This species grows rapidly, has strong ability to resprout and has a high dispersion capacity (high production of samaras) coupled with its ability to inhibit competition by producing allelopathic chemicals (Lawrence *et al.*, 1991). *Ailanthus altissima* poses some economic problems (Hu, 1979) through damage done to man-made structures and it affects the taste of the honey as well as causing some health problems (Anon, 2010) such as dermatitis and allergic reactions.

As shown in Table 5, all the invasive taxa that have become common (C) or very common (CC) were reported on Corsica more than 50 years ago. The majority (13 out of 19 or 70%) of the rare (R) or the very rare (RR) taxa have appeared over last 50 years. This indicates that many introduced species require a

[3]According to official statistics (INSEE, 2010), new business start-up grew by 175% between 1997 and 2004, and the quantity of new housing under construction increased by 100%. The Corsican GDP grew 31% in 10 years, and the number of passengers reached 7.8 million in 2009, an augmentation of 400% in the number of ferry passengers between 1997 and 2009!

Table 3 Comparison of the number of alien taxa recorded on Corsica, following studies published 11 years apart (Jeanmonod and Gamisans, 2007; Natali & Jeanmonod, 1996)

Year of publication	1996	2007	Increase
Number of alien taxa	375	443	+18.1%
Number of casual	240	277	+15.4%
Number of naturalized	135	166	+23.0%

Table 4 Comparison over time of the species richness of alien taxa according to their abundance class

			2007						
			D	**RR**	**R**	**LOC**	**PF**	**C**	**CC**
1996	**40**	**D**	**33**	7					
	226	**RR**	2	**205**	14	1	4		
	53	**R**		1	**42**		10		
	13	**LOC**				**4**	7	1	
	30	**PF**					**20**	10	
	14	**C**						**13**	1
	0	**CC**							**0**

In the left columns, the number of taxa in each abundance class in 1996, and on the right, the status of these same taxa in 2007. The framed cells indicate the number of taxa whose status remained unchanged. The grey cells (above the diagonal line) indicate the number of taxa whose status has increased. The white cells (below the diagonal line) indicate the number of taxa whose status has decreased.

certain period of time (latency) before they spread and become more abundant.

With respect to the whole invasive flora of Corsica (Fig. 7), the regression line of the function: 'number of invasive taxa (cumulated) per time unit (years)' indicates that, on average, a new invasive species arrives on Corsica every 8.3 years. However, as with the observations on the alien flora of the island, the curve indicates an exponential rather than a linear tendency. In other words, the length of time between the arrival of new taxa is currently diminishing. It is noteworthy that among the 31 invasive or potentially invasive taxa recorded for Corsica, 10 are already listed as invasive plants in Mediterranean France (Muller, 2004), 14 are listed as such for the whole French territory (Brunel, 2003), and 23 are listed as invasive on a global scale (Weber, 2004).

The majority of these taxa (8 out of 31) are members of the *Asteraceae*, followed by the *Fabaceae* sensu lato (4 *Fabaceae* sensu stricto and 3 *Mimosaceae*). Most of these species have a South African origin (9 taxa), followed by a North American (8 taxa) and then a South American (5 taxa) origin.

Conclusions

The arrival of alien species is a process that has expanded to a global scale. In some cases they have caused serious environmental and/or economic problems. Given rapid evolution of the alien flora it has become an increasingly important component of the analysis of the dynamics of the floras across the World. In many areas, after the invasion by alien species, alpha biodiversity changes and plant communities are affected by changing interactions (especially competition) between the various species, leading to an imbalance in the ecosystem. In some extreme cases these processes have lead to the modification of the landscape or the local disappearance of endemic and/or rare species. Environmental management methods must take this process into account and they may need to become more and more complex over time. The alien flora has become an important component of the wild flora and is a real challenge for the management of the environment in the future. Because this phenomenon is evolving quickly, it is now considered to be one of the most significant threats to European flora (Lambdon *et al.*, 2008).

Importance of the alien flora

Our study indicates that Corsica has a high number of alien taxa (16.5% of the whole flora) compared to other geographical areas (average = 10.3%) with a more or less equivalent surface area and climate. More importantly, the results highlight the rapid and ongoing evolution of the alien flora on the island and indicate that an exacerbation of this process in the future is likely. In addition to the increase of the species richness of the alien flora (+18.1%) over the last 11 years, our results also show an even higher increase of the number of naturalized taxa (+23.0%) and an increase in the abundance of 24.8% of the alien taxa during the same period.

Arrival and spread of the alien flora

The arrival, the penetration axes and the spread of the alien flora on the island, and its impact on the native flora, can be evaluated using several of our findings. Over a third (37.5%) of the alien taxa have become naturalized and are now well-established on the island. Only a small proportion of the alien taxa (8.4%) are not able to establish and disappear from the island after some time. For the remaining 54.1% of the alien taxa, many survive in their arrival localities without showing any signs of spreading, while others show a progressive tendency to increase their abundance indicating a move towards naturalization. The abundance of the alien flora (which represent a potential impact) is quite significant with 68 fairly widespread taxa (15.4% of the alien flora or 3% of the native flora) now known to occur on the island. Although the majority (64.4%) of the alien taxa are classified as very rare (RR), this result is misleading as 61 of them have arrived on the island recently and thus have not yet spread accordingly to their potential. Indeed, 26 of them have been recorded from an increasing number of localities over the last 11 years. As already shown by Natali & Jeanmonod (1996), the localities corresponding to the first records for the alien species are mainly coastal cities (especially Bastia, Ajaccio and Calvi). It seems likely that alien plants first colonize in the surroundings of these coastal cities, then spread to the lowlands and valleys, occupying mainly anthropogenic habitats, and finally they spread into

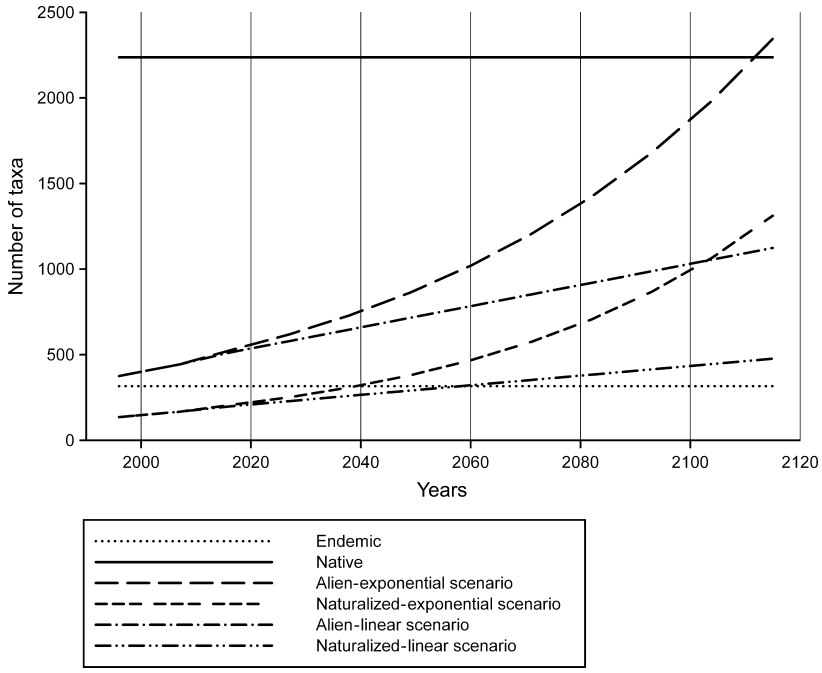

Fig. 6 Projection of two scenarios of the trends of the alien species richness (and also naturalized) compared with the number of native species richness (and also the endemic taxa) on Corsica.

more natural vegetation in lowlands and, it is expected, eventually also at higher altitudes.

The penetration of the alien flora on the island and its potential impact on the native flora can be estimated through assessing the presence of the alien taxa in the various vegetation belts and in the different habitats. Our results show that the alien flora is mainly restricted to lowland vegetation belts, especially the Mesomediterranean one which hosts 83.1% of this flora. However, alien taxa also spread into the Supramediterranean belt (17.4% of the alien flora) and, to a lesser degree, into the montane belt (5.4%). These proportions are similar to those recorded by Natali & Jeanmonod (1996) indicating that there has been no altitudinal increase of the alien species richness. The short time span between the two studies and the dynamic nature of the alien flora means that its spread into the higher altitudinal needs to be monitored and more data acquired before any conclusions can be drawn. A study performed in Switzerland (Becker *et al.*, 2005) showed that many alien species that were initially limited to lowlands have shifted their altitudinal limits upwards over the last decade, and that the maximum altitude reached by each species was significantly correlated to the time elapsed since their introduction. The same general trend is expected for Corsica over the coming years.

One of the interesting features of Corsica, that also may facilitate the control of alien and invasive taxa, is the physical and ecological compartmentalization of the island. The presence of mountain ranges separated by deep valleys and diverse vegetation belts induced by the differing climatic conditions, may prevent the rapid spread of the alien plants. The distribution of the alien taxa in the different habitat types is a good measure of the degree of penetration of these taxa into the natural vegetation. Our results show a lower spread rate into the more or less natural and densely vegetated habitats (such as forests, meadows and grasslands, and bushy and shrubby habitats) than that observed for the same habitats across Europe as a whole. However, the penetration rate is significantly higher than that measured 11 years ago, indicating that the process of colonization is increasing in intensity on Corsica.

Characterization of the alien flora

The characteristics of the alien flora are highlighted by several of our analyses. A predominance of alien taxa are found amongst the *Asteraceae, Poaceae* and *Fabaceae,* especially with regards to naturalized plants. The taxonomic spectrum is close to what has been observed based on the native flora of Corsica as well as on the alien flora of other Mediterranean regions. However, each Mediterranean island demonstrates a different ranking order in the families with alien representatives. This tendency indicates that the intrinsic capabilities of the various species determine their success on a given island, but also that stochastic factors influence the arrival of a new taxon. These two factors are strongly influenced by the transit trade and tourism between the mainland and the islands. In the long term, the differences between islands may fade and the various taxonomic spectra may become more homogeneous, at least if the various abiotic factors are similar (climate, relief etc.). The biological spectrum of the alien flora is markedly different from that of the native flora. The alien flora has a much higher proportion of phanerophytes and chamaephytes (34.8% for both instead of 15%) and a lower proportion of hemicryptophytes. The spectrum on Corsica is quite similar to those found on Sardinia and in the Balearic Islands, particularly with respect to the proportion of phanerophytes and chamaephytes (46% for both in Sardinia and 39% for

Table 5 List of the 31 invasive or potentially invasive taxa recorded on Corsica, with their status (abundance class, type), their geographical origin, and the year of their first record on the island. The list is given in order of their abundance (from high to low) and within these categories from the oldest to the most recent records

Taxon	Abundance class	Type	Origin	First year of observation
Xanthium italicum	CC	Naturalized	North America	1863
Gomphocarpus fruticosus	C	Naturalized	South Africa	1820
Opuntia ficus-indica	C	Naturalized	Neotropics	1834
Carpobrotus edulis	C	Naturalized	South Africa	1877
Robinia pseudoacacia	C	Naturalized	North America	1913
Ailanthus altissima	C	Naturalized	Asia	1931
Cotula coronopifolia	C	Naturalized	South Africa	1954
Bidens frondosa	C	Naturalized	North America	1958
Phytolacca americana	PF	Naturalized	North America	1834
Carpobrotus acinaciformis	PF	Naturalized	South Africa	1978
Helianthus xlaetiflorus	PF	Naturalized	North America	1985
Cortaderia selloana	PF	Naturalized	South America	1989
Nicotiana glauca	R	Naturalized	South America	1900
Senecio angulatus	R	Subspontaneous	South Africa	1979
Cytisus striatus	R	Naturalized	Mesogean region	1985
Solidago canadensis	R	Subspontaneous	North America	1985
Aptenia cordifolia	R	Subspontaneous	South Africa	1988
Cytisus multiflorus	RR	Subspontaneous	Mesogean region	1910
Paraserianthes lophanta	RR	Subspontaneous	Australia	1911
Polygala myrtifolia	RR	Subspontaneous	South Africa	1911
Elide asparagoides	RR	Naturalized	South Africa	1920
Acacia saligna	RR	Subspontaneous	Australia	1977
Araujia sericifera	RR	Naturalized	South America	1977
Acacia dealbata	RR	Naturalized	Australia	1983
Senecio inaequidens	RR	Naturalized	South Africa	1984
Ambrosia artemisiifolia	RR	Adventitious	North America	1987
Acer negundo	RR	Subspontaneous	North America	1988
Sesbania punicea	RR	Subspontaneous	South America	1990
Lonicera japonica	RR	Naturalized	Asia	1990
Buddleja davidii	RR	Naturalized	SE Asia	1991
Myriophyllum aquaticum	RR	Adventitious	South America	1996

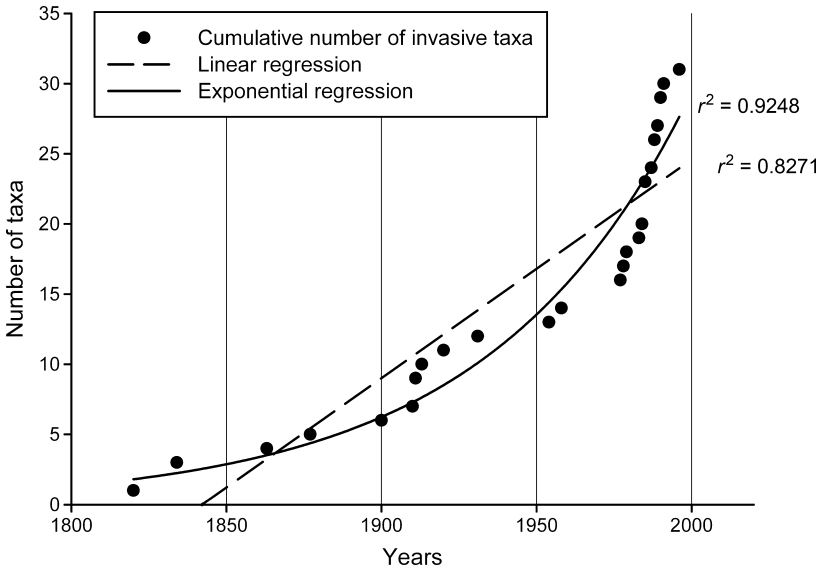

Fig. 7 Cumulative number of invasive taxa per time unit showing the linear regression line (dotted line) and exponential curve (black line).

both in the Balearic Islands), which may reflect a general trend for the Mediterranean islands. The high proportion of phanerophytes and chamaephytes is likely to have a significant impact on the vegetation structure as they both contain many dominant taxa, and the two groups often consist of tall individuals that occupy large volumes.

Invasive plants

Within the alien flora, invasive taxa present a challenge for the maintenance of the native biodiversity. They are therefore of particular interest to conservationists and especially for the 'Conservatoire Botanique de Corse'. Currently, 17 invasive species have been reported on the island. Despite the fact that some of these taxa are not yet widespread, their potential negative impact on the native flora of Corsica should not be underestimated. Some species, such as *Senecio inaequidens* DC., have been monitored and controlled effectively for many years in order to limit their expansion (Paradis *et al.*, 2008). The analysis of the arrival dates of these invasive taxa shows that their number has increased exponentially in recent times. This finding demonstrates that the island is not immune to the threats posed by invasive taxa. Several invasive species that are spreading in other geographical areas, such as *Amorpha fruticosa* L., *Baccharis halimifolia* L., *Impatiens glandulifera* Royle, *Reynoutria japonica* Houtt. and *R. sachalinensis* Nakai, or *Heracleum mantegazzianum* Sommier & Levier, have not yet arrived on Corsica. It is expected that, given the great habitat diversity of Corsica, it is only a matter of time before these species are recorded from the Island.

Future scenarios

The increase in the number of alien taxa on Corsica that has been observed over the last 100 years, and especially over the last 11 years, has led us to propose two scenarios for the future. These scenarios predict that the number of introduced plants will exceed the number of native plants, at best, in 400 years or, at worst, in 100 years. When the same scenarios are applied only to the naturalized group an even higher increase in the number of taxa are shown. The naturalized taxa are expected to exceed the number of endemic (and sub-endemic) taxa in the next 30–50 years. If some of these current or future naturalized taxa behave as invasive plants the increase in them is likely to have a huge impact on the natural vegetation and the biodiversity of the island. An example of this process is the recent arrival of *Ludwigia peploides* (Kunth) P. H. Raven, which is already causing serious management problems on the island (Delage & Hugot in Jeanmonod & Schlüssel, 2008; Spinosi & Delage in Jeanmonod & Schlüssel, 2010). Our scenarios are similar to those proposed by Sala *et al.* (2000) for the year 2100, who indicate that the major risks to biodiversity in the Mediterranean areas are due to biotic exchange.

The dramatic increase of xenophytes is not unique to Corsica, as it has also been observed in other parts of Europe (Lambdon *et al.*, 2008). However, for Corsica, this phenomenon may be linked with the increase of human travel between the island and other geographical regions. Our two scenarios demonstrate that the native species richness being exceeded by the number of xenophytes is perfectly probable. We know that there are already 5789 xenophytes in Europe, out of which many are potentially able to colonize the island. While many of these taxa will pose no threat and will probably integrate into existing plant communities without unbalancing the system, others may become invasive. Indeed, invasive plants can adversely affect the structure and stability of native plant communities as well as threaten native or worse, endemic taxa. One could argue that the introduction of one or two species into an area increases the alpha diversity in that region, but this overlooks the fact that this so-called increase masks a uniformity of the flora at a global level, and finally, in the case of an invasion by an aggressive taxon, the decrease of the species richness.

The results presented here demonstrate that it is very important to strengthen the control of plant introductions, as well as to focus on the monitoring of alien taxa in order to detect the arrival of invasive plants as early as possible. Applying an efficient strategy for rapid eradication of these plants before their establishment and spread is a priority.

Acknowledgements

The authors kindly thank S. Brunel for her careful reading of the text and her constructive comments, and M. Price for checking the English. The authors are also grateful to Y. Naciri for her remarks on the statistical analyses.

Analyse et évolution de la flore allochtone en Corse

Cet article synthétise et analyse une partie des données publiées dans *Flora Corsica* (Jeanmonod & Gamisans, 2007) concernant la partie introduite de sa flore (richesse spécifique, abondance, formes biologiques, étages de végétation, milieux, origine biogéographique). La richesse spécifique de la flore allochtone est élevée et représente 16.5% de la flore corse, dont 37.5% correspondent à des plantes naturalisées. La pénétration de cette flore dans les étages supérieurs s'avère faible, mais celle dans les milieux naturels fermés s'accroît avec le temps. En 11 ans, la progression des xénophytes est forte, avec une augmentation de 18.1% de leur nombre, de 23% du nombre de naturalisées, et de l'abondance de 24.8% des taxons allochtones. Ces résultats permettent de proposer un scénario mettant en évidence les tendances évolutives de la flore introduite avec les enjeux de conservation de la biodiversité indigène que cela implique. Le cas particulier des invasives est également examiné et leur augmentation exponentielle mis en évidence. D'autres aspects comme le spectre taxonomique et les diverses origines biogéographiques sont analysés et plusieurs de ces résultats sont mis en perspective avec les données d'autres régions méditerranéennes comme la Sardaigne, les Baléares,…, ainsi que l'ensemble de l'Europe.

Статус и тенденции в чужеродной флоре Корсики

В статье резюмируются и анализируются некоторые данные, опубликованные во «*Флоре Корсики*» (Jeanmonod & Gamisans, 2007), позволяющие охарактеризовать чужеродную флору сосудистых растений острова. Анализы данных сосредотачиваются на различных

аспектах чужеродной флоры, таких как разнообразие (богатство видов), изобилие, биологические формы, пояса растительности, места обитания и биогеографическое происхождение. Результаты показывают, что богатство чужеродных видов в настоящее время высокое, представляя собой 16.5% всей флоры, среди которой было натурализовано 37.5%. Проникновение этой флоры происходит, главным образом, на более низких высотах, и все еще остается слабым или совсем отсутствует на более высоких поясах растительности, в то время как оно увеличилось со временем в естественно закрытых местах обитания. За последние одиннадцать лет богатство видов ксенотипов увеличилось на 18.1%, что соответствует увеличению на 23% натурализованных растений. Кроме того, 24.8% чужеродных таксонов сильно увеличилось в численности. На основе конкретных результатов предлагается сценарий, выдвигающий на первый план тенденции интродуцированной флоры, включая вопросы сохранения биоразнообразия. Особый случай инвазивных видов также рассматривается, и подчеркивается экспоненциальное увеличение их численности на Корсике. Другие аспекты чужеродной флоры, такие как ее таксономический спектр и биогеографическое происхождение, также были проанализированы и, по мере возможности, сравнивались с таковыми из других географических областей, особенно из Средиземноморья (Сардинии, Балеарских островов) и континентальной Европы.

References

Aeschimann D & Heitz C (2005) Index synonymique de la flore de Suisse. Ed. 2. *Documenta Floristicae Helvetiae* **2**, 323 pp.

Alziar G (1995) Généralités sur la flore de l'île de Chypre. Quelques données quantitatives. *Ecologia Mediterranea* **21**, 47–52.

Anon. (1993) Convention on Biological Diversity. In http://www.cbd.int/doc/legal/cbd-un-en.pdf [accessed on 29 October 2010].

Anon. (2010) Commission suisse pour la conservation des plantes sauvages (CPS). http://www.cps-skew.ch [accessed on 29 October 2010].

Aubin P (1999) *Catalogue des plantes vasculaires du Gard*. Société linnéenne de Lyon et Conservatoire Botanique National de Porquerolles, Villeurbanne (FR).

Bacchetta G, Mayoral García-Berlanga O & Podda L (2009) Checklist of Sardinian exotic flora (Italy). *Flora Montiberica* **41**, 35–61. (in Spanish).

Becker T, Dietz H, Billeter R, Buschmann H & Edwards PJ (2005) Altitudinal distribution of alien plant species in the Swiss Alps. *Perspectives in Plant Ecology, Evolution and Systematics* **7**, 173–183.

Blondel J & Aronson J (1999) *Biology and Wildlife of the Mediterranean Region*. Oxford University Press, Oxford (UK).

Brooks JR, Flanagan LB, Buchmann N & Ehleringer JR (1997) Carbon isotope composition of boreal plants: functional grouping of life forms. *Oecologia* **110**, 301–311.

Brunel S (2003) *Plantes envahissantes de la région méditerranéenne*. Agence Méditerranéenne de l'Environnement, Agence Régionale pour l'Environnement Provence-Alpes-Côte d'Azur (FR).

Conti F, Abbate G, Alessandrini A & Blasi C. (Eds) (2005) *Annotated Checklist of the Italian Vascular Flora*. Libreria Universitaria, Roma (I).

Daget P (1980) Les types biologiques en tant que stratégie adaptative (les thérophytes). In: *Recherches d'écologie théorique. Les stratégies adaptatives* (Eds Barbault R, Blandin P & Meyer J), pp. 89–114. Maloine, Paris (FR).

Gamisans J (1978) La végétation des montagnes corses. 5. *Phytocoenologia* **4**, 377–432.

Gamisans J & Jeanmonod D (1993) Catalogue des plantes vasculaires de la Corse (ed. 2). In: *Compléments au Prodrome de la Flore Corse*. Annexe no 3. (Eds Jeanmonod D & Burdet HM). Conservatoire et Jardin botaniques de la Ville de Genève, Genève (CH): 1–258.

Gauthier A (2001) *La Corse; Une île montagne au cœur de la Méditerranée*. Delachaux et Niestlé, Paris (FR).

Genovesi P & Shine C (2004) *European Strategy on Invasive Alien Species*. Sauvegarde de la Nature 137. Editions du Conseil de l'Europe, Strasbourg (FR).

Girerd B (1978) *Inventaire écologique et biogéographique de la flore du département de Vaucluse*. Société des Sciences Naturelles de Vaucluse, Avignon (FR).

Guyot I & Muracciole M (1995) Inventaires et actions de conservation in situ des plantes rares ou menacées de Corse. *Ecologia Mediterranea* **21**, 231–242.

Hu SY (1979) Ailanthus altissima. *Arnoldia* **39**, 29–50.

INSEE (2010). Institut National de la Statistique et des Etudes économiques. Région Corse. http://insee.fr/fr/regions/corse/default.asp [accessed on 29 October 2010]

IUCN (2000) *IUCN Guidelines for the Prevention of Biodiversity Loss Caused by Alien Invasive Species*. IUCN, Gland (CH).

Jahn R (2003) The phytodiversity of the flora of Kriti (Greece) – a survey of the current state of knowledge. *Bocconea* **16**, 845–851.

Jeanmonod D (2000) Notes et contributions à la flore de Corse, XVI. *Candollea* **55**, 41–74.

Jeanmonod D & Burdet HM (1996–1999) Notes et contributions à la flore de Corse, XII. *Candollea* **51**, 515–557; XIII. *Candollea* **52**, 239–279; XIV. *Candollea* **53**, 171–210; XV. *Candollea* **54**, 385–416.

Jeanmonod D & Gamisans J (2007) *Flora Corsica*. Edisud, Aix-en-Provence (FR).

Jeanmonod D & Schlüssel A (2001–2006) Notes et contributions à la flore de Corse, XVII. *Candollea* **56**, 139–170; XVIII.*Candollea* **56**, 326–362; XIX.*Candollea* **58**, 273–287; XX.*Candollea* **59**, 65–94; XXI.*Candollea* **61**, 93–134;

Jeanmonod D & Schlüssel A (2008) Notes et contributions à la flore de Corse, XXII. *Candollea* **63**, 131–151.

Jeanmonod D & Schlüssel A (2010) Notes et contributions à la flore de Corse, XXIII. *Candollea* **65**: 267–290.

Jeanmonod D, Schlüssel A & Gamisans J (2011) Analyse de la flore Corse. Aspects biologiques. *Candollea* **66**, in press.

Kowarik I (1983) On the naturalization and plant-geographic behavior of the tree of heaven (Ailanthus altissima (Mill.) Swingle) in the French Mediterranean area (Bas-Languedoc). *Phytocoenologia* **11**, 389–405. (in German).

Lambdon PW, Pysek P, Basnou C, Hedja M, Arianoutsou M, Essl F *et al.* (2008) Alien Flora of Europe: species diversity, temporal trends, geographical patterns and research needs. *Preslia* **80**, 101–149.

Larrucea JR & Coll TP (2006) Balearic vascular plant biodiversity. *Orsis* **21**, 41–58. (in Spanish).

Lawrence JG, Colwell A & Sexton O (1991) The ecological impact of allelopathy in *Ailanthus altissima* (Simaroubaceae). *American Journal of Botany* **78**, 948–958.

Loope LL & Mueller-Dombois D (1989) Characteristics of invaded islands with special reference to Hawaii. In: *Biological Invasions. A Global Perspective*. Scope 37 (Eds Drake JA, Money HA, Di Castri F, Groves KH, Kruger FS, Rejmánek M & Williamson M). John Wiley & Sons, New York (US): 257–281.

MacDonald LAW & Cooper J (1995) Why worry about islands? Insular lessons for global biodiversity conservation. In: *Islands: Biological Diversity*

and Ecosystem Function (Eds Vitousek PM, Loope LL & Adsersen H). Springer, Berlin (GE): 189–203.

Mac Neely JA (2001) *The Great Reshuffling: Human Dimensions of Invasive Alien Species*. IUCN, Gland (CH).

Médail F, Roche P & Tatoni T (1998) Functional groups in phytoecology: an application to the study of isolated plant communities in Mediterranean France. *Acta Oecologica* **19**, 263–274.

Molinier R (1981) *Catalogue des plantes vasculaires des Bouches-du-Rhône*. Imprimerie Municipale, Marseille (F).

Muller S (2004) *Plantes Invasives en France*. Museum d'Histoire Naturelle, Paris (F).

Natali A & Jeanmonod D (1996) Flore analytique des plantes introduites en Corse. In: *Compléments au Prodrome de la Flore Corse*. Annexe no 4 (Eds Jeanmonod D & Burdet HM), pp. 1–211. Conservatoire et Jardin botaniques de la Ville de Genève, Genève (CH).

Paradis G, Hugo L & Spinosi P (2008) Les plantes envahissantes: une menace pour la biodiversité. *Stantari* **13**, 18–26.

Raunkiaer C (1934) *The Life Form of Plants and Plant Geography*. Clarendon Press, Oxford (UK).

Richardson DM, Pysek P, Rejmanek MM, Barbour G, Panetta FD & West CJ (2000) Naturalization and invasion of alien plants: concepts and definitions. *Diversity and Distribution* **6**, 93–107.

Sala OE, Chapin FS, Armesto JJ, Below E, Bloomfield J, Dirzo R *et al.* (2000) Global biodiversity scenarios for the year 2100. *Science* **287**, 1770–1774.

Verlaque R, Médail F & Aboucaya A (2001) Valeur prédictive des types biologiques pour la Conservation de la flore méditerranéenne. *Compte Rendu de l'Académie des Sciences*, Paris. Série 3, Sciences de la vie **324**, 1157–1165.

Vilà M & Muñoz I (1999) Patterns of correlates of exotic and endemic plant taxa in the Balearic islands. *Ecologia Mediterranea* **25**, 153–161.

Vilà M, Tessier M, Suehs C, Brundu G, Carta L, Galanidis A *et al.* (2006) Local and regional assessments of the impacts of plant invaders on vegetation structure and soil properties of Mediterranean islands. *Journal of Biogeography* **33**, 853–861.

Weber EF (1997) The alien flora of Europe: a taxonomic and biogeographic overview. *Journal of Vegetation Science* **8**, 565–572.

Weber EF (2004) *Invasive Plant Species of the World. A Reference Guide to Environmental Weeds*. CABI Publishing, Oxon (UK).

Zar JH (1996) *Biostatistical Analysis*. Prentice Hall, New Jersey (US).