ALIEN INSECT IMPACT ON CULTURAL HERITAGE AND LANDSCAPE: AN UNDERESTIMATED PROBLEM

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What is an invasive alien insect?

Invasive species are referred to as non-natives, exotics, aliens, non-indigenous harmful species and by a host of other names. All these definitions incorporate a basic concept: invasive species are organisms that have been introduced into an environment in which they did not evolve and whose introduction causes or is likely to cause economic or environmental harm [1]. Typically, they have few or no natural enemies to limit their reproduction and/or spread. Moreover, the hosts (e.g. native trees) for invasive insects often have not co-evolved with the introduced pest. Consequently native hosts are much more likely to be damaged or killed by the invasive pest. Today, invasive species cause millions of dollars of damage to croplands, rangelands, pastures, wetlands, waterways and forests. In addition, they have caused ecological and societal impacts [2]. Alien insects are more than 30% of all other alien species introduced into Italy and represent one of the most important environmental worries as they are considered one of the major causes of loss of biodiversity. More than 60% of these alien insects have a negative impact on economic and human health. However, their impact on cultural heritage and on landscape is still underestimated [3, 4].

Alien insect and landscape

The number of new records of alien species increases continuously, with a marked acceleration in recent decades. Aliens accidentally introduced into Europe originate from all parts of the world, but mainly from Asia. Among the alien species, the majority are generally Coleoptera. In fact, more than 250 alien Coleoptera species belonging to 41 of the 137 beetle families have been recorded in Europe and in particular Weevils and Bark Beetles [5]. Wood and seed borers are specially linked to human-mediated dispersal due to their protected habitat. Alien coleopterans mainly attack stems and half of them are xylophagous. The majority of alien Coleoptera, in particular Anobiidae and Curculionidae, live in human-modified habitats, but many species live in forests and other natural or semi-natural habitats.

An evident and well-known example of how an alien insect can change the landscape is the case of *Rhynchophorous ferrugineus* (Coleoptera Curculionidae) known as the Red Palm Weevil, which has affected the Sicilian (Italy) landscape [4]. However the list is really long. In northern Italy, the alien Citrus Longhorn Beetle (Figure

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1a, b) (CLB, *Anoplophora chinensis*, Coleoptera: Cerambycidae) was detected in 2007, becoming a widespread and serious pest (Figure 1c) even though several million Euro were spent only to try to control it [6, 7]. *A. chinensis* is a native from Asia, particularly widespread in China, Korea and Japan, where it is a serious pest of *Citrus* and many other ornamental and forest plants [8]. Recorded in the A2 list of quarantine pests of EPPO, and regulated according to the EU Directive 2000/29/CE (Figure 1d), the species was first detected in Europe in 1980, in the Netherlands; then, in 1998 in Austria, in 2000 in the UK, in 2003 in France, in 2007 in Croatia and Germany.

Figure 1. Anoplophora chinensis (a, adult; b, larvae) and the consequences of its damage (c, d).

Extremely polyphagous, it attacks different species of broadleaf plants (e. g. *Citrus*, *Acer, Aesculus, Platanus, Betula, Carpinus, Fagus, Malus, Pyrus, Rosa*). Damage is caused by the xylophagous larvae which bore tunnels into the trunk and roots, causing the plants to easily die.

An ad, serving as a public warning on-line and on television was also realized by the *Servizio Fitosanitario della Lombardia* (available at https://www.youtube.com/watch?v=RUv865h-T6k).

In North Italy *A. chinensis* was detected in the region of Marche and in Rome, creating great concern about this invasive species arriving in southern Italy, where *Citrus spp*. is one of the major crops and a symbol of the cultural heritage.

But the situation is even more complicated as another species of *Anoplophora,* the species *A. glabripennis* known as the Asian Longhorn Beetle and *A. malesiaca,* have recently been recorded in Italy, in public and private gardens, and in urban and rural areas [7, 9]. They can attack many different plant taxa e.g. those belonging to the genera *Ulmus, Acer, Aesculus, Salix, Populus* and *Betula*. The heaviest attacks were found on *Ulmus campestris* (a common tree in rural landscapes) and on *Acer* spp..

The list of alien invasive insects is very long and not only includes coleopteran species that can threaten our trees and landscape; for example, the horse chestnut leaf-miner, *Cameraria ohridella* (Lepidoptera, Gracillariidae) produces severely defoliated trees with smaller seeds and poor health that seriously affects horse chestnut regeneration. A single leaf can host up to a hundred leaf-miners (Figure 2a, d) often spoiling the panorama and boulevards in historical Villas [10].

Figure 2. Attacks of Cameraria ohridella on the horse-chestnut in Lombardy (Italy). a) Leaf miners; b) larvae; c) pupa inside the leaf; d) adults.

Alien insects known to cause damage to heritage works

Coleopteran species are also the major pests in heritage works. Among the 105 coleopteran species declared pests for heritage assets, 70 are certainly Alien Invasive Species (corresponding to 67% of the pest species) (Table 1). The origin of the other 35 species is often uncertain as they are synanthropic and have lived with man for centuries. Nowadays, the majority are cosmopolitan. Since the start of the 19th century, the number of coleopteran aliens introduced into Europe has continued to increase. Many species-rich families have surprisingly few aliens, whereas some relatively minor families, such as Anobiidae, Dermestidae and Nitidulidae, have a relatively high representation of alien species. More than 50% of Anobiidae infesting cultural heritage assets in Europe are alien species. These last two families are well known and have had significant economic impacts, particularly as pests of wood, stored foodstuffs, tissues, but in Italy *Gastrallus pubescens* preferentially eats paper and is now considered a threat for books and libraries [11]. Moreover, invasive species often have a higher biotic potential than native ones. This is the case of *Lyctus brunneus* (Coleoptera, Lyctidae). This pest originates in the tropics and was recorded for the first time in Venice in 1972 [13]; it is more aggressive and prolific (60–70 eggs per female) than the European species *L. linnearis* (20 eggs per female) and is now more common than the native species. Alien species strongly impact on the conservation of European herit-

age [13]. Wood and paper heritage works can also be affected by termites. In this case too, the number of alien species is higher compared to native ones. In 2008, Sbrenna and Sbrenna claimed that only two species of Isoptera are present in Italy, *Kalotermes flavicollis* and *Reticulitermes lucifugus*.

The West Indian drywood termite, *Cryptotermes brevis* (Walker) (*Isoptera: Kalotermiti*), is another exotic pest from west India and has been recorded in Sicily. It was described for the first time in Naples in 1997 and in Sicily in 1999 [14], it infests structural lumber and has caused great damage to many historical buildings and artifacts.

After the report by Sbrenna and Sbrenna [15] another three species were collected in Italy. *Reticulitermes urbis* (*Isoptera Rhinotermitidae*) was recorded in 2011 [16], after the accidental introduction of *Reticulitermes flavipes,* commonly known as the eastern subterranean termite, and is native to the eastern and central regions of North America, ranging from Ontario to Florida and from Colorado to north-eastern Mexico. In the same year, the accidental introduction of *Coptotermes gestroi* was recorded in Italy and Europe [17]. Considering that termites are important pests in buildings and structures, particular attention should be paid to the timely detection of events announcing their introduction and to the identification of the species involved, in order to adopt suitable measures to ensure eradication of the infestation, thus avoiding alien termites settling and spreading in Italy. At present, 6 species of termites have been reported in Sicily (Italy). Isoptera infestation has a devastating impact on cultural heritage with important economic consequences. The cost of treatments and sanitary measures against termites and cockroaches is significant in Europe.

Table 1. List of coleopteran native and Alien Species (1) causing damage to heritage works.

Families	**Species**	**Species**
Anobiidae	*Anobium punctatum* (De Geer, 1774)	
Anobiidae	*Ernobius mollis* (Linnaeus, 1758)	1
Anobiidae	*Gibbium psylloides* (Czenpinski, 1778)	1
Anobiidae	*Gibbium aequinotiale* (Boieldieu, 1854)	1
Anobiidae	*Calymmderus oblungus* (Gorham, 1883)	1
Anobiidae	*Epauloecus unicolor* (Piller and Mitterpacher)	1
Anobiidae	*Lasioderma serricorne* (Fabricius, 1792)	1
Anobiidae	*Mezium affine* (Boieldieu, 1856)	1
Anobiidae	*Mezium americanum* (La Porte de Castelnau, 1840)	1
Anobiidae	*Gastrallus pubescens* (Fairmaire, 1875)	1
Anobiidae	*Nicobium castaneum* (Olivier, 1790)	1
Anobiidae	*Ozognathus cornutus* (Le Conte, 1859)	1
Anobiidae	*Niptus hololeucus* (Faldermann, 1835)	
Anobiidae	*Oligomerus ptilinoides* (Wollaston, 1854)	
Anobiidae	*Priobium carpini* (Herbst, 1793)	

Anobiidae	*Pseudeurostus hilleri* (Reitter, 1877)	1
Anobiidae	*Ptilinerua marmoratus* (Reitter, 1877)	1
Anobiidae	*Ptilinus pectinicornis* (Linnaeus, 1758)	
Anobiidae	*Ptinus clavipes* (Panzer, 1792)	1
Anobiidae	*Ptinus bicintua* (Sturmr, 1837)	1
Anobiidae	*Ptinus latro* (Fabricius, 1775)	1
Anobiidae	*Ptinus fur* (Linnaeus, 1758)	1
Anobiidae	*Ptinus variegatus* (Rossi, 1792)	
Anobiidae	*Stegobium paniceum* (Linnaeus, 1758)	
Anobiidae	*Trigonogenius globulus* (Solier, 1849)	1
Anobiidae	*Xestobium rufovillosum* (DeGeer, 1774)	
Bostrichidae	*Bostrychoplites cornutus* (Olivier 1790)	1
Bostrichidae	*Bostrichus capucinus* (Linnaeus, 1758)	
Bostrichidae	*Dinoderus minutus* (Fabricius, 1775)	1
Bostrichidae	*Rhyzopertha dominica* (Fabricius, 1792)	1
Chrysomelidae	*Acanthocelides obtectus* (Say, 1831)	
Cerambycidae	*Trichoferus holosericeus* (Rossi, 1790)	
Cerambycidae	*Hylotrupes bajulus* (Linneaus, 1758)	
Cleridae	*Necrobia ruficollis* (Fabricius, 1775)	1
Cleridae	*Necrobia rufipes* (DeGeer, 1775)	1
Cleridae	*Necrobia violacea* (Linnaeus, 1758)	
Cleridae	*Opetiopalpus scutellaris* (Panzer, 1797)	
Cryptophagidae	*Cryptophagus cellaris* (Scopoli, 1763)	1
Cryptophagidae	*Cryptophagus fallax* (Balfour-Browne, 1953)	
Laemophloeidae	*Cryptolestes ferrugineus* (Stephens, 1831)	1
Laemophloeidae	*Cryptolestes duplicatus* (Waltl, 1834)	
Curculionidae	*Hexarthrum exiguum* (Boheman, 1838)	
Dryophthoridae	*Sitophilus oryzae* (Linnaeus, 1763)	
Dryophthoridae	*Sitophilus zeamais* (Motschulsky, 1855)	
Dermestidae	*Anthrenocerus australis* (Hope, 1843)	1
Dermestidae	*Anthrenus caucasicus* (Reitter, 1881)	1
Dermestidae	*Anthrenus flavidus* (Solsky, 1876)	1
Dermestidae	*Anthrenus flavipes* (LeConte, 1854)	1

Dermestidae	*Anthrenus museorum* (Linnaeus, 1761)	
Dermestidae	*Anthrenus pimpinellae* (Fabricius, 1775)	
Dermestidae	*Anthrenus scrophulariae* (Linnaeus, 1758)	
Dermestidae	*Anthrenus verbasci* (Linnaeus, 1767)	
Dermestidae	*Attagenus bifasciatus* (Olivier, 1790)	1
Dermestidae	*Attagenus smirnovi* (Zhantiev, 1973)	1
Dermestidae	*Attagenus cyphonoides* (Reitter, 1881)	
Dermestidae	*Attagenus fasciatus* (Thunberg, 1795)	1
Dermestidae	*Attagenus pellio* (Linnaeus, 1758)	
Dermestidae	*Attagenus unicolor* (Brahm, 1790)	1
Dermestidae	*Dermestes ater* (DeGeer, 1774)	1
Dermestidae	*Dermestes bicolor* (Fabricius, 1781)	1
Dermestidae	*Dermestes carnivorus* (Fabricius, 1775)	1
Dermestidae	*Dermestes frischii* (Kugelann, 1792)	1
Dermestidae	*Dermestes lardarius* (Linnaeus, 1758)	1
Dermestidae	*Dermestes maculatus* (DeGeer, 1774)	1
Dermestidae	*Dermestes murinus* (Linnaeus, 1758)	
Dermestidae	*Dermestes peruvianus* (Laporte de Castelnau, 1840)	1
Dermestidae	*Dermestes undulatus* (Brahm, 1790)	
Dermestidae	*Megatoma undata* (Linnaeus, 1758)	
Dermestidae	*Phradonoma villosulum* (Dufschmid, 1825)	
Dermestidae	*Reesa vespulae* (Milliron, 1939)	1
Dermestidae	*Sefrania bleusei* (Pic, 1899)	1
Dermestidae	*Thylodrias contractus* (Motschulsky, 1839)	1
Dermestidae	Dermestes haemorrhoidalis (Küster, 1852)	
Dermestidae	Dermestes mustelinus (Erichson, 1846)	
Dermestidae	*Trododerma augustum* (Solier, 1849)	1
Dermestidae	*Trogoderma glabrum* (Herbst, 1783)	1
Dermestidae	*Trogoderma granarium* (Everts, 1898)	1
Dermestidae	*Trogoderma inclusum* (LeConte, 1854)	1
Dermestidae	*Trogoderma megatomoides* (Reitter, 1881)	1
Lathridiidae	*Adistemia watsoni* (Wollaston, 1871)	1
Lathridiidae	*Cartodere constricta* (Gyllenhal, 1827)	1

Lathridiidae	*Corticaria elongata* (Gyllenhal, 1827)	1
Lathridiidae	*Dienerella argus* (Reitter, 1884)	1
Lathridiidae	*Dienerella filum* (Aubé, 1850)	1
Bostrichidae	*Lyctus brunneus* (Stephens, 1830)	1
Bostrichidae	*Lyctus cavicollis J. L.* (LeConte, 1805)	1
Bostrichidae	*Lyctus linearis* (Goeze, 1777)	1
Bostrichidae	*Trogoxylon impressum* (Comolli, 1837)	
Mycetophagidae	*Litargus balteatus* (LeConte, 1856)	1
Mycetophagidae	*Thyphea stercorea* (Linnaeus, 1758)	1
Nitidulidae	*Carpophilus dimidiatus* (Fabricius, 1792)	1
Nitidulidae	*Carpophilus hemipterus* (Linnaeus, 1758)	1
Nitidulidae	*Carpophilus ligneus* (Murray, 1864)	1
Nitidulidae	*Carpophilus obsoletus* (Erichson, 1843)	1
Silvanidae	*Ahasverus advena* (Waltl, 1834)	1
Silvanidae	*Oryzaephilus mercator* (Fauvel, 1889)	1
Silvanidae	*Oryzaephilus surinamensis* (Linnaeus, 1758)	1
Silvanidae	*Silvanus bidentatus* (Linnaeus, 1792)	
Tenebrionidae	*Alphitobius diaperinus* (Panzer, 1797)	1
Tenebrionidae	*Alphitobius laevigatus* (Fabricius, 1781)	1
Tenebrionidae	*Palorus depressus* (Fabricius, 1790)	
Tenebrionidae	*Tenebrio molitor* (Linnaeus, 1758)	
Tenebrionidae	*Tenebrio obscurus* (Fabricius, 1792)	1
Tenebrionidae	*Tribolium castaneum* (Herbst, 1797)	1
Tenebrionidae	*Tribolium confusum* (Jacquelin du Val, 1861)	1

Alien species from the past

Human populations have migrated and interacted throughout time and in their travels have intentionally or unintentionally carried other organisms with them. Several alien species have been recorded from archaeological sites dating to the Roman occupation of Britain. Fragments of insects found in Roman and Viking graves (e.g., *Sitophilus granaries* [18]; *Pulex irritans*, [19]) have proved that some invertebrate species were introduced into Europe long ago.

The recovery of *Blatta orientalis*, the 'oriental' cockroach, from late Roman Lincoln [20] reflects Roman trade connections, direct or indirect, with Africa [21]. In the 1600s the American cockroach (*Periplaneta americana*) was able to settle in various parts of

Europe and more recently in Italy, where it began to pose a serious threat to cultural heritage, as in the case of statues of the Virgin Mary.

Only six species are known in Europe, all of them having been introduced from tropical or subtropical regions: none is considered native. *Blatta orientalis*, *Periplaneta* spp. and *Neostylopyga rhombifolia* are synanthropic species that have long been introduced into Europe.

Another example of ancient introduction is the known Indian Meal Moth, Common Clothes Moth, Webbing Clothes Moth or simply Clothing Moth, *Tineola bisselliella* (*Lepidoptera: Tineidae)* and *Tinea pellionella*; they are now a pest all over Europe, but was probably imported centuries ago from Asia (Figure 3).

Figure 3. Leather painter: (a) infested by Tinea pellionella; b) larva; c) pupa; d) adult.

Although some of these human-introduced fauna were able to successfully colonise these new geographical regions, a number of species struggled to find suitable niches when confronted with environmental or climatic restraints. Our ability to recognise and distinguish the indigenous species from the foreign is of great archaeological interest, just as the mapping of animal movement can provide insight into the movement and interaction of past peoples. However, considering this, faunal remains may serve as traces to elucidate past exchange and trade networks [22].

Discussion and conclusion

However, researchers and policy makers rarely address directly the connection between invasive species and loss in natural and cultural heritage. Invasive species have substantial, albeit not fully quantified impacts on cultural services including aesthetic values, recreation and tourism. Furthermore, studies of the links between these species and loss in natural biodiversity and heritage, in botanical and historical gardens as well as in natural landscapes, are largely lacking in the literature [4]. Even current legislation is not enough, although in the Legislative Decree - *D.Lgs n. 152/2006* - there are some potential quotations that could also refer to biological invasions. However, specific risk analysis on the introduction of alien pests relating to cultural heritage and landscape is scant.

The precautionary principle, that could be useful in the situation of a potential alien species threatening the landscape and the cultural heritage, is restricted to market products. In fact, it enables a rapid response in the face of possible danger to human, animal or plant health, or to protect the environment. In particular, where scientific data do not permit a complete evaluation of the risk, recourse to this principle may, for example, be used to stop distribution or order withdrawal from the market of products likely to be hazardous [23]. Some authors [24] suggest that new legislative instruments similar to “the polluter pays principle” mentioned in the Declaration of the United Nations Conference on the Human Environment should be implemented [25].

Perhaps the key lesson stemming from these few examples is that while we lack full knowledge of the comprehensive impact of invasive species on natural and cultural heritage, the impact perceived thus far has been severe enough to warrant action. Our existing experience and practices indicate the need for a clear path forward in order to minimise the threats of invasive species. With better research, longer-term data and site-level specifics, we will be able to fill in gaps in knowledge and lessen uncertainty regarding future scenarios.

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Summary

The impact of alien invasive insects on cultural heritage and landscapes is very often neglected; even though, more than 50% of species that threaten cultural heritage in Europe are of exotic origin. In addition they are more aggressive. Several examples and a description, are given of the most dangerous alien insects present in heritage sites that constitute a risk for the conservation of cultural property: museum collections, libraries, archives and historic buildings. Globalisation has increased this phenomenon but traces of the accidental introduction of insect pests have occurred since Roman times. The paper discusses the need to implement an estimation of the costs that arise from the damage caused by these species and the lack of specific legislative aspects.

Riassunto

L'impatto degli insetti alieni sui beni culturali e sul paesaggio e spesso sottovalutato, sebbene più del 50% delle specie dannose per beni culturali in Europa sono di origine esotica. Si fornisco diversi esempi ed informazioni di queste introduzioni e si illustrano possibili soluzioni anche legislative. Si evidenzia pure documentate notizie che eventi simili si sono manifestati anche in tempi lontani quale il periodo dell'antico romano. Viene discussa la necessità di implementare la stima dei costi dovuti ai danni create da queste specie e la mancanza di aspetti legislative specifici.