Nature Conservation 19: 97–110 (2017)
doi: 10.3897/natureconservation.19.12637
http://natureconservation.pensoft.net

REVIEW ARTICLE

A peer-reviewed open-access journal
Nature Conservation
Launched to accelerate biodiversity conservation

Monitoring and management of *Cerambyx cerdo* in the Mediterranean region – a review and the potential role of citizen science

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Academic editor: *S. Hardersen* | Received 13 March 2017 | Accepted 11 May 2017 | Published 31 July 2017

http://zoobank.org/4BA7D133-5DFC-48B5-AFD5-945B59ACCE39

Citation: Casula P (2017) Monitoring and management of *Cerambyx cerdo* in the Mediterranean region – a review and the potential role of citizen science. In: Campanaro A, Hardersen S, Sabbatini Peverieri G, Carpaneto GM (Eds) Monitoring of saproxylic beetles and other insects protected in the European Union. Nature Conservation 19: 97–110. https://doi.org/10.3897/natureconservation.19.12637

Abstract
The Great Capricorn beetle, *Cerambyx cerdo*, and Mediterranean oak habitats (*Quercus ilex* – 9340 and *Quercus suber* – 9330) are protected by the Habitats Directive (HD). However, in the Mediterranean basin, these habitats are also traditionally used for animal, wood, and cork productions. *Cerambyx cerdo* feeds into the wood of trees and can be perceived by forest practitioners as an umbrella species or as a pest, depending on the context. Monitoring programmes involving forest practitioners could thus focus on assessing: 1) the conservation status of the Great Capricorn beetle and habitats (distribution and abundance of insects and reproductive sites or colonised trees), 2) pest status, and 3) management options to achieve both conservational and economic benefits. Considering that *Cerambyx cerdo* and Cork and Holm oak forests are not priority species or habitats under the HD, targeted funding is likely to be limited for monitoring. In this context, citizen science could gather important information on the target species useful for the monitoring programmes and management. To address management questions, the citizen science based programme for *Cerambyx cerdo* monitoring and habitat conservation should be seen not only as citizens collecting good data sets, but also as a deeper collaboration amongst different knowledge bodies and perspectives within a community – based environmental monitoring and learning network.

Keywords
Citizen Science, Habitats Directive, Monitoring protocol, Saproxylic beetle

Introduction

The Great Capricorn beetle, *Cerambyx cerdo*, plays a key role in decomposition of wood and ecosystem functioning of natural and semi-natural oak forests (Buse et al. 2008a). When attacked by *C. cerdo* and other saproxylics, a tree may survive over long periods with increasing quantities of dead wood and galleries created by larvae. In this long lasting state, the tree represents habitats for other species and *C. cerdo* is thus considered an important ecosystem engineer and umbrella species (Buse et al. 2008a). For its key ecological role, the species is strictly protected under the European Union's Council Directive 92/43/EEC (Habitats Directive, HD), which requires mandatory monitoring (Article 11). Although the species is still reasonably widely distributed (Figure 1), the beetle is now considered "Near Threatened" at European level by the IUCN because the population in most of the countries is in significant decline and it is dependent upon veteran trees which are also declining in Europe (Horak et al. 2010). The species is also assessed at the Mediterranean level as "Least Concern" since it has a large geographical range and is abundant in the region, although sub-populations are often scattered and there is a low probability that the habitat would recover if destroyed in the future (Buse et al. 2016). Major threats for the species are the decline in the number of old trees situated in open or semi-open landscapes (Buse et al. 2007, Albert et al. 2013), fragmentation and isolation of sub-populations (Buse et al. 2016, but see Torres-Vila et al. 2017), changes in habitat and landscape structure such as plantations with exotic plants and alteration of grazing regimes (Buse et al. 2016, Oleksa and Klejdysz 2017), and forest sanitary measures (Luce 1997, Horak et al. 2010, Buse et al. 2016). In fact, *Cerambyx* spp. are considered serious pests of oak stands in the Mediterranean basin (Martín et al. 2005, Sallé et al. 2014, Torres-Vila et al. 2017), where semi-natural Holm oak (*Quercus ilex*) and Cork oak (*Quercus suber*) forests are traditionally exploited for pasture and firewood or cork production respectively (Bergmeier et al. 2010). Considering that the species has this double interest for Mediterranean forest management, mandatory monitoring under the HD perhaps should be aimed at assessing both conservation and pest status of *C. cerdo*.

Citizen science is the practice of engaging volunteers in a scientific project (Bhattachrjee 2005, Burgess et al. 2017, McKinley et al. 2017). By simultaneously engaging a large number of data collectors, citizen science is providing important information to assess the distribution and abundance of protected species (Silvertown 2009, Kosmala et al. 2016, Zapponi et al. 2017). Such information is fundamental to establish conservation priorities and policies (Hochkirch et al. 2013), with the latter also supporting sustainable development of socio-ecological systems (Keulartz 2009). However, to bridge the gap between knowledge about distribution and abundance of species and practical environmental management, it is very important to involve in monitoring those who are responsible for hands-on management of ecological resources, i.e. local practitioners with their perspectives (Hulme 2011). Indeed, even if citizen scientists are often engaged as mere data collectors for large scale monitoring (Lakshminarayanan 2007), they can contribute to science in several ways, e.g. by developing scientific questions,

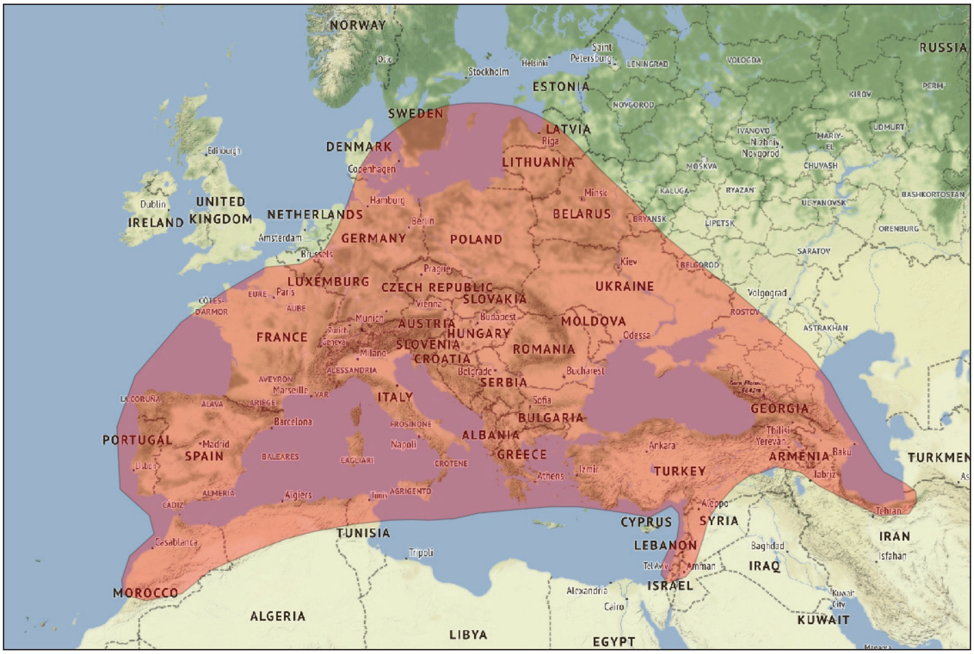

Figure 1. Distribution map of *Cerambyx cerdo* based on data from the IUCN (background map from Stamen Design, OpenStreetMap).

analysing data, and evaluating results (Silvertown 2009, McKinley et al. 2017). Within this broader view of citizen science, community – based monitoring can be included, a process where concerned citizens, government agencies, academia, local institutions and other stakeholders collaborate to monitor, track and respond to issues of common environmental concern (Conrad and Hilchey 2010), and where local practitioners can be involved. In fact, when local practitioners face conservation tasks, they search for convincing solutions that can be practically implemented without jeopardising community welfare (Horwich and Lyon 2007). For example, limits to sanitary measures of productive oak forests could be perceived by local stakeholders with interest in cork extraction or wood production as unwarranted regulations that could jeopardise their income. Forest practitioners of local authorities could therefore be rather sceptical about taking any action to strictly protect species that could also be considered as pests, such as *C. cerdo*. To achieve consensus about conservation goals and their compatibility with local community interests, it is therefore important to successfully involve practitioners in the learning process of evaluating conservation problems and viable management solutions for the socio – ecological system at hand (Nichols and Williams 2006, Conrad and Hilchey 2010, Keith et al. 2011, McKinley et al. 2017).

By applying this perspective, the following sections: 1) review management obligations for *Cerambyx cerdo* and oaks under the HD, 2) call for the application of a citizen science that can strengthen the link between *C. cerdo* monitoring and management, and 3) underline some relevant practitioner's objectives of *C. cerdo* monitoring within adaptive management (Nichols and Williams 2006). Overall, there is a gap between available knowledge about *C. cerdo* and information needed to manage Mediterranean oak habitats. This gap could be filled by involving practitioners in evaluating conservation or pest status of the species, as well as viable management options to achieve conservation and sustainable development goals.

Managing *Cerambyx cerdo* and Mediterranean oaks under the Habitats Directive

The *Cerambyx cerdo* is listed as a non priority species in annexes II and IV of the HD. That is, core areas of *C. cerdo* habitats are designated as Sites of Community Importance (SCIs) and included in the Natura 2000 network which must be managed to maintain or restore favourable conservation status of the species (Epstein et al. 2016) (Annex II). Additionally, a strict protection regime must be applied across the entire natural range of *C. cerdo* within the European Union, both within and outside Natura 2000 sites (Annex IV). In practice, within the whole territory of the European Union, the beetle cannot be deliberately killed, captured or disturbed, and its breeding or resting sites (trees colonised by *C. cerdo*) cannot be deteriorated or destroyed (HD, Article 12, see Table 1). This strict protection regime can create conflicts when there is an economic interest in oaks and stakeholders may wish to cut down trees or branches colonised by *C. cerdo* to protect woodlands (Buse et al. 2016). However, the significance of the pest status of the protected *C. cerdo* should be carefully assessed and disentangled from that of similar species such as *C. scopolii* and *C. welensii* which are not protected under the HD and can be associated with *C. cerdo* (Buse et al. 2008b, 2016, Torres-Vila et al. 2017, Wang 2017). It is thus very important to assess whether and in which conditions *C. cerdo* can be a serious pest for oak woodlands. Indeed, Article 2 of the HD states that economic issues and local context should be taken into account, while Article 16 allows derogation to restrictions of Article 12 if a risk of damage to forests is shown.

Holm oak and Cork oak forests are protected habitats (HD, Annex I, habitats 9340 and 9330 respectively and habitat 6310 for dehesas with evergreen *Quercus* species). That is, core areas of habitats are designated as SCIs and included in the Natura 2000 network which must be managed to maintain habitats in favourable conservation status (Epstein et al. 2016). To achieve this, the specific structure and functions necessary for long-term persistence of habitats must be maintained and the conservation status of typical species must be favourable (Article 1e, see Table 1). When necessary, land-use planning and development policies should encourage the management of features of the landscape which are of major importance for biodiversity (Article 10). Therefore, forest management of SCIs should aim at maintaining or restoring the typical biological diversity associated with habitat structure and functions, with appropriate management plans (Article 6). How habitat structure and associated saproxylic beetle communities should be maintained or restored is a challenging question (Vodka et al. 2008, Sebek et al. 2013, 2015), with particular

Table 1. Obligations arising from the Habitats Directive for the conservation of animal species and habitats.

Article	Text (English version, only relevant parts)	Obligations
1	e) The conservation status of a natural habitat will be taken as "favourable" when: - its natural range and areas it covers within that range are stable or increasing and - the specific structure and functions which are necessary for its long-term maintenance exist and are likely to continue to exist for the foreseeable future and - the conservation status of its typical species is favourable as defined in (i); i) The conservation status will be taken as "favourable" when: - population dynamics data on the species concerned indicate that it is maintaining itself on a long-term basis as a viable component of its natural habitats and - the natural range of the species is neither being reduced nor is likely to be reduced for the foreseeable future and - there is, and will probably continue to be, a sufficiently large habitat to maintain its populations on a long-term basis;	Define favourable conservation status (FCS) for each listed species and habitat.
2	1. The aim of this Directive shall be to contribute towards ensuring biodiversity through the conservation of natural habitats and of wild fauna and flora in the European territory of the Member States to which the Treaty applies. 2. Measures taken pursuant to this Directive shall be designed to maintain or restore, at favourable conservation status, natural habitats and species of wild fauna and flora of Community interest. 3. Measures taken pursuant to this Directive shall take account of economic, social and cultural requirements and regional and local characteristics.	Take appropriate measures to maintain or restore species and habitats at FCS. Consider economic, social and cultural issues, and local context.
3	1. A coherent European ecological network of special areas of conservation shall be set up under the title Natura 2000. This network, composed of sites hosting the natural habitat types listed in Annex I and habitats of the species listed in Annex II, shall enable the natural habitat types and the species' habitats concerned to be maintained or, where appropriate, restored at a favourable conservation status in their natural range.	Identify a suitable Natura 2000 network for the conservation of habitats listed in annex I and species listed in annex II.
6	1. For special areas of conservation, Member States shall establish the necessary conservation measures involving, if need be, appropriate management plans specifically designed for the sites or integrated into other development plans and appropriate statutory, administrative or contractual measures which correspond to the ecological requirements of the natural habitat types in Annex I and the species in Annex II present on the sites.	Develop conservation measures and, if necessary, appropriated management plans for species and habitats.
10	Member States shall endeavour, where they consider it necessary, in their land-use planning and development policies and, in particular, with a view to improving the ecological coherence of the Natura 2000 network, to encourage the management of features of the landscape which are of major importance for wild fauna and flora. Such features are those which, by virtue of their linear and continuous structure (such as rivers with their banks or the traditional systems for marking field boundaries) or their function as stepping stones (such as ponds or small woods), are essential for the migration, dispersal and genetic exchange of wild species.	If necessary, develop plans and policies for the conservation of landscape features important for species.

Article	Text (English version, only relevant parts)	Obligations
11	Member States shall undertake surveillance of the conservation status of the natural habitats and species referred to in Article 2 with particular regard to priority natural habitat types and priority species.	Do monitoring, particularly on priority species or habitats.
12	1. Member States shall take the requisite measures to establish a system of strict protection for the animal species listed in Annex IV (a) in their natural range, prohibiting: (a) all forms of deliberate capture or killing of specimens of these species in the wild; (b) deliberate disturbance of these species, particularly during the period of breeding, rearing, hibernation and migration; (c) deliberate destruction or taking of eggs from the wild; (d) deterioration or destruction of breeding sites or resting places.	Take measures to strictly protect animal species listed in Annex IV.
16	1. Provided that there is no satisfactory alternative and the derogation is not detrimental to the maintenance of the populations of the species concerned at a favourable conservation status in their natural range, Member States may derogate from the provisions of Articles 12 ... : a) in the interest of protecting wild fauna and flora and conserving natural habitats; b) to prevent serious damage, in particular to crops, livestock, forests, fisheries and water and other types of property.	Ask derogations to protect habitats and avoid serious damage to forests, provided FCS of the species is maintained.

reference to the Mediterranean basin which has high and poorly known levels of diversity and endemism (Baselga 2008).

The long lasting association of *C. cerdo* with old and decaying trees (Buse et al. 2007, 2008a) suggests that trees colonised by *C. cerdo* represent keystone structures (Tews et al. 2004) to maintain saproxylic diversity and functions associated with Mediterranean protected oak habitats (Sirami et al. 2008). Due to past forest exploitation, old growth forests are rare in the Mediterranean basin (Blondel and Aronson 1999, Scarascia-Mugnozza et al. 2000), suggesting the need of delimiting non-intervention areas within the Natura 2000 network to "re-wilding" landscapes (Schnitzler 2014). However, in central European countries, the *C. cerdo* and other saproxylic beetles have been found to be associated with sun-exposed wood located near ground (Buse et al. 2007, Albert et al. 2013, Oleksa and Klejdysz 2017) and could benefit from the restoration of traditional management practices such as coppice with standards or woodland pastures (Buse et al. 2007, Vodka et al. 2008). Retention forestry is also emerging as a practical way to harvest forest and maintain or restore old-growth features of landscapes (Fedrowitz et al. 2014, Mason and Zapponi 2015). Management options to protect *C. cerdo* and related habitat structures and functions range therefore from strict protection of old growth forests, to conservation of habitat trees over managed landscapes, and to forest harvesting coupled with grazing and retention (Sirami et al. 2008, Vodka et al. 2008, Sebek et al. 2013, 2015, Fedrowitz et al. 2014, Mason and Zapponi 2015). Traditional forest management practices are thus seen as potential conservation tools to protect saproxylic communities (Buse et al. 2007, Vodka et al. 2008), as well as sustainable and viable production systems (Scarascia-Mugnozza et al. 2000, Sjölund and Jump 2013).

In practice, forest management or conservation bodies face a mandatory task to monitor through space and time a long and incomplete list of species and habitats (Hochkirch et al. 2013), to assess a rather context-dependent favourable conservation status (Epstein et al. 2016), as well as to test management options available to maintain or restore such favourable conditions and achieve sustainable development (Keulartz 2009). Giving this overwhelming task, conservation institutions are forced to focus on priorities (Hochkirch et al. 2013) which implies that important funding explicitly targeted at non-priority species and habitats such as *C. cerdo*, Holm oak and Cork oak woodlands are rather unlikely (see Article 11, HD). Within these challenges and constraints, citizen science has great potential to do most of the required tasks in conservation science, natural resource management, and environmental protection (McKinley et al. 2017).

Citizen science and *Cerambyx cerdo* management

It has been shown several times that knowledge coming from non-professionals, either called citizen science (Silvertown 2009, Conrad and Hilchey 2010, Kosmala et al. 2016, Burgess et al. 2017, Casula et al. 2017, McKinley et al. 2017, Zapponi et al. 2017) or local ecological knowledge (Anadón et al. 2009, Irvine et al. 2009, Angelstam et al. 2011, Vignoli et al. 2016) can be a reliable source of information for species conservation and management. Nevertheless, many studies involving non-professionals still emphasise the role of citizens as data collectors (Silvertown 2009, Kosmala et al. 2016, Zapponi et al. 2017), while from the social fields there have been calls to move away from using citizens on unequal terms and towards treating citizens as scientists to create learning networks with real transformative potential (Lakshminarayanan 2007, Feyerabend 2011, Bela et al. 2016) to achieve conservation goals (Conrad and Hilchey 2010, McKinley et al. 2017).

In other words, citizen science programmes to assess distribution and abundance of *C. cerdo* and other saproxylics can certainly take advantage of involving many citizen scientists as data collectors (Zapponi et al. 2017). Nevertheless, if a consensus about what to do to protect or manage the species is sought, more focus should be put on community-based environmental monitoring, with the involvement of practitioners to establish objectives, methods and interpret results. In the long term, such an approach is more likely to affect decisions made by the practitioners themselves who are responsible for the management of local natural resources in the face of multiple objectives and uncertainty (Conrad and Hilchey 2010, Keith et al. 2011, McKinley et al. 2017). Indeed, from a management perspective, monitoring for conservation is viewed as an essential element of the adaptive cycle of informed decision-making which includes objectives, potential management actions, models of system response to management actions, with consequent monitoring of relevant state variables (Nichols and Williams 2006, Keith et al. 2011). That is, counting beetles for conservation can practically affect conservation decisions if relevant information about management options can be gathered. For example, if *C. cerdo* is found to be rare in given management scenarios (e.g. coppices without retention or conversion to high forest), abundant in others (e.g. coppice with retention or unmanaged old growth forests) and at damaging levels in productive landscapes (e.g. dehesas with Cork oak), forest practitioners or policy makers can link monitoring results to the best management options available to maintain the species in favourable conservation status at national level without jeopardising local community welfare. From a practitioner's point of view, it is very important that monitoring objectives for *C. cerdo* are framed within a real management perspective.

Practitioner's objectives for *Cerambyx cerdo* monitoring

Recent efforts in developing standard monitoring protocols for saproxylic beetles focused on applications of advanced statistical tools to address issues of insect detectability and to provide reliable estimates of distribution and abundance that can be compared across large spatial scales (Chiari et al. 2013b, 2013a, Campanaro et al. 2016, Redolfi De Zan et al. 2017). Several sampling methods have been applied to study *C. cerdo* populations, including visual censuses of adult exit holes to assess microhabitat requirements (Buse et al. 2007, Regnery et al. 2013, Albert et al. 2013, Oleksa and Klejdysz 2017), comparison of evening transects, night surveys of trunks, pitfall and bait traps for distribution and population monitoring of adult beetles in a Natura 2000 network (Vrezec et al. 2012) and bait traps to estimate dispersal in a Mediterranean woodland pasture (Torres-Vila et al. 2017). Most of the available studies come from central Europe and focus on microhabitat selection in open landscapes, as summarized in Table 2. Although it is very rare to find Mediterranean habitats without some traditional land use system (Blondel and Aronson 1999, Scarascia-Mugnozza et al. 2000, Bergmeier et al. 2010), there is very little information about the association of *C. cerdo* with habitats differing in management history (but see Regnery et al. 2013).

Information about the effect of different management histories on *C. cerdo* populations and habitat structure (e.g. number and quality of colonised trees) is very important as even the most reliable estimates of distribution and abundance of species cannot be translated into action if an explanation about the underlying process (e.g. why a trend is negative) is not available (Nichols and Williams 2006). For example, given the assumed preference of the beetle for lower parts of sun-exposed trunks (Buse et al. 2007, Albert et al. 2013, Oleksa and Klejdysz 2017), is the abandonment of traditional management, based on coppice with standards or open woodland pastures, underlying the decline of *C. cerdo* and associated saproxylic communities (Vodka et al. 2008, Sebek et al. 2015)? However, given that *C. cerdo* has been extensively studied in open woodlands of central Europe (Buse et al. 2007, Albert et al. 2013, Oleksa and Klejdysz 2017), does the strong association with lower parts of sun-exposed trunks hold in other ecological contexts? Indeed, detailed habitat preference in the Mediterranean region is largely unknown and may differ from the preference observed in central Europe (Buse et al. 2016). Additionally, *C. cerdo* colonisations have been observed in northern Italy mostly in the upper

Table 2. Main studies on biology, conservation, and management of *Cerambyx cerdo* in Europe.

Topic	Reference	Country	Main tree / Habitat type
Pest status	Martin et al. 2005	Spain	*Quercus suber* / Woodland
Microhabitat selection and spatial distribution	Buse et al. 2007	Germany	*Quercus robur* / Woodland pasture
Role as ecosystem engineer	Buse et al. 2008a	Germany	*Quercus robur* / Woodland pasture
Microhabitat selection	Albert et al. 2012	Czech Republic	*Quercus robur* / Woodland pasture
Comparison of sampling methods for distribution and population monitoring	Vrezec et al. 2012	Slovenia	Unknown
Microhabitat selection	Regnery et al. 2013	France	*Quercus ilex* / Woodland
Dispersal	Torres Vila et al. 2016	Spain	*Quercus ilex* / Woodland pasture
Microhabitat selection and exotic plants	Oleksa & Klejdysz 2017	Poland	*Quercus robur* / Woodland pasture

part of the canopy of dense forests (Redolfi De Zan et al. 2017). This fact would suggest that *C. cerdo* conservation could be as well achieved by delimiting non-intervention areas to maintain or restore structure and function of forests, as requested by the HD to maintain favourable conservation status of natural habitats and typical species. Last, but not least, are sanitary measures for trees colonised by *C. cerdo* needed in productive Mediterranean landscapes such as woodland pastures and do the species in Annex IV really need listing? In other words, microhabitat association and eventual pest status of the species should be more extensively studied in widespread Mediterranean habitats such as Holm oak or Cork oak woodland pastures, coppice with retention and open or closed old growth forests, so that conservation practices of *C. cerdo* and sustainable use of associated habitats could be based on sound knowledge about the socio-ecological system at hand (Horwich and Lyon 2007, Keulartz 2009).

Conclusion

Scientific questions arising from the practitioner's perspective may differ from those arising from professional scientists or amateur naturalists and these are more related to the need to understand which management decisions will result in societal benefits from the development and conservation perspectives. This is an open question in European oak woodlands dominated by *Quercus* species, where *C. cerdo* is considered by many forest practitioners as a serious pest (Sallé et al. 2014), even if it might be confused with other *Cerambyx* spp. known to attack healthy trees in managed forest systems (Torres-Vila et al. 2017, Wang 2017). To address these issues, the citizen science paradigm for *C. cerdo* monitoring and habitat management should be seen not only as citizens collecting good data sets, but as a deeper collaboration amongst different knowledge bodies and perspectives, within a community based environmental monitoring and learning network.

Acknowledgments

Many thanks to Alessandro Campanaro and Lara Redolfi De Zan for their kind invitation to the MIPP workshop, Sergio Fantini for help with Figure 1 and two anonymous reviewers for constructive comments.

Special issue published with the contribution of the LIFE financial instrument of the European Union.

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