An updated inventory of the non-native flora of Sardinia (Italy)

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Abstract
We provide an updated inventory of the non-native flora of the Italian island of Sardinia, including accepted names, family, synonyms, biological form, fruit type, introduction pathway and native origin. This inventory was performed by reviewing the available literature and conducting dedicated field surveys across the entire island. The inventory catalogues 931 non-native taxa, including 31 cryptogenic species, 901 species, 14 subspecies, 13 varieties, two forms and one cultivar. We utilised the position on the introduction–invasion continuum concept and meta-population criterion to further label each species. Based on these frameworks, the non-native flora of Sardinia can be divided into 274 casual, 169 naturalised, 19 invasive, 440 exclusively planted and 29 unobserved after 1950. There are 204 archaeophytes and 727 neophytes. The majority of the non-native species (791) were introduced to the island voluntarily, and 140 species were introduced accidentally. The present inventory identifies 72 additional non-native taxa not previously reported in the literature.

Keywords: Non-native flora, Sardinia, invasive alien plants, pathways, population groups

Introduction
Biological invasions are a primary threat to native biodiversity, and invasive alien plants have particularly adverse impacts on the natural environment, ecosystem services and human livelihood and health (e.g. Hulme et al. 2013). Invasive alien plants are not restricted to human-disturbed habitats but can thrive in natural and semi-natural habitats, including protected areas (Foxcroft et al. 2013). These plants often compete with native species for natural resources, resulting in a reduction in the abundance of native species and, consequently, a loss of genetic diversity (Richardson et al. 1989; Rejmánek et al. 2005; Gaertner et al. 2009). Invasive alien plants can also lead to ecosystem changes by modifying fire regimes (Brooks et al. 2004), soil properties and nutrient fluxes (Gordon 1998; Christian & Wilson 1999; Ehrenfeld 2003). They can also negatively impact agro-ecosystems, decreasing yields and/or product quality and promoting the increased use of plant protection products (Di Tomaso 2000). Invasive alien plants can also cause health problems because many are allergens or are toxic to humans and animals (Laaidi et al. 2003; Celesti-Grapow et al. 2010b).

The adverse effects of invasive plant species are increasingly recognised worldwide. Consequently, information on invasive species and methods to combat them is becoming more readily available on the Internet, in scientific and popular publications, and via special interest groups. Many countries have national or subnational blacklists that identify species whose introduction is prohibited or discouraged due to their potential adverse effects (e.g. Simberloff 2006; Essl et al. 2011). The efficacy of any strategy to address invasive alien plants strictly depends on the information available, and on the sharing of data, knowledge and experience. Information sharing systems may help prevent the introduction and spread of invasive species (Genovesi & Shine 2004), although the environmental effects and behaviour of an invasive alien plant may vary within the invaded range (Kumschick et al. 2015).

Many studies have addressed non-native plant species in Italy at the national and regional levels (e.g. Celesti-Grapow et al. 2009; Stanisci et al. 2010; Comin et al. 2011; Siniscalco et al. 2011; Brundu et al. 2013; Iberite et al. 2013; Vacchiano et al. 2013), frequently as international collaborations (e.g. Lambdon et al. 2008; Signorini et al. 2013). However, the dynamics of plant invasion
and the introduction of non-native species require continuous updating of existing databases. The first step in any national or local strategy to combat invasion is the collection and publication of data indicating the presence of non-native plant species and the position of each species’ population along the introduction–naturalisation–invasion continuum (INIC; Blackburn et al. 2011). This information must then be maintained and updated. Understanding the biological mechanisms that facilitate invasive species introduction and distribution is crucial for the effective management of these species, and thus the biological traits of non-native species must be incorporated into databases and inventories at both the national and regional levels (Celesti-Grapow et al. 2010b). The availability of this basic information is of paramount importance to the application of any prioritisation or risk assessment scheme, such as the EPPO prioritisation plan (Brunel et al. 2010), the Austrian–German GABLIS (Essl et al. 2011), the method proposed by Weber and Gut (2004) and the Australian Weed Risk Assessment (Pheloung et al. 1999), to cite a few. In 2014, the European Union adopted legislation addressing invasive alien species (Regulation EU No. 1143/2014). The backbone of this regulation is a blacklist of harmful invasive species, “Invasive Alien Species of Union Concern”, that are non-native to the EU and that have been identified as invasive by a detailed risk assessment (Genovesi et al. 2015). Species included on this list are subject to automatic, stringent provisions designed to prevent their introduction into the EU, including bans on their import, trade, possession, breeding, transport, use and release in the environment. A key innovation in this legislation is the requirement that each European state assesses the primary pathways of introduction of the listed species into their country and develops an action plan that prevents new, unwanted arrivals by strengthening controls over the intentional and accidental movements of organisms (Genovesi et al. 2015).

Therefore, the primary aims of this research are to (1) provide an updated inventory of all non-native flora in Sardinia, including accepted names, biological traits, region of origin, and time, pathways and purposes of introduction onto the island; (2) categorise all non-native species along the INIC and provide an updated list of regional invasive plant species according to the meta-population criterion (Pyšek et al. 2012) to differentiate invasive and naturalised species; and (3) provide a priority list of candidate species for full pest risk analysis.

Materials and methods

Study area

Sardinia encompasses an area of 24,090 km² and has 1,800 km of coastline, making it the second largest island in the Mediterranean. Its typical Mediterranean climate is characterised by mild, humid winters, hot, dry summers and a long period of aridity each year that, along the coasts, can last up to five months. The average population density is approximately 69 inhabitants per km², with the highest densities in the largest urban areas (i.e. Cagliari and surroundings, Olbia, Sassari, Alghero and Oristano), which are located close to the coast, and considerably lower densities in the rural inner region of the island (ISTAT 2011). Thanks to the island’s geological diversity, its isolated position and its wide range of habitats (Camarda et al. 2011), Sardinia supports a particularly rich array of approximately 2400 flora taxa (Arrigoni 2006–2014) includes naturalised non-native species in this total number but does not indicate the precise number of naturalised species). Among the 2400 species present, 347 are endemic (sensu Arrigoni, cited), 100 are considered threatened and 5 are categorised as narrowly endemic and are among the “Top 50 Mediterranean Island Plants” (Camarda 2005). These last five species are thus critically endangered according to IUCN criteria and thus require strict conservation measures.

Despite its low population density, the anthropogenic impact is quite high across the island due to the significant grazing of farm animals in the wild, widespread agroforestry activities, a dense road network and frequent human-induced wildfires during the summer (Camarda et al. 2010).

Data sources and criteria used to compile the inventory

The most recent studies of the non-native flora of Sardinia were performed by Viegi et al. (1974), Viegi (1993, 2001), Chiappini (1985), Camarda (1982, 1983, 1998, 2001), 109, Camarda and Brundu (2004), Bacchetta et al. (2009), Camarda et al. (2010), Celesti-Grapow et al. (2009, 2010a, 2010b), and Podda et al. (2012). Studies focusing on the impact of non-native plants or single species were performed by Filigheddu et al. (2001), Brundu et al. (1998, 2013), Carta et al. (2004), Carta (2005), Usai et al. (2008), Bacchetta et al. (2010), and Zedda et al. (2010). Cossu et al. (2014) addressed non-native weeds in irrigated crops of Sardinia. We also considered all other available data sources on the
flora of Sardinia that also included information on non-native plants, including Fara (1570 publ. 1838), Moris (1827–1829, 1837–1859), Angius (1838), Gennari (1874), Barbey (1884), Terracciano (1914–1938), Mola (1916, 1919a, 1919b), Martinoli (1942–1956 in Viegi 1993), Pignatti (1982), Chiappini (1985), Viegi (1993), Achenza (1995), Perra (1997), Camarda (2001), Virdis (2002), the six volumes of the flora of Sardinia by Arrigoni (2006–2014), Bacchetta et al. (2009), Celesti-Grapow et al. (2010b), Mastino and Zucca (2011), and Podda et al. (2012). The data from the literature were verified during dedicated field surveys conducted since 2000 (Brundu et al. 2003) and annual monitoring of the entire island. These surveys and monitoring efforts were conducted to confirm both the presence and persistence of the non-native species reported in the literature and to detect the presence of new species. Specimens were collected whenever possible and preserved in a dedicated section at the herbarium of the University of Sassari (SS).

The earliest literature to discuss non-native flora of Sardinia is Plinius’ Naturalis Historia (Pliny the Elder, Natural History). Plinius described Castanea sativa as a common tree of Sardinia, and Fara considered it native. In his Opus Agriculturae (V Century), the Latin writer Rutilius Palladius (landowner in the Sinis region in Sardinia) describes the cultivation of Citrus, most likely Citrus limon or C. medica (Perra 1997; Mastino & Zucca 2011).

The nomenclature used in the inventory follows Arrigoni (2006–2014) and Celesti-Grapow et al. (2009, 2010a, 2010b) and has been cross-checked in four online databases, i.e. The International Plant Names Index (2014), The Plant List (2013), the African Plants Database (2014) and the World Checklist of Selected Plant Families (WCSP 2014). These databases were also used to collect synonyms for the accepted names. Family names follow Christenhusz et al. (2011b) for ferns, Christenhusz et al. (2011a) for gymnosperms and APG III (Haston et al. 2009) for angiosperms.

Following Pyšek et al. (2004, 2012), Celesti-Grapow et al. (2009, 2010a, 2010b) and Blackburn et al. (2011), the non-native (alien) species included in the present inventory are those species whose presence in Sardinia is due to intentional or unintentional human involvement and those that arrived in Sardinia without human involvement from an area where they were also non-native (e.g. from Corsica). Following Carlton (1996), we use the term cryptogenic (doubtful aliens) to denote those species whose status is undefined due to a lack of information.

We classified non-native species according to their position along the INIC, which describes how species invade an area by overcoming geographical, environmental and biotic barriers (Richardson et al. 2000, 2011; Richardson & Pyšek 2006; Blackburn et al. 2011; Pyšek et al. 2012). Based on this concept, we used the terms casual, naturalised and invasive to describe each species’ invasion status. Invasive species are a subset of naturalised species; they form self-replacing populations over many life cycles, produce reproductive offspring, often in very large numbers at considerable distances from the parent and/or site of introduction and have the potential to spread over long distances. In addition to this definition, we applied the meta-population criterion described in Pyšek et al. (2012) to separate invasive species from naturalised species based on the historical population dynamics of the studied taxa. Therefore, to classify a species as invasive, we analysed the species’ reproduction and survival in relation to its historical trend. This analysis permitted the differentiation of species that survived in a single or a few populations with-in a spatially restricted area from those that spread and formed meta-populations over large areas across Sardinia.

Similar to Natali and Jeanmonod (1996), our inventory also lists those non-native species present only as cultivated species, particularly those that are considered the most commonly used species in Sardinian gardens, recreational open facilities, forest plantations, landscaping and/or soil protection. Although Jeanmonod et al. (2010) distinguish non-native casual species from Corsica as “adventitious” and “subspontaneous”, we use only one category to identify all casual species (sensu Celesti-Grapow et al. 2009, 2010a, 2010b).

Non-native species were also classified as archaeophytes or neophytes if they were introduced before or after 1500 A.D., respectively. Plant traits, i.e. Raunkiaer’s life forms (Raunkiaer 1934; Camarda 1989), and fruit type were obtained from the literature and field observations. Selected sources for these data include Flora Europaea (Tutin et al. 1968–1980), Flora d’Italia (Pignatti 1982), The European Garden Flora (Cullen et al. 1986–2000) and online databases such as JSTOR (2000–2014) and the Plant Traits Database – TRY (Boenisch & Kattge 2011–2013).

We collected all available information on introduction pathways. In particular, we distinguish between voluntary and accidental introductions, and in the cases of voluntary introductions, we list the primary reasons for introduction (e.g. crop, forestry or ornamental). We consider 6 main pathways of introduction, as defined by Hulme et al. (2008) and Hulme (2009): release, escape, contaminant, stowaway, corridor or unaided. In Sardinia, the last two are generally pathways of secondary release rather than of first introduction.
Results

Number of taxa, residence time and native range

The inventory of Sardinia’s non-native flora comprises 931 taxa, of which 900 are considered non-native and 31 are cryptogenic. This total number includes 901 species, 14 subspecies, 13 varieties, two forms and one cultivar (hereafter referred to interchangeably as “entities” or “species”). In terms of residence status, 204 species are archaeophytes and 727 are neophytes (Table I). All species are listed alphabetically in a table provided in the supplementary material together with data on their family, residence time, invasion status, native range and primary reference sources.

Table I. Non-native plant species categorised by residence time and invasion status in Sardinia. Thirty-one cryptogenic species (all doubtful archaeophytes, with 24 naturalised and 7 casual species) are included in the totals.

| No. | Non-native species | Not recorded since 1950 | Exclusively cultivated | Casual | Naturalised | Invasive | Archaeophytes | Not recorded since 1950 | Exclusively cultivated | Casual | Naturalised | Neophytes | Not recorded since 1950 | Exclusively cultivated | Casual | Naturalised |
|-----|-------------------|----------------------|-----------------------|--------|-------------|----------|--------------|----------------------|-----------------------|--------|-------------|----------|----------------------|-----------------------|--------|-------------|
| 931 | 900 | 29 | 440 | 274 | 169 | 19 | 204 | 12 | 23 | 98 | 71 |
| 727 | 417 | 17 | 176 | 117 | 17 | 417 | 17 | 23 | 417 | 176 | 117 |

Table II. Classification of the non-native flora s.s. of Sardinia into population groups (PG 1-18) based on Pyšek et al. (2012); the number of species is given in parentheses. The codes in the first column (B3, C2, C3, D1, D2, E) refer to the categorisation of population types addressed in Figure 1 and Table 1 in Blackburn et al. (2011). Population groups are clustered into the three main invasion classes, i.e. casual, naturalised and invasive species. The scheme also separates taxa introduced unintentionally (contaminant, stowaway), marked “none” in the Cultivation column, from those introduced deliberately.

(a) Not self-sustaining (B3, C2)

- (a1) None: PG1: casual (33)
- (a2) Past: PG3: casual (4)
- (a3) Ongoing: PG4 & 5: casual (218 & 19)

(b) Self-sustaining (C3, D1, D2)

- (b1) None: PG7: naturalised (21)
- (b2) Past: PG9: naturalised (1)
- (b3) Ongoing: PG11: naturalised (44)

(c) Meta-populations (E)

- (c1) None: PG13: naturalised (77)
- (c2) Past: PG15: naturalised (6)
- (c3) Ongoing: PG17: naturalised (13)

Total species (482) 270 4 162 7 – 19

Species that are cultivated only (440) are the most numerous non-native flora in Sardinia, accounting for 47.3% of the total (Table I). There are also 274 casual species, 188 naturalised species and 29 species for which there are no recent records.

Of the 204 archaeophytes, casual species are most numerous (98); 71 are naturalised, 23 are exclusively cultivated and 12 lack recent records. The majority...
of the 727 neophyte species are exclusively cultivated (417), 176 are casual, 117 are naturalised and 17 have not been recorded since 1950.

When we exclude the 440 exclusively cultivated species and those unobserved after 1950 (29) and apply Pyšek’s categorisation scheme (2012) to naturalised and casual species (462 species in total, Table II), we conclude that the majority of the species analysed (218) belong to population group 4 (PG04), i.e. they are introduced species without self-sustaining population or individuals that have an ongoing connection to cultivation but failed to establish upon introduction. Therefore, these species rely on continued input of propagules from planted/cultivated populations. They are typically planted as garden ornamentals, and planted populations and wild populations are very closely linked. The second largest group is PG13 (77 species), i.e. species with invasive meta-populations that have no link to cultivation and which are established on the island but are not increasing. PG13 is followed by PG11 (44), i.e. species with self-sustaining isolated populations that have an ongoing link to cultivation and are established but have not spread; PG 1 (33), i.e. introduced species without a self-sustaining population or a link to cultivation that failed to establish on the island; and PG 7 (21), i.e. species with a self-sustaining isolated population and no link to cultivation that are established but have not spread. All other species were classified as follows: PG05 (19), PG17 (13), PG18 (11), PG12 (7), PG14 (6), PG15 (6), PG03 (4), PG 16 (2) and PG09 (1), (Table II).

This analysis allows us to identify each species’ position along the INIC (Pyšek et al. 2012) as follows: 440 exclusively cultivated, 29 unobserved after 1950, 274 casual (PG01, 03, 04, 05), 169 naturalised (PG07, 09, 11, 13, 15, 17) and 19 invasive (PG14, 16, 18) (Table II).

Notably, the 19 non-native invasive species belong to 3 different population groups: PG14 – Arctotheca calendula, Elesine indica, Oxalis articulata, Oxalis pes-caprae, Senecio inaequidens, Solanum sisymbriifolium; PG16 – Ailanthus altissima, Asclepias fruticosa; and PG18 – Acacia mearnsii, Acacia saligna, Agave americana, Agave fourcroydes, Amorpha fruticosa, Carpobrotus acinaciformis, Carpobrotus edulis, Cortaderia selloana, Eichhornia crassipes, Opuntia ficus-indica, Pinus halepensis.

PG14 includes neophytes that became invasive following unintentional introduction. PG16 includes neophytes that continue to spread but whose naturalisation and invasion were supported by more intensive planting in the past. Finally, PG18 includes both neophytes and archaeophytes that are currently spreading and have been supported by planting throughout their invasion history, including currently.

Due to the small number of invasive species compared to the total, invasive species are included among naturalised species in the results (e.g. Figures 1 and 2) and discussion, unless otherwise specified. Furthermore, the term non-native flora s.s. (in the narrow sense) is used to indicate the subset of all non-native flora in Sardinia (931 species), which are casual, naturalised and invasive species (462 species).

**Taxonomy**

Of Sardinia’s 931 non-native species, 3 are pteridophytes, 47 are gymnosperms and 881 are angiosperms, which are in turn divided into 704 dicotyledons and 177 monocotyledons. Sardinia’s non-native flora include 121 families and 522 genera. The families with most non-native species are Fabaceae (67), Asteraceae (63), Poaceae (46), Solanaceae (38), Cactaceae (32), Rosaceae (30), Asparagaceae (29) and Amaranthaceae (28) (Figure 2). The families Fabaceae, Asteraceae and Poaceae also represent the largest groups of naturalised species. Twenty-five Poaceae species are naturalised, followed by 19 Asteraceae and 17 Fabaceae species. The family Amaranthaceae has the fourth largest number of naturalised species (14). Among Italian non-native flora, Asteraceae and Poaceae include the most non-native flora species and naturalised species (Celesti-Grapow et al. 2009).

The most highly represented genera are Eucalyptus (15), Amaranthus (14), Acacia (13), Aloe (12), Ficus (11) and Pinus (11). The genera with highest number of naturalised species are Amaranthus (9), Papaver (7), Oxalis (6), Setaria (6), Acacia (5) and Agave (5). Eucalyptus (10), Ficus (9), Aloe (8), Citrus (7), Opuntia (7), Cereus (7), Pelargonium (6) and Artemisia (6) are the genera with the highest number of exclusively cultivated species on the island (Figure 1).

**Life forms and fruit types**

Most of Sardinia’s non-native species are perennial (720); 179 species are annual, and the other 32 include 11 biannual species and 21 that are both annual and perennial. Of the non-native flora s.s., 288 are perennial, 150 are annual, 9 are biannual and 15 are both annual and perennial.

Of the 931 non-native species of Sardinia, phanerophytes are most numerous (399), followed by therophytes (176), hemicyrptophytes (81), nano-phanerophytes (81), chamaephytes (78), geophytes (65), hydrophytes (9) and helophytes (7). The group “others” comprises species that can have more than one life form, such as those that can be both hemicyrptophytes and therophytes (35) (Figure 3).
Non-native flora of Sardinia (Italy)

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including exclusively cultivated taxa. Bacchetta et al. (2009) listed 51 species that had not been reported previously; one year later, Celesti-Grapow et al. (2010b) added seven species, followed by Podda et al. (2012), who contributed 16 more species. The present inventory identifies 72 additional records not previously reported in the literature.

Native range, pathways of introduction and main uses

The majority of the non-native species in Sardinia originally came from the Americas (271) and Eurasia (268). In total, 152 species originated in Africa, 71 in the Mediterranean region, 68 in Australasia (Australia and/or New Zealand) and 58 in other tropical regions. Among the total species, 25 are widely distributed on more than one continent, 16 have garden origins and two belong to other geographical areas. These values and those for the non-native flora s.s. are reported in Table III.

The majority of Sardinia’s non-native species (791) were introduced voluntarily, and 140 species were introduced accidentally; 330 and 132 non-native flora s.s. were introduced voluntarily and accidentally, respectively.

Of the 791 species introduced voluntarily, 551 were introduced as ornamental plants, 174 as crops (species cultivated for the production of forage, fruit, fibre, dye or drugs) and 66 for forestry (plantation forestry, reforestation, sand dune stabilisation or soil protection; Figure 6).

All 399 phanerophytic non-native flora were voluntarily introduced, primarily for ornamental purposes (71%), forestry (16.5%) or as crops (12.3%). By contrast, 47.7% of the non-native therophytes were introduced accidentally, while 37.5% were introduced voluntarily as crops. Only 14.8% of

Cumulative number of non-native species in Sardinia

A cumulative plot of the records of non-native species in Sardinia is presented in Figure 5 based on the most important contributions addressing casual, naturalised and only planted species. The first records considered are those from Moris (1827–1829, 1837–1859), who listed 170 non-native entities; Gennari (1874), who listed 190 additional entities; Barbey (1884), who added 12; Terracciano (1914), who added 13; Martinoli (1942–1956 in Viegi 1993), who added 78; Pignatti (1982), who added 65; Chiappini (1985), who added 48; and Arrigoni (2006–2014), who in his six volumes added 209 new species

The most common fruit types are capsule (270), berry (134), drupe (66), achene (63), cypsela (59), carypsis (46), cone (including aryl) (44), follicle (43), nutlet (30) and siliqua (19); 94 entities have other, less frequent fruit types (Figure 4).
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No plants that live rooted in soil are capable of natural transport without considerable risk and a strong probability of destruction (Good 1931). The human-mediated dispersal of species to regions beyond their normal range (i.e. introduced or non-native organisms) has considerably impacted global biodiversity, particularly in the last few centuries (112).

The present phenomenon is an accentuation of an ancient trend that began with the development of agriculture and human migration. Consequently, it can be difficult to distinguish archaeophytes from truly native plant species. In Sardinia, isolation has long been a major barrier to the introduction of new species. However, modern means of transport have overcome this barrier, and the island is now subject to invasion trends very similar to those occurring on mainland Italy and elsewhere in Europe.

The 931 non-native plant species in Sardinia listed in the present inventory include a total of 462 species representing the Sardinian non-native flora s.s. (i.e. casual, naturalised and invasive species). This figure includes 45.2% of the total non-native flora listed by Celesti-Grapow et al. (2009) for Italy (including the islands of Sicily and Sardinia). The total number of non-native entities in Sardinia (931) is considerably high, particularly when compared with the 443 non-native flora identified in Corsica (Jeanmonod et al. 2010), despite Corsica’s smaller area and population.

As in Italy nationally, the majority of non-native species were introduced to Sardinia after 1500 A.D.; however, the percentage of archaeophytes among non-native flora in Sardinia (21.8%) is more than double that calculated for all of Italy (10%).

Of the neophytes, 57.3% are exclusively cultivated species, whereas 11.3% of the archaeophytes are exclusively cultivated. However, 35% of archaeophytes are naturalised, while only 16.1% of neophytes are naturalised in Sardinia.

Origin status (i.e. native vs. non-native) is, of course, important not only with respect to floras...
occur in human-made habitats, knowledge of their ecology may enable the identification of their potentially native habitats in the Sardinian landscape prior to human influence.

As remarked by Pyšek et al. (2012), the native ranges of many archaeophytes are not known or are highly uncertain, and some archaeophytes are regarded as non-native throughout their known global range. These taxa, termed anecophytes or homeless plants (Thellung 1925; 114; Scholz 2007), may be cultivated plants that escaped to the wild or plants that co-evolved with human land uses such as agriculture (Pyšek et al. 2012 and references cited therein). These plants include the 7 species of the genus *Papaver* recorded in Sardinia.

Phanerophytes and nano-phanerophytes are the most common life forms in Sardinia. Their abundance is the result of many ancient and recent voluntary introductions of trees and shrubs for many different purposes. Phanerophytes continue to be introduced as fruit crops (e.g. *Prunus* sp.pl.), for ornamental purposes (e.g. *Acer* sp.pl., *Platanus* sp.pl., *Polygala myrtifolia*, *Sesbania punicea*, *Juniperus sinensis*, *Myoporum insulare*), for forestry (e.g. *Acaia* sp.pl., *Eucalyptus* sp.pl., *Pinus* sp.pl.) and for multiple other purposes (e.g. soil protection, landscaping and recreational uses). The most prominent increase in the number of tree species and hybrids introduced for forestry occurred in the last century.

Table III. Native ranges of non-native flora species within Sardinia (No.) and species of non-native flora s.s. (s.s. indicates casual, naturalised, invasive species).

| Region                        | No. (s.s.) | No. |
|-------------------------------|------------|-----|
| Asia                          | 157        | 71  |
| Europe                        | 63         | 33  |
| Eurasia                       | 53         | 37  |
| Total Eurasia                 | 273        | 141 |
| North America                 | 83         | 42  |
| Central America               | 62         | 24  |
| South America                 | 101        | 39  |
| North and South America       | 25         | 20  |
| Total America                 | 271        | 125 |
| Africa                        | 52         | 20  |
| Macaronesia                   | 19         | 10  |
| Southern Africa               | 89         | 45  |
| Total Africa                  | 160        | 75  |
| Mediterranean                 | 71         | 50  |
| Australasia                   | 69         | 19  |
| Old tropics                   | 15         | 12  |
| New tropics                   | 13         | 1   |
| Tropics                       | 16         | 10  |
| Total tropics                 | 44         | 23  |
| Widely distributed            | 25         | 20  |
| Garden origin                 | 16         | 8   |
| Others                        | 2          | 1   |
| Non-native total              | 931        | 462 |

Figure 7. Pathways of introduction (primary introduction and secondary release) in Sardinia.

Notes: R = release; E = escape; C = contaminant; S = stowaway; CR = corridor; U = unaided.

and inventories (Pyšek et al. 2004; Blackburn et al. 2011) but also for legislative, nature conservation (van Leeuwen et al. 2001) and management purposes. The other formal distinction, between natives and archaeophytes (or archaeophytes and neophytes), i.e. residence status, is generally very difficult to determine and relies on a combination of palaeobotanical, archaeological, ecological and historical evidence (Preston et al. 2002, 2004; Pyšek et al. 2004). Accumulating palaeobotanical and palaeoecological evidence is improving the precision and the determination of species’ residence status in Sardinia (Sabato 2014; Sabato et al. 2015; Ucchesu et al. 2015) and elsewhere (Pyšek et al. 2002; Froyd & Willis 2008; Gillson et al. 2008). Habitat is also an important criterion for determining whether a species is an archaeophyte or neophyte in Sardinia. Because many archaeophytes now only occur in human-made habitats, knowledge of their ecology may enable the identification of their potentially native habitats in the Sardinian landscape prior to human influence.

As remarked by Pyšek et al. (2012), the native ranges of many archaeophytes are not known or are highly uncertain, and some archaeophytes are regarded as non-native throughout their known global range. These taxa, termed anecophytes or homeless plants (Thellung 1925; 114; Scholz 2007), may be cultivated plants that escaped to the wild or plants that co-evolved with human land uses such as agriculture (Pyšek et al. 2012 and references cited therein). These plants include the 7 species of the genus *Papaver* recorded in Sardinia.

Phanerophytes and nano-phanerophytes are the most common life forms in Sardinia. Their abundance is the result of many ancient and recent voluntary introductions of trees and shrubs for many different purposes. Phanerophytes continue to be introduced as fruit crops (e.g. *Prunus* sp.pl.), for ornamental purposes (e.g. *Acer* sp.pl., *Platanus* sp.pl., *Polygala myrtifolia*, *Sesbania punicea*, *Juniperus sinensis*, *Myoporum insulare*), for forestry (e.g. *Acaia* sp.pl., *Eucalyptus* sp.pl., *Pinus* sp.pl.) and for multiple other purposes (e.g. soil protection, landscaping and recreational uses). The most prominent increase in the number of tree species and hybrids introduced for forestry occurred in the last century.

**Position in the introduction–invasion continuum and main population groups**

Although many introduced non-native species are arguably innocuous, some are extremely harmful
(111), and others can simultaneously bring many benefits and cause substantial environmental harm. These qualities frequently lead to conflicts over how non-native species should be managed. For example, the impacts of invasive alien trees increase over time as invasions spread, and societal perceptions of the value of non-native species also change as understanding grows and values shift (e.g. Dickie et al. 2014; van Wilgen & Richardson 2014). These general rules apply to Sardinian non-native flora as well. For example, Robinia pseudo-acacia and Eucalyptus sp.pl. are alien trees appreciated by bee-keepers because they increase honey production.

In a previous non-native flora list for Sardinia, Camarda et al. (2010) reported the presence of 41 invasive species. In the present inventory, which follows the methodology elaborated by Pyšek et al. (2012), only 19 species are considered invasive, i.e. 2% of the total number (931) and 4.1% of the narrower set of non-native flora s.s. The lower number of invasive species compared to Camarda et al. (2010) reflects the more conservative approach espoused by Pyšek et al. (2012), which considers only species that are currently spreading as invasive. Many of the species ranked as invasive in the previous assessment (e.g. agricultural weeds such as Amaranthus sp.pl.) invaded all available habitats in the past and have consequently reached a post-invasive, stable status, i.e. they are not invading new habitat types, and their abundance may even be decreasing within currently invaded areas. Of course, this stable, post-invasive state does not imply that these species do not continue to have negative impacts. Therefore, even though they are identified here only as naturalised, they may still be defined as invasive according to the Convention on Biodiversity or after a full risk assessment procedure (e.g. according to art. 5 of the Reg EU No. 1143/2014). The small number of invasive species identified here does not indicate that Sardinia’s problems with invasive plants are diminishing; rather, the opposite is true, as recent spectacular outbreaks (e.g. Eichhornia crassipes) indicate.

The 19 non-native species categorised here as invasive belong to 3 different population groups (14, 16, 18), and they are predominantly neophytes (only one, Pinus halepensis, is an archaeophyte). In fact, PG14 includes neophytes that became invasive following unintentional introduction. PG16 includes neophytes that are still spreading, but whose naturalisation and invasion was supported by more intensive planting in the past. Finally, PG18 includes both neophytes and archaeophytes that are currently spreading and have been supported by planting throughout their invasion history, including currently. These species were primarily introduced for ornamentation, forestry or multiple purposes.

The presence of native populations of Pinus halepensis in Sardinia is questionable. Those that are considered doubtful natives are quite restricted and can be found mainly in the south-west (Camarda & Valsecchi 2008). Nevertheless, this species was extensively used for afforestation in Sardinia during the twentieth century. These forests were planted in a variety of habitat types, some of which are clearly beyond the natural distribution of P. halepensis, as recognised today. Furthermore, the seed sources that were used for these plantations were mostly exotic, genetically different from the local variety and, in many cases, of unknown origin. The use of Pinus brutia in Sardinian forest plantations and for other purposes complicates the general scenario, as the two species can hybridise. The expansion of P. halepensis from plantations into adjacent natural sites, some of which are of high conservation importance, is becoming a frequent occurrence not only in Sardinia but in several areas across the Mediterranean (e.g. Lavi et al. 2005). This expansion is consequently an important environmental issue and a source of debate among foresters and nature conservationists. The pine expansion is clearly related to the extensive use of P. halepensis for afforestation, but our understanding of the factors that determine the intensity and dynamics of this process is certainly inadequate. Similar considerations apply to Pinus pinea.

Abundant information is also available on the negative impacts of the 19 invasive species identified in this study, both in Sardinia and in other parts of the Mediterranean basin; however, full pest risk analyses are available only for a few of the species (e.g. for Eichhornia crassipes). Therefore, specifically assessing the risks related to all invasive, naturalised and casual species observed in Sardinia using standard methods for prioritisation, risk assessment and analysis should be prioritised (EPPO Pest Risk Analysis, Australian Weed Risk Assessment) and implemented according to the requirement of EU Regulation No. 1143/2014.

Our research demonstrates that the number of non-native species listed in the primary literature sources for Sardinia has continuously increased, and new species are being introduced at a rapid rate for very different purposes. We therefore emphasise the importance of supporting legislation dedicated to invasive alien species, along with the implementation and use of voluntary codes of conduct for various sectors. These voluntary, soft regulatory tools will not replace any statutory requirements under international or national legislation; rather, they should be considered complementary to legislation. The principles in the Code of Conduct for Horticulture and Invasive Alien Plants published by the Council of Europe and the European Codes of Conduct for Botanic Gardens on Invasive Alien Species and for Forest Plantations and Invasive Alien Trees could...
certainly promote the more responsible use of non-native plant species on the island of Sardinia.

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