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The Role of Alien and Native Weeds in the Deterioration of Archaeological Remains in Italy[1]

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Abstract: Plants growing on ancient buildings and archaeological remains pose a severe threat to their conservation. Controlling such weeds is costly, and the use of herbicides may lead to serious ecological problems. We surveyed 20 archaeological sites in Mediterranean Italy and estimated the relative effect of alien and native weeds on archaeological remains on the basis of their abundance, frequency, and danger index (DI), which is a measure of the potential damage that each species can cause to buildings and remains. DI is assessed according to plant morphology, vigor, and life-form. The results show that, although alien plant species are potentially harmful, as revealed by their significantly higher DI, they rarely grow on remains, whereas native plants thrive. Despite human disturbance and abundant propagule supply, factors that generally enhance the establishment of aliens, the flora growing on archaeological remains was relatively resistant to alien invasion. Among the aliens observed, only tree-of-heaven turned out to be relatively harmful. Although this invasive tree is not frequent on remains, it is expected to become more widespread on them, as areas surrounding archaeological sites become increasingly urbanized.

Nomenclature: Tree-of-heaven, *Ailanthus altissima* (Mill.) Swingle #[3] AILAL.
Additional index words: Biodeterioration, invasion resistance, Mediterranean Basin.
Abbreviations: DI, danger index.

INTRODUCTION

Most studies on alien plant invasion deal with severe effect on the recipient habitat (see e.g., Brundu et al. 2001; Child et al. 2003). However, new insights may be obtained by analyzing those systems upon which aliens have less effect, seeking to understand, for instance, why such communities are less vulnerable to invasion (Levine et al. 2003). This study therefore was aimed at investigating a case of relative resistance to nonnative plants: archaeological remains in Mediterranean Italy.

Archaeological sites in the Mediterranean Basin are often of great artistic and historical value and play an important role in the tourist industry. Plants present a severe threat to their conservation mainly because of their roots, which induce chemical, as well as mechanical, deterioration (Caneva and Altieri 1988; Lisci et al. 2003). Despite considerable efforts to keep them clear, many ancient remains in Italy (buildings, ruins, walls, artifacts, statues, columns, etc.) are colonized by vigorous and abundant vegetation, which is very rich in species. Control of these weeds—defined, after Rejmánek (1995) as "plants growing where they are not wanted"—has posed serious economic and environmental problems, consequent upon the use of herbicides, and eradication of persistent species, if possible, would be an extremely difficult and costly goal.

Although troubling for archaeologists, flora growing on ruins has interested botanists for centuries. Early research consisted of compilation of lists of species, whereas more recent studies have focused on relating different groups of species to site characteristics, such as urbanization, type of use and intensity of human disturbance (see e.g., Caneva et al. 2003).

There is general agreement in the literature on the role of disturbance in alien plant invasion (Alpert et al. 2000; Davis et al. 2000; Hobbs and Huenneke 1992; Rejmánek 1989). Disturbance on archaeological remains is frequent, mostly related to repeated mowing and weeding through the year to remove plants and keep the sites clear. It is also widely accepted that successful establishment of aliens is positively related to propagule pressure

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[3] Letters following this symbol are a WSSA-approved computer code from *Composite List of Weeds*, Revised 1989. Available only on computer disk from WSSA, 810 East 10th Street, Lawrence, KS 66044-8897.

(Kolar and Lodge 2001; Williamson 1996). Innumerable historical records testify that archaeological sites have for thousands of years been centers of introduction of exotic plants (see e.g., De Bérenger 1859). Three phases of plant introduction can be identified: (1) during ancient Roman times, species were brought from newly conquered territories and planted as ornamentals around monuments (Follieri 1975); (2) after the fall of the Roman Empire, abandoned ruins were surrounded by orchards, vineyards, and vegetable gardens. In these cultivations, alien crops and medicinal healing herbs were planted, and alien weeds were accidentally introduced (Caneva et al. 2003); and (3) from the beginning of restoration work and archaeological surveys in the 19th century to the present day, the sites have become an increasingly important source of income for the tourist industry, and new ornamental aliens have been used to adorn and shade tourist sites.

Thus, because of both frequent disturbance and intense alien propagule import, archaeological remains would be expected to be rich in invasive alien species. However, floristic studies have drawn attention to the fact that there is a relative lack of alien plants on ancient remains (Anzalone 1951; Celesti-Grapow 1995; Lisci 1997), although there has been little research up to date on plant invasion in archaeological sites.

As a contribution to this little-investigated field, this study examined the role of aliens in the invasion of archaeological remains in Mediterranean Italy, comparing the relative effect of alien and native weeds on ancient remains on the basis of their frequency, abundance, and danger index (DI) (Signorini 1996), which is a measure of the potential damage that each species can cause to remains.

MATERIALS AND METHODS

During a 1-yr survey (2001), we recorded the flora of twelve 1-ha-sized plots located in large archaeological sites in Mediterranean Italy, ranging from Tuscany (the most northerly was Ansedonia, 42°24′29″N; 11°17′1″E) to Campania (the most southerly was Paestum, 40°24′22″N; 15°0′6″E). The data from eight 1-ha plots previously sampled using the same methodology (Celesti-Grapow and Blasi 1998) in the cities of Cagliari (39°12′56″N; 9°6′41″E), Ancona (43°37′6″N; 13°30′31″E), and Rome (41°58′11″N; 12°29′44″) were added to the data set. Out of this total of 20 plots, 10 were selected in the city of Rome. Each plot was surveyed once in all three main vegetative seasons: spring, summer, and autumn. All spontaneously occurring plant species were recorded, both alien and native. Following Richardson et al. (2000b) and Pyšek et al. (2004), we regarded as alien "a plant taxa whose presence in a given territory is because of intentional or accidental introduction as a result of human activity." We classified the invaded habitats into two groups: (1) habitats typically found on archaeological remains (walls, ruins, artifacts, statues, and columns) where disturbance takes the form of frequent mowing and weeding and (2) habitats of recent man-made origin (gardens, trampled areas, paths for visitors, and deposits of material close to excavations or restoration work) where human effect is higher because trampling, digging, and soil disturbance are added to mowing and weeding. The occurrence and abundance of each species in the two habitat groups were recorded. As a measure of abundance, we estimated the percentage ground cover of each species on remains. The DI, developed by Signorini (1995) and applied to the flora of various remains of historical importance in Italy (Corbetta et al. 2002; Signorini 1996), was used to evaluate the potential threat of each species to the conservation of archaeological remains. A DI index, ranging from 0 to 10, was assessed for each species on the basis of plant and root features using information contained in published floras and databases, herbarium material, and direct measurement of collected specimens. The DI index is obtained as the sum of (1) root morphology: assigned to a species as a value from 0 to 2, according to its shape and size (e.g., taking into account the presence of taproots and root depth); (2) plant vigor: assigned as a value ranging from 0 to 2; and (3) plant life form: a value ranging from 0 to 6 assigned, respectively, as annual, biennial, perennial herb, subshrub, shrub, vine, and tree.

To compare the relative threats posed by alien and native weeds to archaeological remains, we used the 498 species recorded in the 20 plots, grouped according to their alien or native origin, as independent variables. The DI, abundance (mean percentage cover), and frequency in the habitats typically found on remains were used as dependent variables. To test the difference of DI and abundance in the two groups of species, alien and natives, we applied t test for independent samples. To test the difference of habitat frequency in the two groups, we applied the Kolmogrov–Smirnov test (Kendall 1963), a nonparametric test that takes into account both the mean values and the distribution of the data, particularly useful for comparing asymmetric data such as frequency data. The nomenclature of the species in this study follows Anzalone (1994, 1996).

Table 1. Alien species recorded in the 20 sample plots in archaeological sites in Mediterranean Italy.

Species	Common name	DI[a]	Abundance[b]	Frequency on remains[c]	Frequency on man-made habitats[d]	Invasion status[e]	Residence status[f]	Life-form[g]
Acer negundo L.	Boxelder	8	3.5	2	5	nat	neo	t
Actinidia chinensis Planch.	Kiwi fruit	5	—	0	1	cas	neo	c
Ailanthus altissima (Mill.) Swingle	Tree-of-heaven	10	9.0	6	12	inv	neo	t
Albizzia julibrissin Durazz.	Silk tree	10	—	0	1	cas	arch	t
Alcea rosea L.	Hollyhock	4	—	0	2	nat	arch	p
Amaranthus albus L.	Tumble pigweed	2	—	0	1	inv	neo	a
A. blitoides S. Watson	Prostrate pigweed	2	—	0	4	inv	neo	a
A. cruentus L.	Red shank	3	—	0	3	inv	neo	a
A. deflexus L.	Perennial pigweed	1	—	0	18	inv	neo	a
A. hybridus L.	Smooth pigweed	3	—	0	13	inv	neo	a
A. retroflexus L.	Redroot pigweed	3	—	0	16	inv	neo	a
A. viridis L.	Slender pigweed	2	—	0	5	inv	neo	a
Apium leptophyllum (Pers.) F. Muell.	Wild celery	1	—	0	1	nat	neo	a
Artemisia verlotiorum Lamotte	Mugwort	5	—	0	6	inv	neo	p
Arundo donax L.	Giant reed	4	—	0	7	inv	arch	p
Aster squamatus (Spreng.) Hieron.	Swamp aster	2	1.0	1	16	inv	neo	a
Avena sativa L.	Oats	1	—	0	2	inv	arch	a
Bromus willdenowii Kunth	Rescue grass	3	—	0	3	nat	neo	p
Broussonetia papyrifera (L.) Vent.	Paper-mulberry	7	—	0	3	nat	neo	s
Chamaesyce maculata (L.) Small	Milk purslane	2	—	0	7	inv	neo	a
C. nutans (Lag.) Small	Eyebane	1	—	0	1	nat	neo	a
C. prostrata (Aiton) Small	Hairy creeping milkweed	2	—	0	2	inv	neo	a
Chenopodium ambrosioides L.	Mexicantea	2	—	0	2	inv	neo	a
Conyza bonariensis (L.) Cronquist	Hairy fleabane	4	—	0	16	inv	neo	a
C. canadensis (L.) Cronquist	Horseweed	4	—	0	2	inv	neo	a
C. sumatrensis (Retz.) E. Walker	Tall fleabane	4	1.0	1	19	inv	neo	a
Coronopus didymus (L.) Sm.	Swinecress	2	—	0	1	inv	neo	a
Cupressus sempervirens L. (seedling)	Italian cypress (seedling)	8	1.0	1	1	cas	arch	t
Datura stramonium L.	Jimsonweed	3	—	0	1	inv	neo	a
Dichondra micrantha Urb.	Dichondra	4	—	0	6	nat	neo	p
Duchesnea indica (Andrews) Focke	Indian mock-strawberry	4	—	0	1	cas	neo	p
Echinochloa crus-galli (L.) P. Beauv.	Barnyardgrass	2	—	0	1	inv	arch	a
Eleusine indica (L.) Gaertn.	Goosegrass	2	—	0	13	inv	neo	a
Erigeron karvinskianus DC.	Mexican daisy	2	2.5	4	4	nat	neo	a
Eucalyptus camaldulensis Dehnh.	Murray red gum	7	—	0	1	cas	neo	t
Galinsoga ciliata (Raf.) S.F. Blake	Hairy galinsoga	1	—	0	6	inv	neo	a
G. parviflora Cav.	Smallflower galinsoga	1	—	0	1	inv	neo	a
Ipomoea purpurea (L.) Roth	Tall morningglory	4	4.0	1	2	nat	neo	a
Ligustrum lucidum Mill.	Glossy privet	6	5.0	1	4	inv	neo	t
Lonicera japonica Thunb.	Japanese honeysuckle	5	2.0	1	2	nat	neo	c
Lycium chinense Mill.	Chinese desert thorn	5	—	0	1	nat	neo	s
Lycopersicon esculentum Mill.	Tomato	1	—	0	3	cas	neo	a
Mirabilis jalapa L.	Common four-o'clock	2	—	0	6	cas	neo	p
Oxalis articulata Savigny	Pink oxalis	5	—	0	9	nat	neo	p
O. dillenii Jacq.	Dillen's oxalis	2	1.0	2	15	inv	neo	p
Papaver rhoeas L.	Corn poppy	1	1.0	1	13	inv	arch	a
Parthenocissus quinquefolia (L.) Planch.	Virginia-creeper	8	7.5	2	10	nat	neo	c
Paspalum dilatatum Poir.	Dallisgrass	3	—	0	1	inv	neo	p
P. distichum L.	Knotgrass	2	—	0	1	inv	neo	p
Passiflora coerulea L.	Siergrenadella	5	2.0	1	1	cas	neo	c
Pennisetum villosum R. Br.	Feathertop	2	1.0	1	1	nat	neo	p
Phalaris canariensis L.	Canarygrass	1	1.0	1	2	inv	neo	a
Phytolacca americana L.	Common pokeweed	4	—	0	9	inv	neo	p
Pinus pinea L. (seedling)	Umbrella pine (seedling)	6	1.0	1	1	cas	arch	t
Platanus × *hispanica* Mill. ex Münchh.	London plane	6	5.0	1	2	inv	neo	t
Robinia pseudoacacia L.	Black locust	10	3.0	1	15	inv	neo	t
Senecio inaequidens DC.	Canary weed	3	—	0	1	inv	neo	a
Veronica persica Poir.	Persian speedwell	1	—	0	5	inv	neo	a
Xanthium spinosum L.	Spiny cocklebur	2	—	0	2	inv	neo	a
X. strumarium L.	Common cocklebur	3	—	0	4	inv	neo	a

[a] DI, danger index (Signorini 1995), is a measure of the potential damage that each species can cause to buildings and remains by growing on them. It ranges from 0 to 10 and is assessed according to plant morphology, vigor, and life-form.

[b] Abundance is measured as the mean percentage ground cover of each species on archaeological remains.

[c] Frequency on remains, number of plots, out of the total of 20 surveyed plots, where the species was found on ancient remains.

[d] Frequency on man-made habitats, number of plots, out of the total of 20, where the species was found on man-made habitats.

Table 2. Frequency of native (n = 438) and alien species (n = 60) on archaeological remains as recorded in 20 sample plots in archaeological sites in Mediterranean Italy. Frequency: 0 = species never found on the remains (but only in habitats of recent man-made origin such as gardens and trampled areas); 1–5 = species found on the remains in one to five sites; 6–10 = species found on the remains in 6–10 sites; 11–15 = species found on the remains in 11–15 sites; 16–20 = species found on the remains in 16–20 sites. The differences in frequency between aliens and natives tested by Kolmogorov–Smirnov test are significant (mean native 2.62 ± 2.82 SD, mean alien 0.48 ± 1.03 SD, P < 0.001).

	0	1–5	6–10	11–15	16–20
Native	12	314	100	10	2
Alien	42	17	1	—	—

Table 3. The variable threat of alien and native species to conservation of archaeological remains, as measured by danger index (DI) and abundance (percentage ground cover).

	Mean native ± SD	Mean alien ± SD	P-level variance
DI[a]	2.78 ± 1.95	3.63 ± 2.42	0.019
Abundance[b]	2.65 ± 2.67	0.86 ± 1.85	<0.001

[a] DI, danger index (Signorini 1995), is a measure of the potential damage that each species can cause to buildings and remains by growing on them. It ranges from 0 to 10 and is assessed according to plant morphology, vigor, and life-form.

[b] Abundance is measured as the mean percentage ground cover of each species on archaeological remains.

RESULTS AND DISCUSSION

In the 20 sample plots, 438 native species and 60 aliens were recorded. The latter are listed in Table 1. Eighteen alien species were found growing in at least one site on archaeological remains (Table 2). Of these species, only five occurred on remains at more than one site, and of these, only tree-of-heaven and Virginia-creeper [*Parthenocissus quinquefolia* (L.) Planch.] were relatively abundant (mean percentage ground cover >5%, Table 1). Instead, most of the alien species were widespread in the recent man-made habitats, such as trampled sites [e.g., goosegrass, *Eleusine indica* (L.) Gaertn.] and mounds of earth close to excavations (e.g., pigweeds, *Amaranthus* sp.) (Table 1). Alien and native species differ significantly (P < 0.001) in each of the three variables analyzed (DI, abundance, and frequency). The results of Student's *t* test for DI and cover are shown in Table 3. The results of Kolmogorov–Smirnov test for frequency were also highly significant (mean native 2.62 ± 2.82 SD, mean alien 0.48 ± 1.03 SD, P < 0.001). These results suggest that nonnative weeds are potentially harmful, because of their generally higher DI, but in reality, they exert hardly any effect on remains because they do not usually spread on them. Instead, they are restricted to recent man-made habitats.

The only really troublesome alien, because of its high DI combined with its ability to grow on walls, was the tree-of-heaven. This species, a native of China, has the ability to spread on both ancient and modern buildings, to which it causes serious damage because it grows quickly and develops vigorous roots (Almeida et al. 1994). Its dispersal strategies are also particularly well suited to the environment of archaeological remains, in that, it has efficient vegetative regeneration after mowing and its wind-dispersed seeds are capable of reaching very high habitats (e.g., 57 m on top of the Colosseum, 30 m on the walls of the Caracalla Baths in Rome), factors making it particularly difficult and costly to control.

The most detrimental species, because of generally high DI, abundance, and frequent occurrence on walls and buildings, were native. Among the most harmful were several bird-dispersed woody plants, such as English ivy (*Hedera helix* L.) and fig tree (*Ficus carica* L.), whose propagules are transported to the top of buildings. Wind-dispersed vines, shrubs, or trees such as old man's beard (*Clematis vitalba* L.) and English elm (*Ulmus minor* Mill.) were also particularly harmful.

The species that were the most widespread, although not necessarily showing high DI or abundance, were mainly of dry Mediterranean meadow origin. They were annual forbs and grasses growing on the tops of walls [e.g., Italian thistle, *Carduus pycnocephalus* L.; soft chess, *Bromus hordeaceus* L.; foxtail chess, *B. madritensis* L.; and zorro fescue, *Vulpia myuros* (L.) C. C. Gmel.] and perennials, which colonize remains [e.g., yellow starthistle, *Centaurea solstitialis* L. and Canada thistle, *Cirsium arvense* (L.) Scop.]. Moreover, several species typical of shaded habitats found shelter at the foot of high walls or in excavation sites [e.g., garlic mustard, *Alliaria petiolata* (Bieb.) Cavara et Grande]. Mediterranean species, such as those mentioned above, are renowned noxious weeds in other countries (Bossard et al.

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[e] Invasion status, according to Pyšek et al. 2004, indicates the degree of naturalization and possible invasion of an alien species in a given area. Abbreviations: cas, casual = alien plants that reproduce occasionally but do not form self-replacing populations; nat, naturalized = alien plants that sustain self-replacing populations; inv, invasive = naturalized plants that have the potential to spread over a large area.

[f] Residence status, after Pyšek et al. 2004, indicates the historical epoch in which an alien species was introduced into a given area (in this case into Mediterranean Italy). Abbreviations: arch, archaeophyte = introduced species that became naturalized before AD 1500; neo, neophyte = introduced species that became naturalized after AD 1500.

[g] Life-form. Abbreviations: a = annual; p = perennial; c = climber; s = shrub; t = tree.

2000; Brown and Rice 2000; Richardson et al. 2000a) or appear as invasive archaeophytes (i.e., old introductions) in Central and northwestern Europe (see e.g., Preston 2002; Pyšek et al. 2002, 2003). Worth underlining is the fact that a large majority of the native species, 426 out of a total of 438, was found growing on remains at least once (Table 2).

These results confirm the hypothesis that, despite frequent disturbance and abundant propagules, nonnative species do not establish successfully on archaeological remains and play only a minor role in the flora spreading on ruins. In contrast, native species were found to dominate at all 20 sites surveyed in this study. In the city of Rome, for instance, extensive archaeological areas act as conservation sites for the native species and hot spots of floristic richness (Ricotta et al. 2001). The most successful alien species in the city as a whole, measured in terms of abundance and frequency, are those which avoid competition with local Mediterranean plants by occupying available spatial and temporal niches unexploited by natives; that is, by being confined to the most disturbed habitats (Celesti-Grapow et al. 2001) and by flowering in late summer when most native species have already completed their life cycle (Celesti-Grapow et al. 2003). The results of this study agree with di Castri et al. (1990), Forman (2003), Groves and di Castri (1991), and Lonsdale (1999) who reported relatively minor roles of alien species on native communities in Europe and the Mediterranean Basin compared with the New World.

The relative resistance of native communities on archaeological remains to the invasion of alien plants is probably because of a combination of various factors, among which are: the coevolution of many Mediterranean species, mainly annuals, with human disturbance (Alpert et al. 2000; Groves and di Castri 1991; Pignatti 1978); the long history of exposure of local plants to other biota (Rejmánek et al. 2004); and the dominance of extreme, resource-poor and xeric habitats, which are generally regarded as relatively less favorable to the establishment of introduced species (Daehler 2003; Rejmánek 1989).

Experimental research is needed to test the role of the above-mentioned factors. However, our hypothesis is that resistance of local vegetation on archaeological remains to invasion is because of competitive advantage of the native flora under xeric conditions and intermediate levels of disturbance. In fact, many of these native species (e.g., Italian thistle and yellow starthistle) are among the most successful invaders elsewhere in the world (di Castri 1989; di Castri et al. 1990).

The results of this study confirm only a minor role for invasive plants in weed communities found on archaeological remains in the Mediterranean region; however, this should not justify complacency. Consider the comments of Williamson (1998), reporting on similar findings from Britain, that the effects of aliens adds an incremental cost to that of natives. Furthermore, native communities growing on archaeological remains may decline in the future because of the increasing urbanization of areas surrounding sites, which isolates native species from seed sources in neighboring countryside. Several native species have declined, or even disappeared, from remains in the past 50 yr (Celesti-Grapow 1995). Increasing urbanization may also actually promote the spread on remains of nonnative species closely related to urban sites and roadsides. This is probably one of the reasons why tree-of-heaven, which was relatively rare on ancient Roman walls in the mid-20th century (Anzalone 1951) has been increasingly colonizing these sites in recent years (Celesti-Grapow 1995) and is expected to become a serious threat to their conservation in the future.

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