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The alien vascular flora of Linosa (Pelagie Islands, Strait of Sicily): update and management proposals

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Abstract: This paper provides an up-to-date overview of the naturalized alien plants of Linosa (Pelagie Archipelago, Sicily), which includes 83 taxa and accounts for 29 % of the total island's flora. Among these plants, 6 are invasive, 49 are naturalized and 28 are casual. With respect to previous available data, our field investigations resulted in the addition of 31 new xenophytes (21 casual and 10 fully naturalized). One of these species is new to the whole European territory (*Kleinia anteuphorbia*), 6 of them are new to Sicily and 11 are recorded for the first time on circum-Sicilian islets. For each alien plant, we indicate the habitat where the naturalization has been observed by using the codes proposed by Natura 2000 and Corine Biotopes habitat classification. We also provide a list of 159 alien plants that are cultivated in Linosa, but currently not naturalized, in order to underline the key role played by horticulture and gardening in the introduction of exotic species. In order to address this phenomenon and its huge impact on the integrity of both the natural and the traditional rural landscape, several actions are proposed that aim at preventing, controlling and monitoring both the ongoing and the potential invasion processes.

Key words: Mediterranean islands, risk assessment, vegetation ecology, landscape planning, agroecosystems, black lists, *Agave attenuata*, *Boerhavia coccinea, Campsis radicans*, *Hylocereus undatus*, *Plumbago auriculata*, *Portulaca grandiflora*, *Portulacaria afra*

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Introduction

Invasive plant species are a growing problem of global concern due to their long-lasting negative effects on native ecosystems, such as the degradation of native plant communities and natural habitats through direct competition with native species and the homogenization of landscapes (Williamson 1996). Although plant invasion is a globally widespread phenomenon that affects almost all ecosystem types, certain habitats seem to suffer the negative consequences more than others (Chytrý & al. 2009). For instance, frequently disturbed and nutrient-enriched sites are widely acknowledged to be particularly prone to invasion by alien plants. However, in such ecological contexts, the negative consequences of invasions may be underestimated, as these areas are already considered degraded from an environmental point of view. However, anthropogenic sites may be only the first and necessary

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stage preceding the invasion of natural habitats in the surrounding areas. Hence, also these disturbed sites should be constantly monitored and studied.

Islands, particularly smaller ones, represent a peculiar case. In fact, the high seasonal pressure of tourists, combined with the ecological fragility of insular biota, makes island ecosystems particularly prone to the establishment and spread of invasive alien species (Gimeno & al. 2006). Furthermore, the endemism rate on islands, which island biogeography theories predict and numerous field evidences confirm to be generally higher than in comparable continental areas, enhances the likelihood that rare or threatened species will be affected by invasion, leading to significant ecological impacts. As they are also geographically confined areas, islands are ideal places to successfully implement effective protection of invasion, as well as for control and eradication strategies to tackle the problem. Hence, insular ecosystems represent preferential areas to investigate both causes and consequences of biological invasions in natural environments (Hulme & al. 2008). Mediterranean island ecosystems seem not to be an exception to this pattern. Although they have not reached the levels of concern recorded on many oceanic islands such as Hawai'i, a growing number of invasive alien plants has been found in the Mediterranean realm in the last decades (e.g. Lloret & al. 2005). The increasing awareness and the large relevance of the problem is further demonstrated by several EU LIFE projects, already completed or still ongoing in the Mediterranean area, which include some specific actions aimed at controlling and eradicating invasive alien plants (e.g. LIFE11+ NAT/IT/000093 Pelagic Birds; LIFE08 NAT/IT/000353 Montecristo 2010).

In Italy, after the recent inventory of the non-native flora published by Celesti-Grapow & al. (2009, 2010), an increasing number of reports on alien species point out the increasing frequency of invasion cases both at the national (Nepi & al. 2009) and regional (Galasso & Banfi 2010) level. This trend has concerned both peninsular and insular territory. However, there is a stark difference in the level of available information between islands of different sizes. A number of studies have investigated plant invasion in the largest Mediterranean islands (Lavorel 1999; Lloret & al. 2005; Lambdon & Hulme 2006; Hulme & al. 2008; Lambdon & al. 2008; Vilà & al. 2008; Bacchetta & al. 2009; Podda & al. 2012; Lazzaro & al. 2013), whereas little is known about small and medium-sized islands (Pasta & La Mantia 2008; La Mantia & al. 2009a; Pretto & al. 2010; Domina & Mazzola 2011; Lastrucci & al. 2012), especially when they are less affected by human impacts.

A good representation of this scenario may be the island of Linosa, a small (5.4 km^2) volcanic island, belonging to the Pelagie Archipelago in the Strait of Sicily, where the increasing spread of alien plants has also been a consequence of the progressive abandonment of agriculture (Pasta & al. 2015). In fact, the abandonment of many cultivated lands has made ecological niches available to the successful establishment of alien plant species. *Nicotiana glauca* Graham is a good example of an invasive alien plant particularly able to exploit areas released from agricultural activities (see http://www.pelagicbirds.eu). Despite the fact that the flora and vegetation of Linosa have been surveyed since the 19th century, including the alien component, a comprehensive assessment of alien flora has never been carried out. In this paper, an updated checklist of all the alien plants occurring in Linosa is provided for the first time. The taxa are recorded as cultivated, casual, naturalized or invasive, according to the standardized classification of Richardson & al. (2000). Semi-quantitative information about the abundance and the local level of invasiveness is also given for each taxon.

The systematic collection and subsequent elaboration of data, arising both from the literature and specific field surveys, had two goals:

(1) providing an initial, overall picture of the alien flora of a small Mediterranean island that may represent an essential reference point to evaluate future trends as well as temporal and spatial invasion dynamics for each taxon;

(2) suggesting the most suitable management options for the control of the worst invasive species, taking into account their current distribution as well as the most likely future trends.

The main aim of this research is to find out an effective strategy in order to reduce the future impacts of plant invasions on Linosa island.

Material and methods

Census and mapping

The field data on the presence and distribution of alien plant species were collected as part of two projects. The first set of data was acquired in 2009 (June), 2010 (June) and 2011 (July) during college internships for undergraduate biologists and naturalists, promoted and carried out by the cultural association *For-Mare* (for details see http://www.for-mare.eu/). The island was cartographically divided into square sectors with 500 m sides, within which non-native flora was carefully surveyed while walking along the main roads as well as the secondary streets (and other places including footpaths, surroundings of private gardens and residential areas; private areas, either fenced or not, in which the plants were clearly planted, were not considered). Within each sector the frequency of each taxon was estimated using the following semi-quantitative scale: C = common species, occurring all over the island's territory in anthropogenic sites; F = frequent species, but with some distribution gaps; S = sporadic species, infrequent, but whose occurrence should not escape the eye of an expert; R = rare species, whose presence is localized and could escape even the eye of an expert; RR = very rare species, hardly noticeable except

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through a thorough reconnaissance, present in 1 or 2 sites with a few individuals. During field surveys, a satellite Global Positioning System (GPS) and a personal digital assistant (PDA) with the application ArcPad® were used to verify the sector to which the surveyed area belonged.

During the spring of 2013, specific field surveys were carried out on the island in order to record in a systematic way, using geo-referenced data, the distribution of nuclei (areas or lines) of *Nicotiana glauca* and *Carpobrotus* cf. *acinaciformis* (L.) L. Bolus, which are target species of a specific action under the Project LIFE11+ NAT/IT/000093 Pelagic Birds (*Conservation of the main European population of* Calonectris d. diomedea *and other pelagic birds on Pelagic Islands*) (Badalamenti & al. 2016). Analogous field surveys were carried out in the following years, until the summer of 2016. The presence and distribution of all alien plant species observed was recorded, assessing the invasive status and the frequency by adopting the same method described above. Furthermore, in order to implement the overall database of cultivated alien plants on Linosa island, other systematic surveys were carried out in the surroundings of private gardens and cultivated lands.

Identification and taxonomic treatment of the surveyed taxa

For the classification of alien plants, *Flora d'Italia* (Pignatti 1982) and *Flora europaea* (Tutin & al. 1964–1980, 1993) were mainly consulted. As they are outdated works, they do not always allow the adequate identification of alien taxa. Hence, dichotomous keys and descriptions of international Floras were also accessed, such as *Flora of North America* (http://floranorthamerica.org/), *Flora of China* (http://efloras.org) and *Flora New South Wales* (http://plantnet.rbgsyd.nsw.gov.au/floraonline.htm), as well as other specific monographic contributions (e.g. Shaw 2008; Verloove 2008; Ward 2008). The consultation of *European garden flora* (Walters & al. 1984, 1986, 1989; Cullen & al. 1995, 1997, 2000) also allowed the identification of many taxa that had escaped from cultivation. The taxonomic-nomenclatural treatment of plant names largely follows Conti & al. (2005) and Celesti-Grapow & al. (2010).

Assessment of invasive status

In the present work, in contrast to what is reported in related studies at the national and regional level (e.g. Celesti-Grapow & al. 2009, 2010; Galasso & Banfi 2010), the term alien is used to refer not only to the plants that are alien to the Italian flora (neophytes, archaeophytes and cryptogenic species), but also to taxa that are considered to be native in other regions of Italy, whose voluntary or accidental introduction to Linosa has been confirmed on the basis of floristic works concerning the island; they were named as "locally alien" (see the following section). Information about residence time was acquired mainly from Celesti-Grapow & al. (2009), while cryptogenic species in Linosa were considered only those reported at national level in Banfi & Galasso (2010).

The invasive status of each alien plant was assessed, distinguishing those taxa exclusively occurring under cultivation from those more or less established within the local ecosystems, which were indicated as casual, naturalized or invasive in accordance with the classification of Richardson & al. (2000). The assessment of invasive status is based on the information issuing from the field surveys, the consultation of regional and national bibliographic works, of the GISD (http://www.iucngisd.org/gisd/) and the DAISIE (http://www.europe-aliens.org/) websites, which are the main databases concerning invasive species at the global and European levels, respectively. Finally, the potential impact of each taxon on local natural and semi-natural ecosystems was assessed strictly considering the chance of establishment, spread and effective inter-specific competition of each alien species with the local flora of Linosa, and taking into account the specific climatic and microsite characteristics of this small Mediterranean island. To do this, available literature on the invasive behaviour of the considered species was thoroughly checked, paying special attention to records and papers concerning the Mediterranean realm. The economic (current or potential) impact of such alien plants as agricultural or street weeds was not taken into account.

Bibliographic research

In order to find all the alien plant species up to now recorded as growing wild in Linosa, the available literature was consulted. Much of the published information on the alien flora of Linosa derives from papers focused on species that are locally employed for agricultural and ornamental purposes (Hammer & al. 1997; Domina & Mazzola 2008), and from a note recently published by Domina & al. (2013). The originality of the data collected in the field was also checked against the most up-to-date checklists of the vascular flora of Linosa (Di Martino 1961; Brullo & Siracusa 1996b; Pasta 2002; La Mantia & al. 2009a) and taking into account the plants quoted in the most recent papers on the island's vegetation (Di Martino 1958; Maugeri & al. 1979; Brullo & Piccione 1980; Brullo & Marcenò 1985; Brullo & Siracusa 1996a).

Results

Overall, 83 non-native plants were found to be growing in the wild in Linosa. Among them, 28 were casual (21 of which are new to the island), 49 were naturalized (10 of which are new) and 6 were invasive (all of which were already recorded; Table 1 in Supplementary Material online). A list of 159 non-native taxa that are strictly confined to cultivation, with no currently recorded signs of

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naturalization, is provided in Table 2 in Supplementary Material online. About one third of the alien plant species were presumed to have been accidentally introduced in the island, while the remaining two thirds were deliberately introduced for the following purposes: (1) ornamental (44.6 %) (plants used in private and public green areas); (2) agricultural services (8.4 %) (plants used to make hedges or to produce tools and equipment); (3) food or medicinal (7.2 %) (especially fruit trees and aromatic plants); (4) forest or hydrological (7.2 %) (mostly trees planted for afforestation). Currently, local natural habitats of community interest according to the Habitats Directive 92/43CE appear to be only marginally affected by the spread of invasive alien species (Table 3 in Supplementary Material online).

It should be noted that the plant communities that are more adapted to the peculiar and adverse pedoclimatic conditions of Linosa, apart from being the richest in terms of species of high biogeographical and conservation value, were found to be less prone to invasion by alien plants. Among them, pseudo-steppe with grasses and annuals of the *Thero-Brachypodietea* (Habitat 6220), thermo-Mediterranean and pre-desert scrub (Habitat 5330) and low formations of *Euphorbia* close to cliffs (Habitat 5320) are the most representative cases. Abandoned terraced fields and fallows, characterized by a slightly lower number of taxa of biogeographical and/or conservation value than the three aforementioned habitats, were found to host 3–5 times more exotics; a similar pattern, though less pronounced, was found in the island's arable lands. Furthermore, chasmophytic vegetation of volcanic rock outcrops belonging to Habitats 8220 and 8320 seem to be quite vulnerable to plant invasion. It also should be pointed out that heavily degraded sites, such as quarries and waste landfills, as well as urban and suburban areas, have high susceptibility to invasion and are home to as many as 52 of the 83 total alien species, thus accounting for 62.7% of the overall alien flora of Linosa.

Discussion

A diachronic comparison of the main floristic checklists of Linosa allowed us to appreciate the increasing number of casual, naturalized or invasive alien plants, probably due to stronger research effort during the recent field investigations specifically focused on them. In fact, only 17 alien species were reported by Di Martino (1961), then the number increased slightly to 25 (Brullo & Siracusa 1996b) and 32 (La Mantia & al. 2009a), until reaching today's number of 83 taxa. This is a rather high value, as these species account for 29 % of the whole island's flora. In Sicily, the alien flora represents 8.5 % of the total vascular flora (Celesti-Grapow & al. 2010), while the national average reaches 13 % (Celesti-Grapow & al. 2009). The value for Linosa is also high in comparison to similar Mediterranean islands. For example, no island within the Tuscan Archipelago gets close to this value (with a mean value of about 10 %), and only the island of Elba, about 44 times larger than Linosa, displays a higher absolute number of naturalized alien plants (Lazzaro & al. 2014). However, the share of invasive species in the alien flora of Linosa is lower, reaching 7.2 %, compared with the average of 22 % in the Tuscan Archipelago (Lazzaro & al. 2014) and the national average, which reaches almost 16 % (Celesti-Grapow & al. 2010). This result suggests that a high portion of the island of Linosa is covered by habitats with low invadability, but it cannot be entirely ruled out that many of the ongoing invasive processes are still at an early stage and may spread much further across the island. Moreover, some alien species showed, in a relatively short time frame, a large increase in their natural distribution. For example, *Boerhavia coccinea* Mill., a well-known South African herb invader of cultivated fields and urban areas, is rapidly spreading through abandoned lands on the Sicilian coast. The first spontaneous individuals of *B. coccinea* were observed on Linosa in 2006; in just 10 years this alien species has gone through a rapid range expansion, and within two years it had invaded almost all the main roads of the island and successfully established in several cultivated fields, especially prickly-pear orchards.

It should be noted that the large increase in the number of alien species recorded (a 2.5-fold increase in less than 10 years) could be attributed to the increased attention paid to biological invasions in recent years and the lack of previous investigations focused on the alien flora of Linosa. Also, it illustrates that in many small-island cases, where similarly detailed studies have not been conducted, current statistics for invasive species may be considerably underestimated. Our survey seems to support the higher vulnerability of small Mediterranean island ecosystems to invasion by exotic plants than that observed in adjacent continental areas or on the main islands, as already highlighted by Pasta & La Mantia (2013). Of 83 alien species reported here, 31 are new to Linosa. Among them, 6 species [*Agave attenuata* Salm-Dyck, *Campsis radicans* (L.) Bureau, *Hylocereus undatus* (Haw.) Britton & Rose, *Plumbago auriculata* Lam., *Portulaca grandiflora* Hook. and *Portulacaria afra* Jacq.] are new for the alien flora of Sicily. Another eleven [*Boerhavia coccinea*, *Erythrostemon gilliesii* (Wall. ex Hook.) Klotzsch, *Ipomoea indica* (Burm.) Merr., *Kalanchoë daigremontiana* Raym.-Hamet & H. Perrier, *Leucaena leucocephala* subsp. *glabrata* (Rose) Zárate, *Opuntia stricta* (Haw.) Haw., *Parthenocissus* cf. *quinquefolia*, *Phoenix canariensis* Chabaud, *Pittosporum tobira* (Thunb.) W. T. Aiton, *Tagetes erecta* L. and *Trichocereus spachianus* (Lem.) Riccob.] are new to the circum-Sicilian islands. Of particular interest is the finding of *Kleinia anteuphorbia* (L.) Haw., as this is the first record of this species in the whole of Europe (see Greuter 2006+). This succulent species, native to Morocco (northern Africa), is sporadically cultivated for ornamental purposes in Sicily and is absent from all other

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circum-Sicilian islands (see Domina & Mazzola 2008), while it is quite frequently used by the inhabitants of Linosa. The small detected nucleus probably originated from the abandonment of pruning residues; pruning is a cultural practice to improve plant re-sprouting. Although this could be an isolated case of casual naturalization, constant monitoring and the evaluation of demographic trends are recommended as precautionary management options.

With regards to other rare alien species in the circum-Sicilian islands, *Datura wrightii* Regel, already reported in Linosa by Hammer & al. (1997) and actually very common on the island, was also observed on Lampedusa island (G. Parolo pers. obs.). *Erysimum cheiri* (L.) Crantz is still present on the island of Salina (S. Pasta pers. obs.), where it had been previously reported only by Lojacono-Pojero (1878). Finally, the importance of finding spontaneous individuals of *Kalanchoë daigremontiana* must be stressed, as its spread may have been previously overestimated due to the hybrid *K.* ×*houghtonii* D. B. Ward, as recent reports of this nothospecies on other Mediterranean islands (Podda & al. 2012; Lazzaro & al. 2013) and along the European Atlantic coast (Silva & al. 2015) would suggest. The marked ability to thrive in dry habitats and prolific and effective reproduction via leaf-borne vegetative propagules make *K. daigremontiana* very likely to spread in the near future. Also of particular interest is the finding of *Hylocereus undatus* growing wild at different sites on the island. This cactus species, native to tropical America, has never been reported in Sicily, and in Italian territory is otherwise solely found in Sardinia (Lazzeri & al. 2013). In Sicily, individuals of the congener species *H. triangularis* (L.) Britton & Rose had escaped from cultivation and been previously observed (Mazzola 1981).

In Linosa, a total of 242 alien plant species, 83 naturalized and 159 only cultivated, were recorded. This is a huge number if compared to that of the native flora, which includes 283 specific and infraspecific taxa (La Mantia & al. 2009a; Domina & al. 2013). It therefore seems evident that the massive introduction of ornamentals, especially in private gardens, is one of the main causes of the recent invasion by exotic species (Table 3 in Supplementary Material online). Our research shows that nearly 45 % of the alien plant species were intentionally introduced for their aesthetic value in Linosa. This is also a general trend as the incidence of such species among invasive taxa is widely recognized to be quite high (e.g. Reichard & White 2001; Foxcroft & al. 2008). For most of the non-native, cultivated species, it appears to be very difficult to predict whether or not they will be able to spread in the wild in the future and whether they will eventually compete with the native flora and threaten local biodiversity (Williamson 1996), as the invasiveness of a species is particularly influenced by local dynamics (Pino & al. 2013). However, in other cases, it is likely that the natural spread of some alien species is just a matter of time. It is on these species that most of the management and control strategies should be focused, in order to intervene as promptly as possible, thus significantly increasing the chances of success in tackling invasive species (Myers & al. 2000). For example, *Senecio angulatus* L. f., hitherto only present in cultivation, is likely to escape to the wild as it is fairly common in Mediterranean climate areas and has shown a considerable increase in its level of diffusion in island ecosystems (Celesti-Grapow & al. 2016), including Sicily (E. Badalamenti pers. obs.).

In this regard, it is highly desirable to set a limit to the uncontrolled introduction of alien taxa, particularly those introduced for afforestation or rehabilitation purposes, such as *Acacia* sp., *Pinus halepensis* Mill. and *Tamarix canariensis* Willd., or autochthonous species such as *Spartium junceum* L. (Cardinale & al. 2010) or other tree species that have already shown considerable invasive potential both regionally [e.g. *Acacia saligna* (Labill.) H. L. Wendl. (Bazan & Speciale 2002), *Ailanthus altissima* (Mill.) Swingle (Badalamenti & al. 2012), *Melia azedarach* L. (Badalamenti & al. 2013) and *Parkinsonia aculeata* L. (Bazan & al. 2011)] and in circum-Sicilian islands [e.g. *Acacia cyclops* A. Cunn. ex G. Don (Pasta & al. 2012; Badalamenti & al. 2014) and *Anredera cordifolia* (Ten.) Steenis (Rossitto & Ilardi 2000; Pasta & al. 2016)]. *Leucaena leucocephala* subsp. *glabrata* and *Vachellia karroo* (Hayne) Banfi & Galasso are two other non-native woody species that, while showing only early signs of naturalization on the island, need to be carefully monitored in light of their incipient invasiveness in Mediterranean Europe (e.g. Dana & al. 2003) and in other Mediterranean-type ecosystems (O'Connor 1995). Plants alien to Linosa but native elsewhere in the Mediterranean basin should also be subject to the same precautionary measures. It is in fact very likely that the establishment and spread of species such as *Chamaerops humilis* L. (Ardenghi & Mossini 2013; Buono & Manni 2013), *Arbutus unedo* L., *Nerium oleander* L. and *Phillyrea latifolia* L. may alter the structure, composition and physiognomy of the local vegetation in the medium and long term.

Conclusions

Based on the results presented here, Linosa appears to be particularly prone to invasion by non-native plant species, not only due to substantial introductions for ornamental and horticultural purposes, but also as a consequence of the increasing availability of ecological niches linked to the growing abandonment of traditional agricultural practices. In fact, nutrient-rich, abandoned sites are especially exposed to invasion by several alien pioneer species, while the linear structures (dry-stone walls, terraces and prickly-pear hedges) connected with local, traditional cultures often seem to represent a preferential path for exotic species, whose invasive success is known to be facilitated by the availability of disturbed, moist and shady microhabitats.

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It appears urgent to start an intense, awareness-raising campaign addressed to the local community about the issue of biological invasions and their possible impacts on local natural heritage. In our opinion, the sharing of certain clear rules on alien species introduction and trade is the only way to ensure that the planned and/or expected monitoring activities of the non-native flora, as well as control and eradication interventions of the invasive taxa, such as those carried out within the aforementioned project LIFE Pelagic Birds, are not frustrated by their prompt reintroduction (Dehnen-Schmutz & al. 2007). With this aim, a clear legislative reference is the recent EU Regulation No. 1143/2014, including provisions aimed at preventing and managing the introduction and spread of invasive alien species. The data presented here underline the need to integrate the policies aimed at the protection and management of natural resources with those related to the preservation, enhancement and possible recovery of local cultivation practices and farming systems, which appear at risk today (La Mantia & al. 2012, 2013). This is particularly relevant in the context of Mediterranean islets, which are often characterized by patches of extensive crops, resting crop areas or fallows, which often represent a useful niche for several species of particular biogeographic and/or conservation interest (Brullo & Marcenò 1980, 1985; Brullo 1983; La Mantia & al. 2011). The need for integrated management has been emphasized by Pretto & al. (2010) in similar microinsular contexts and has been recognized within the management plan of the Site of Community Importance ITA040001 *Isola di Linosa* (designated as Special Area of Conservation ITA040001 *Isola di Linosa* after the adoption of effective conservation measures) and Special Protection Area ITA040013 *Arcipelago delle Pelagie-Area marina e terrestre*, where the key role of Mediterranean agroecosystems (La Mantia & al. 2009a, b) in the conservation of native biodiversity is adequately stressed. The succession processes after land-abandonment should be counteracted by means of dedicated incentives in support of agricultural activities, such as rewarding those farmers who adopt and preserve the local germplasm (Di Lorenzo & al. 2010; Guidi & al. 2013; Sottile & al. 2013). This could help make Linosa a reserve for the preservation of cultivated germplasm, as was already proposed twenty years ago by Hammer & al. (1997).

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