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Presence of the endangered saproxylic species *Cucujus haematodes* (Coleoptera: Cucujidae) in Aspromonte National Park (Southern Italy)

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Abstract
The knowledge of the ecological preferences of threatened species is critical to all conservation programs. Analyses of habitats and ecological parameters of species are necessary to predict future distribution and responses to climate change. *Cucujus haematodes* Erichson, 1845 (Coleoptera: Cucujidae) is a threatened obligate saproxylic species, listed in the IUCN European Red List of Saproxylic Beetles. After a few decades of apparent absence, the species was recently found in Calabria (Southern Italy) in some good quality biotopes of the Sila National Park in association with *Cucujus cinnaberinus* (Scopoli, 1763) and *Cucujus tulliae* Bonacci, Mazzei, Horák & Brandmayr, 2012 (Coleoptera: Cucujidae). Field surveys carried out from 2014 to 2020 in Aspromonte National Park (Calabria) revealed large populations of *C. haematodes*. Larvae of *C. haematodes* were collected from under the bark of dead trees in 11 sampling areas within Aspromonte National Park. The presence of larvae of *C. haematodes* on the non-autochthonous conifer *Pseudotsuga menziesii* (Mirb.) Franco (Pinales: Pinaceae) was also reported for the first time in Italy.

Keywords: *Aspromonte National Park, Italy,* Cucujus haematodes, *IUCN threatened species, saproxylic beetles*

Introduction

Recent studies report dramatic declines in arthropod populations worldwide and the possible consequences of this serious problem for ecosystems (Hallmann et al. 2017). Among arthropods, insects play important ecological roles, and the decline in number of species and individuals is alarming (Crossley et al. 2020). About a quarter of insect species are at risk of extinction, and an increasing number of them are included in the Red List of the International Union for Conservation of Nature and Natural Resources (IUCN) (Collen et al. 2012). Saproxylic beetles depend on dead and decaying wood for their lifecycle, and thus, land management practices and forest logging are a major threat for them (Cálix et al. 2018). Several species of saproxylic beetles are included in the IUCN Red List (https://www.iucnredlist.org/).

The genus *Cucujus* Fabricius, 1775 (Coleoptera: Cucujidae) includes more than 20 taxa of saproxylic beetles (species and subspecies) distributed in the Holarctic region and Asia (Lee & Pütz 2008; Horák & Chobot 2009; Bonacci et al. 2012). New *Cucujus* species have been recently reported from Asia and the Indochinese region (Hsiao 2020; Jaskuła et al. 2021), and among the European species, four have been reported in Italy, *C. cinnaberinus* (Scopoli, 1763), *C. haematodes* Erichson, 1845, *C. tulliae* Bonacci, Mazzei, Horák & Brandmayr, 2012 and *C. clavipes*

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(Fabricius, 1781). The first three species are officially part of the Italian fauna, but the fourth one, *C. clavipes*, is apparently an allochthonous one, quoted only once in the Port of Venice in 1968, probably accidentally imported from native North America (Ratti 2000; see also, Ratti 1986 for the question concerning *Cucujus siculus* Tournier, 1894, described from Sicily). The first two species, *C. cinnaberinus* and *C. haematodes*, are enlisted in the IUCN European Red List of Saproxylic Beetles: in 2018, the IUCN Red List Category for Europe reported *C. haematodes* as "endangered" (EN) and *C. cinnaberinus*, indicated as endemic for Europe, as Near Threatened (NT) (Cálix et al. 2018). The third Italian species, *C. tulliae*, is not yet enlisted in the IUCN European Red List of Saproxylic Beetles but only in the Red List of Italian Saproxylic Beetles (Audisio et al. 2014; Carpaneto et al. 2015).

Among *Cucujus* species, *C. haematodes* is considered an aggregate species complex, including the subspecies *C. haematodes opacus* Leiws, 1888 distributed in Japan and Taiwan, *C. haematodes caucasicus* Motschulsky, 1845 in the Caucasus, and *C. haematodes haematodes* Erichson, 1845 in the rest of its range (Horák & Chobot 2009). In Europe, the species shows a boreal-montane distribution with an irregular population density (Horák & Chobot 2009; Horák et al. 2011), mainly in less disturbed forests (Roubal 1936), and subsequently considered a relic of virgin forests (Horák et al. 2011). Although *C. haematodes* has a wide distribution in Europe (Horák et al. 2009), records of this species in Italy are limited only to Calabrian and Lucan Apennines (Ratti 2000; Bonacci et al. 2012; Mazzei et al. 2018). In the Sila plateau (Calabria), *C. haematodes* occurs in sympatry with *C. cinnaberinus*, but with lower abundance (Mazzei et al. 2011, 2018). The presence of *C. haematodes* is very important not only for the management of protected areas but also for the conservation status of forests and overall biodiversity (Mazzei et al. 2018).

Few data are known on the ecological preferences and distribution of this endangered saproxylic beetle in Europe; therefore, the aim of this study was to collect more data on distribution and choice of host species trees of *C. haematodes* in the southernmost forest area of Calabria, the territory of Aspromonte National Park.

Materials and methods

Sampling area

The field research was carried out from 2014 to 2020 in Region Calabria (Southern Italy), in 15 sites of 11 areas within Aspromonte National Park (Figure 1). The Aspromonte Massif is formed by relict metamorphic assemblages (Pezzino et al. 2008) and covers an area of about 3000 km^2 with a peculiar vegetation that includes many endemic species. In the territory of the protected area, there are beech forests, *Fagus sylvatica* L. 1753 (Fagales:

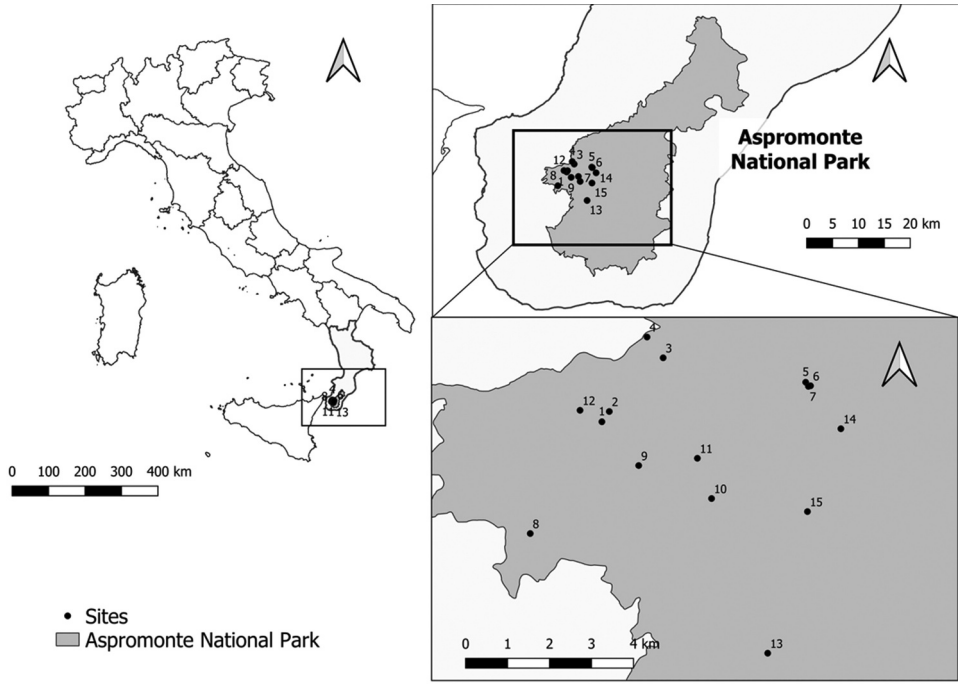

Figure 1. Sampling sites in Aspromonte National Park, Calabria (Southern Italy). Maps produced with QGIS software (https://qgis.org).

Fagaceae), that reach the highest altitudinal limits around 1950 m a.s.l., and pine forests, mostly *Pinus nigra* var. *calabrica* Debazac 1965 (Pinales: Pinaceae) extending to 1400–1500 m a.s.l. (Spampinato 2014). In some locations, *P. nigra* is mixed with *Abies alba* Mill. subsp. *apennina* (Pinales: Pinaceae) and the introduced species *Pseudotsuga menziesii* (Mirb.) Franco (Pinales: Pinaceae). The mountain area of Aspromonte National Park is characterized by a temperate climate. According to rainfall and thermal data from ARPACAL (https://www.cfd.calabria.it), Gambarie pluviometer station (code 2470), in the studied period, the annual rainfall ranged from 1718 mm (2014) to 1474 mm (2020), while the annual average temperature was 10.5°C.

Sample collection

The sites were randomly selected and only dead trees were checked, a necessary condition for the possible presence of *Cucujus* spp. individuals. The larvae of *Cucujus* spp. were collected by hand from under the bark of fallen or standing dead trees (Mazzei et al. 2018). The larvae were then placed in separate glass containers with pieces of dead wood and bark, transported to the entomological laboratory of the Department of Biology, Ecology and Earth Sciences (University of Calabria, Arcavacata di Rende, Cosenza, Italy), and placed in a thermostatic chamber at 15°C, 12:12 L:D photoperiod and under humidity 90%. For correct species identification, larvae were reared in the laboratory until the emergence of adults (Bonacci et al. 2012). The emerged adults were released back to the sampling areas. Beetles and hymenopterans co-occurring with the cucujids were also collected and identified to the family level using keys (https://sites.google.com/view/mikes-insect-keys/mikes-insect-keys).

Results and discussion

A total of 166 larvae, belonging to the genus *Cucujus* and at developmental stages from L1 to L5, were collected. The larvae were found on dead logs of *A. alba*, *P. nigra*, and *Ps. menziesii*, in altitude range from 1238 to 1826 m a.s.l. and within an area of 15 km^2. All emerged adults belonged to *C. haematodes* (Table I).

Among the larvae, 45 were found on *Ps. menziesii* on site 8 (Bisurgi). As far as we know, this is the first report of the presence of *C. haematodes* on this non-autochthonous conifer species in Italy.

Earlier reports on the distribution of *C. haematodes* in Europe indicated mountain and foothill areas as its preferred habitat (Ratti 2000). In the Primorsky region of eastern Russia, the species was found at lower altitudes (<1000 m a.s.l.) (Horák et al. 2011) and in northeastern Kazakhstan (foothills of West Altai Mountains) at 472 m a.s.l. (Szczepański et al. 2018). The species is relatively common in lowland areas of North Eastern Poland, especially in the Białowieża Forest (Jaworski et al. 2019). The occurrence of *C. haematodes* at higher altitudes could be related to intensified forestry and competition with *C. cinnaberinus* (Horák et al. 2011).

The results of this study show that, apart from only one larva of *C. tulliae* found in the Aspromonte National Park (Bonacci et al. 2012), *C. haematodes* is the only *Cucujus* species recorded in the extreme southern part of Calabria and that *A. alba*, *P. nigra*, and *Ps. menziesii* are its tree hosts. The larvae of this cucujid were found with other insect families associated with dead wood, 15 of Coleoptera (Buprestidae, Carabidae, Cerambycidae, Curculionidae, Elateridae, Eucnemidae, Melandryidae, Mycetophagidae, Nitidulidae, Pyrochroidae, Scarabaeidae, Staphylinidae, Tenebrionidae, Trogossitidae, and Zopheridae) and 2 of Hymenoptera (Formicidae and Vespidae). The larvae of *C. haematodes* were found in association with dead trees, supporting their ecological role as saproxylic and the fact that the species was not found in areas with few dead trees (Mazzei et al. 2018).

This study supports the hypothesis that the southern limit of the distribution of *C. haematodes* is the Aspromonte National Park, although beech forests are also found in Sicily (Ciccarello et al. 2015). The limit may be related to the regional glacial history during the Pleistocene when climatic fluctuations affected the distribution of many species (Avise 2000; Hewitt 2004) and their genetic diversity (Canestrelli et al. 2010, 2012). The current ranges of species of the genus *Cucujus* in Calabria (Figure 2) show a large gap, as found for other species in the same region (Bisconti et al. 2018). The gap was probably caused by glacial events in southern areas of the three Mediterranean peninsulas, Italy, Iberia, and the Balkans (Hewitt 1996; Taberlet et al. 1998). In Calabria, the current gap between the populations of *C. haematodes* of Sila and Aspromonte is probably due to postglacial events leading to the formation of the Catanzaro Trough (Pezzino et al. 2008).

Although several taxa underwent northward dispersal during the interglacial periods (Hewitt 2004), this apparently did not occur for the Calabrian populations of genus *Cucujus*, probably because of thermal barriers. In other geographical areas in

Table I. Characteristics of the sampling areas, tree host species, and insect families associated with *C. haematodes* larvae.

Sampling area	Site number	Altitude a.s.l	Forest composition (M/H)	Habitat quality	Above ground biomass	No.of dead trees	Tree host species	No.of *C. haematodes*	Co-occurring families
Mount Basilicò West and Tre Aie (Santo Stefano in Aspromonte)	1	1358	**M** (*A. alba*, *P. nigra*, *Ps. menziesii)*	MQ	High	16	*P. nigra*	13	Formicidae Staphylinidae Vespidae
	2	1395	**M** (*A. alba*, *P. nigra*, *Ps. menziesii)*	MQ	High	10	*P. nigra*	2	Cerambycidae Elateridae Eucnemidae Melandryidae Staphylinidae Tenebrionidae Zopheridae
Bosco dei Terreni Rossi di Gambarie (Santo Stefano in Aspromonte)	3	1480	**M** (*A. alba*, *P. nigra)*	HQ	High	19	*A. alba* *P. nigra*	8 22	Carabidae Pyrochroidae Tenebrionidae
	4	1360	**M** (*A. alba*, *P. nigra)*	HQ	High	21	*A. alba* *P. nigra*	7 16	Cerambycidae Elateridae Formicidae
Mount Guardia del Falcone South-West (Sinopoli)	5	1825	**H** (*A. alba*)	MQ	Low	2	*A. alba*	1	Mycetophagidae Staphylinidae
	6	1826	**H** (*A. alba*)	MQ	Low	1	*A. alba*	1	Carabidae Cerambycidae Pyrochroidae Staphylinidae
	7	1820	**H** (*A. alba*)	MQ	Medium	3	*A. alba*	10	Carabidae Pyrochroidae Staphylinidae
Bisurgi (Reggio Calabria)	8	1250	**M** (*A. alba*, *P. nigra*, *Ps. menziesii)*	HQ	High	34	*A. alba* *P. nigra* *Ps. menziesii*	21 7 45	Carabidae Cerambycidae Pyrochroidae Staphylinidae
Mount Basilicò South and Serro Longo (Santo Stefano in Aspromonte)	9	1384	**M** (*A. alba*, *P. nigra*)	MQ	Medium	5	*A. alba*	1	Cerambycidae Tenebrionidae Zopheridae

(*Continued*)

Table I. (Continued).

Sampling area	Site number	Altitude a.s.l	Forest composition (M/H)	Habitat quality	Above ground biomass	No.of dead trees	Tree host species	No.of *C. haematodes*	Co-occurring families
Serro Sgarrone South, Tre Limiti (Roccaforte del Greco)	10	1559	**H** (*A. alba*)	MQ	Low	1	*A. alba*	1	Buprestidae Melandryidae Nitidulidae Staphylinidae Tenebrionidae Trogossitidae
Serro Sgarrone West (Roccaforte del Greco)	11	1644	**H** (*A. alba*)	MQ	Medium	1	*A. alba*	4	Pyrochroidae Staphylinidae
Mount Pietra Cappella South, Contrada Scala (Roghudi)	12	1238	**H** (*P. nigra*)	MQ	Low	1	*P. nigra*	2	Cerambycidae
Punton di Lappa West, Baracca del Brigante (Roccaforte del Greco)	13	1586	**H** (*A. alba*)	MQ	Low	1	*A. alba*	3	Cerambycidae Staphylinidae
Mount Montalto South West, Contrada Materazzelli (Samo)	14	1814	**H** (*A. alba*)	MQ	Low	1	*A. alba*	1	Scarabaeidae Tenebrionidae
Contrada Telegrafo (Roghudi)	15	1705	**H** (*A. alba*)	MQ	Low	1	*A. alba*	1	Buprestidae Cerambycidae Curculionidae

Abies alba subsp. *apennina, A. alba.; Pinus nigra* var. *calabrica, P. nigra; Pseudotsuga menziesii, Ps. menziesii*. All sampling areas refer to the metropolitan city of Reggio Calabria. Forest composition: M, mixed; H, homogeneous. Habitat quality: MQ, Medium Quality; HQ, High Quality. Forest composition and habitat quality were assessed according to Mazzei et al. (2011).

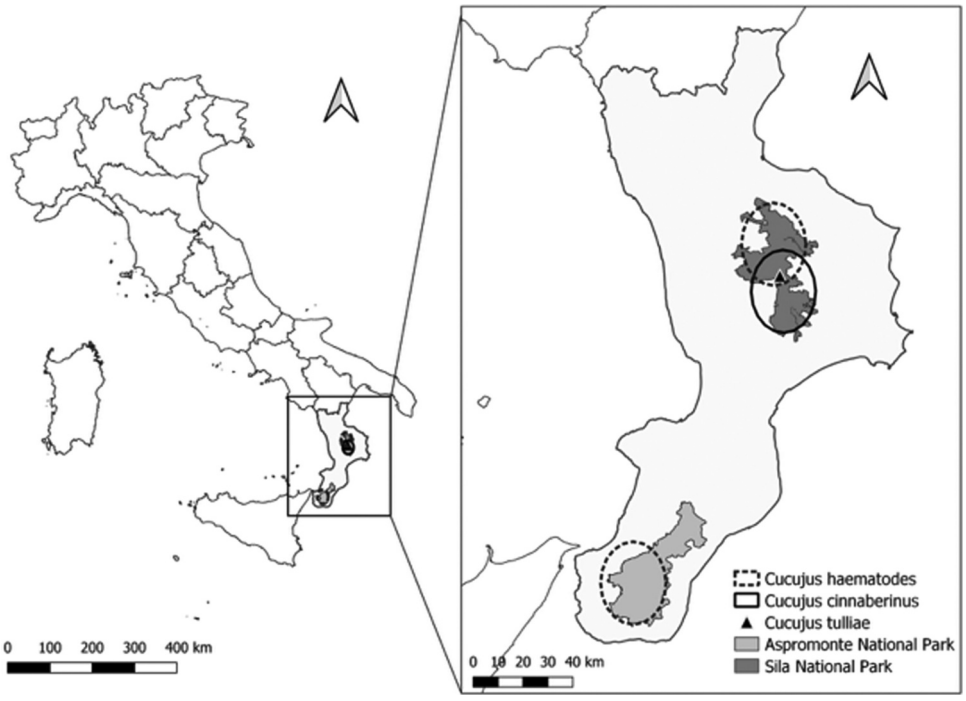

Figure 2. Distribution of *Cucujus* spp. in Calabria. Full circle: *C. cinnaberinus*, triangle: *C. tulliae*, dashed circle: *C. haematodes* Maps produced with QGIS software (https://qgis.org).

Europe, *C. haematodes* has been recorded at lower altitudes, but in Calabria, the species has been found only at altitudes above 1100 m a.s.l. and only within cold and old-growth forests (Mazzei et al. 2011, 2018). Currently, three *Cucujus* species have been recorded in Sila National Park: *C. cinnaberinus*, *C. haematodes*, and *C. tulliae* (Bonacci et al. 2012). Except for the larva of *C. tulliae* previously mentioned (Bonacci et al., 2012), only *C. haematodes* was recorded in the Aspromonte National Park (Figure 2).

The Calabrian region is a well-known glacial refugium for various species in the Italian peninsula and is considered a reservoir of genetic diversity for several vertebrate taxa such as *Bombina pachypus* (Bonaparte, 1838; Anura: Bombinatoridae) (Canestrelli et al. 2006). Thanks to its geographic characteristics, this region provides one of the best examples of a scenario known as "refugia-within-refugia", as observed for the peninsula Iberia (Gómez & Lunt 2007). For species such as *Myodes glareolus* (Schreber, 1780; Rodentia: Cricetidae), *Dryomys nitedula* Pallas, 1778 (Rodentia: Gliridae), and *B. pachypus*, the Calabrian region provided suitable (although fragmented) habitats during most of the Pleistocene, allowing the long-term survival of relict populations (Senczuk et al. 2017; Bisconti et al. 2018). The repeated insularization of Sila and Aspromonte Massifs, which strongly affected the population structure of most terrestrial animals living in these areas (Canestrelli et al. 2006, 2008, 2010, 2012), may have caused extreme geographic isolation and possibly genetic differentiation also in *Cucujus* populations. Although the occurrence of a species is known to be determined by many intra- and interspecific interactions as well as abiotic factors (Thompson 1994), we advance the hypothesis that the geological and biogeographical past was a key factor determining the current distribution of the species. Climatic changes could alter the dynamics and survival of some forest insect species, mainly specialist ones such as saproxylic beetles. In the case of *C. haematodes*, climate changes and frequent forest fires could lead to decline of local populations. Further studies are necessary to evaluate the population structure of *C. haematodes* from Aspromonte and Sila and other European sites, in order to devise the most appropriate strategies in forest environments for species survival.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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