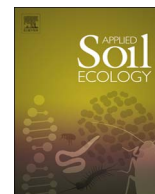




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Applied Field Research Article

## Importance of large, deep-burrowing and anecic earthworms in forested and cultivated areas (vineyards) of northeastern Italy

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## ABSTRACT

Through their activities earthworms and especially the long, deep-burrowing and anecic species, may modify the chemical-physical, biological and mechanical properties of the soil. They build mull soils. Their presence has a key role in soil ecology relating to its quality in agricultural ecosystems and especially in orchards, on vineyards and in woodlands. For comparison, this study shows the distribution of earthworm species on 29 vineyards and 32 deciduous forests in northeastern and central Italy and in parts of Croatia and Slovenia. The study located 3215 specimens: 1193 from woodlands and 2022 from cultivated areas collected between 2010 and 2017. Twelve anecic and 19 endogeic/epigeic species were identified. Rarely more than two or three anecic species live together. Some species of *Octodrilus* Omodeo, 1956 and some other species from the collecting sites were subject to barcoding analysis. The phylogenetic tree based on COI is rather consistent with current taxonomy. Of the few genera studied, the key genus *Octodrilus* is most abundant with *Oc. complanatus* having wide circum-mediterranean range and another three endemic species having restricted ranges: *Oc. mimus*, *Oc. tergestinus* and *Oc. istrianus*. They cover the prime wine producing area in the Friuli Venezia Giulia region, including the Collio with a wine of the same name. Another couple of species *Octodrilus* nov. sp. and *Eophila crodabepis* are distributed throughout the classical prosecco wine production area. Although natural deciduous forests are anecic earthworm's selective habitat, in certain circumstances however, rural areas can receive anecic recruits from nearby forests or hedgerows. Reducing tillage, trampling, and use of pesticides along with introduction of mulching are a means to make the rural environment and specially vineyards more attractive to these anecic deep-burrowing and beneficial species.

## 1. Introduction

Through their activity, earthworms can modify both the chemical-physical, mechanical and biological soil properties (Edwards and Bohlen, 1996; Brown, 1995). They have a key role in the ecology of soil in many regions of the world being classified as *soil ecosystem engineers*. Earthworms species are divided by their size, coloration, and their

behavior into different ecological categories namely epigeics (litter species), endogeics (topsoil and subsoil species) and anecics (Darwin, 1881; Bouché, 1972; Sims and Gerard, 1985; Lee, 1985; Edwards, 1998; Paoletti, 1999; Paoletti et al., 2013). Anecic earthworms (deep-burrowing species that feed on the surface litter) in particular have positive influences on soil biotic and abiotic properties (Bagni et al., 2006; Dauber et al., 2005; Edwards and Bohlen, 1996; Edwards, 2004; Lee

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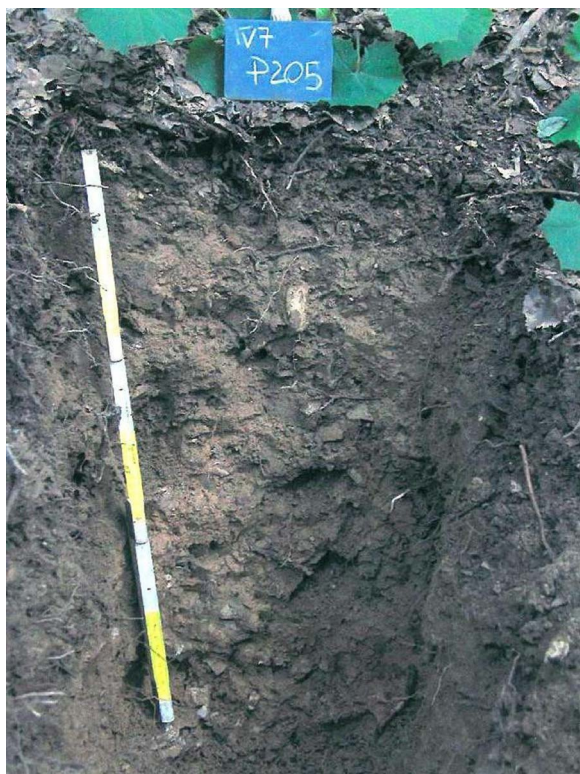


Fig. 1. Typical mull soil in which *Eophila crodabepis* and *Octodrilus* sp. nov. live near Valdobbadiene.

1985; Paoletti, 1988, 1999; Paoletti et al., 1998; Scullion and Malik, 2000; Van Straalen, 1998) and they are very important in promoting organic matter decomposition and mixing in the soil profile, nutrient cycling and soil formation, thereby accelerating the pedological process (Kiyasudeen et al., 2015).

Figs. 1 and 2 show a typical mull soil habitat of anecic earthworms *Eophila crodabepis* and *Octodrilus* n. sp. near Valdobbadiene and *Octodrilus tergestinus* and *Oc. complanatus* in the Motovun forest, Croatia. These forested stands of Motovun with mull soils produced by the activity of *Octodrilus tergestinus* support collection of truffles (*Tuber magnatum*) (in particular St 1 and St 5) (Bragato et al., 2004). *Hormogaster redii* and *Octodrilus complanatus* dominate the landscape in Rome. *H. redii* and *Scherotheca targionii* dominate the rural landscape in Tuscany (ex. San Carlo farm).

Information on deep-burrowing (anecic) earthworm taxonomy, ecology and relationship with other earthworm species in different environments and agriculture is fragmentary in Italy, except for some data from the northeast (Paoletti and Omodeo, 1981; Paoletti, 1988; Paoletti et al., 2010, 2016). Our research in the northeast of Italy and its bordering countries is concentrated on the larger anecic species that have a consistent role in building fertile soil mediated by bacteria and fungi (Thakuria et al., 2010; Scullion and Malik, 2000).

Anecic species tend to large size, in general more than 20 cm length, and are thus exposed in cultivated areas to soil management practices such as tillage, trampling, soil erosion, crop inputs such as fertilizers and pesticides. They are also affected by loss of heterogeneity in the landscape such as due to removal of hedgerows, fallows and woodland. Grey-brown pigmentation is present especially dorsally, however a color banding in each segment could be seen on *Octodrilus mimus* and

*Oc. tergestinus*, a puce violet pigmentation banding on *Eophila tellinii* and *Eo. crodabepis* (Paoletti et al., 2016). In general they produce a system of vertical galleries (Pelosi et al., 2009).

Agricultural areas, if compared with forested areas and permanent grasslands, have earthworm community declines due to several inappropriate management factors that result in a very fragmented distribution and a very low biomass especially for large burrowing species. In a recent survey in 12 European countries, based on 205 farms and 1470 fields in which 30,000 adults belonging to 49 species were identified, and only 10 species with a few specimens, less than of 5%, belonged to the anecic category (Lüscher et al., 2014; Paoletti et al., 2012).

Anecic earthworms such as *Lumbricus terrestris*, come to the soil surface usually during the night or when it is more humid and draw leaf litter down into the lower strata. Other species (e.g., *Eophila tellinii* and *Eo. crodabepis*) consume seasoned litter of the deciduous vegetation close to the soil surfaces where they migrate at night or when it is very wet and have been documented mating (Fig. 3). Furthermore, deep-burrowing earthworms can live in a system of semi-permanent burrows, often going vertically to a few meters depth (Lamparski et al., 1987; Paoletti et al., 2013; Pelosi et al., 2009).

Casts are different for typology: in some anecic species such as *Octodrilus mimus* and *Octodrilus tergestinus* characteristic tall vertical tube-shaped casts that look like towers are produced (Fig. 4). Other species like *Eophila tellinii* or *Eophila crodabepis*, instead produce castings scattered and spread irregularly when they are at the soil surface. Most earthworms feed on decomposed litter, however, *L. terrestris* and many other anecic (*L. polyphaemus* and *F. platyura platyura*, *F. platyura montana*, *F. platyura depressa*) pull leaves into a vertical gallery producing a sort of midden. Similar behavior has been documented in areas newly colonized by *Octodrilus mimus* (Fig. 5).

In southern Europe some species included in genera *Allolobophora*, *Aporrectodea*, *Eophila*, *Hormogaster*, *Lumbricus*, *Octodrilus*, *Scherotheca* and from the families Lumbricidae and Hormogastridae due to their behavior are considered anecic (Braido et al., 1997; Csuzdi et al., 2003, 2011; Hackenberger and Hackenberger, 2013; Mršić, 1992; Paoletti, 1988; Paoletti et al., 2013).

The native populations of these deep-burrowing species live in deciduous forests and some grasslands, and some like *L. terrestris* have been adapted to wet meadows and gardens (Paoletti, 1988).

Following is the current state of art about the deep-burrowing species for these genera:

*Aporrectodea* includes 43 valid species according to Blakemore (2008), but 50 species listed in <http://taxo.drilobase.org/>. The anecic species reported are *A. longa*, with distribution similar to *L. terrestris* (Atlavinytė, 1989; Blakemore, 2006, 2007a, 2007b; Carpenter et al., 2012; Christian and Zicsi, 1999; Csuzdi and Zicsi, 2003; Csuzdi and Szlávecz, 2003; Garbar and Vlasenko, 2007; Gudleifsson et al., 2003; Haraldsen et al., 1994; Ivask et al., 2006; Kasprzak, 1989; Makin et al., 2014; Omodeo et al., 2003; Perel, 1979; Reynolds, 1995, 2012; Stojanović et al., 2013; Szederjesi, 2013; Terhivuo, 1988; Valchovski, 2012; Ventinš, 2011; Zangerlé, 2011; Zicsi, 1986) and *A. carpathica* endemic species of Carpatian region (Cherevatov, 1994; Kasprzak, 1989; Pop et al., 2012; Zicsi and Csuzdi, 1986).

*Allolobophora* include 66 species listed in <http://taxo.drilobase.org/>, but 49 valid species according to Blakemore (2008). The anecic species in Italy are *A. januaeargenti* and *A. asconensis* (Diaz Cozín et al., 1992; Paoletti et al., 2013).

*Eophila* has two Italian species: *Eo. tellinii* and *Eo. crodabepis*. *E. tellinii* is endemic to the Eastern Friuli Venezia-Giulia area along the peaks of Ciaurlec mount and the hills of Ragoonna and Cravest (Braido et al., 1997; Paoletti et al., 2016); *E. crodabepis* is located in the

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