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# Wildflower strips of 2.5-year-old promote earthworms and enchytraeids (Annelida, Oligochaeta) in arable fields

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ABSTRACT

In the last 50 years, humans have increased crop yields due to intensive agricultural practices and by homogenizing cultivated lands (e.g., larger and more uniform fields). However, this land management practice has led to serious environmental issues, and now, the importance of heterogeneity and semi-natural landscape elements in production systems is acknowledged. Perennial habitats, such as flower strips, could play a key role in agroecosystem sustainability, but little is known about their effects on earthworm and enchytraeid (Annelida: Oligochaeta) communities. The aim of this study was to assess earthworms and enchytraeids in 2.5-year-old wildflower strips that were sown in the middle of arable fields in northern France. Samples (soil, earthworms and enchytraeids) were collected at ten locations, in flower strips and in adjacent cropped fields. The same number of earthworm species was found in both habitats, but more enchytraeid species were detected in the flower strips than in the adjacent cropped fields. Moreover, the total abundance of earthworms and enchytraeids significantly increased in the flower strips compared with the adjacent cropped fields, by 69 % and 61 %, respectively. Flower strips had a significant positive effect on anecic and endogeic earthworms but not on the abundance of epigeic earthworms, which was highly variable among the samples, although on average, it was seven times greater in the flower strips than in the cropped fields. Although the flower strips were sown only 2.5 years earlier, significant changes were observed in the soil Oligochaeta communities. These findings advocate for sowing flower strips within cultivated land as a source of soil biodiversity in the current changing environment. Considering the positive role of flower strips on biodiversity and particularly on the studied tiny soil engineers, these perennial landscape elements should be more widely considered to support the agroecological transition.

## 1. Introduction

Through the use of pesticides, tillage and landscape simplification, agriculture strongly affects biodiversity [1], which is currently massively declining [2,3]. Pesticide-free or no-till cropping systems have beneficial effects on biodiversity, including soil fauna [4,5]. Moreover, ecological features in or around fields, such as hedges and flower strips, can increase the diversity of aboveground and belowground organisms [6–8]. As these perennial habitats are weakly disturbed or not disturbed, they constitute refuges for wildlife within agricultural landscapes, mainly in intensive agricultural contexts [9]. For many years, removing these ecological features has been common agricultural practice, but recent reports underline the key role they play in agroecosystem sustainability and agroecological transition [3].

Perennial habitats, such as flower strips and beetle banks, protect populations of epigeic arthropods and soil organisms against disturbances in the vicinity of cropped habitats [10,11]. Dense vegetation with complex architecture as well as accumulated plant litter offer more stable microclimate conditions throughout the year than does the cropped field surface [12]. The permanent plant cover and diverse vegetation of perennial habitats provide resources for the soil decomposer community through root exudates and plant litter deposition [13,14]. Therefore, perennial habitats, such as flower strips, promote soil organisms (e.g., earthworms and enchytraeids) that are also a trophic resource for many invertebrates, birds and mammals and consequently enhance biodiversity at higher trophic levels.

However, the effects of planting flower strips on soil organisms are poorly known. Terrestrial Oligochaeta communities are modified (e.g., in terms of abundance, species diversity, and vertical distribution) by soil tillage and by the use of pesticides and organic matter inputs [15,

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16]. Therefore, earthworms and enchytraeids are used as indicators of land use and management [17,18]. However, there are very few studies on the effects of flower strip implementation within arable fields on these invertebrates. Kohli et al. [19] reported that the earthworm total abundance, biomass and species richness increased in a rotational maize field turned into wildflower strips. This indicates that strips with wildflowers are suitable habitats for earthworms. Some species, such as *Lumbricus terrestris*, a common epi-anecic earthworm, were more favoured than others, potentially due to their sensitivity to soil tillage and their epigeic behaviour [20]. In long-term set-aside plots sown with a meadow seed mixture, earthworm density, biomass and richness were favoured by the absence of mowing [21]. In contrast, nothing is known about the effects of flower strips on enchytraeids, which might be less sensitive to environmental factors (e.g., pesticides, soil tillage, salinity) than earthworms [22–24]. However, several studies have suggested that enchytraeids are even more important than earthworms in conventionally cultivated arable land because they are less sensitive to ploughing (they can even be favoured by minimum tillage [25]) and are more active metabolically [26,27].

The aim of this study was to assess earthworm and enchytraeid (Annelida: Oligochaeta) communities in 2.5-year-old wildflower strips in arable cropped fields. To this end, these invertebrates were sampled in both habitats (flower strips and cropped fields) at ten locations near Paris, France. Our initial hypotheses were that i) the abundance and diversity of earthworms and enchytraeids are greater in wildflower strips than in arable cropped fields and that ii) the beneficial effect of flower strips is less important for enchytraeid than earthworm communities because the former are less sensitive to soil tillage.

## 2. Materials and methods

### 2.1. Sampling area and design

The study was carried out in the northern part of France, a region dominated by arable farmland (mostly cereals and oilseed rape) in open field landscapes. In fall 2018, at ten farms managed using organic, conservation or conventional farming and with different cropping systems (Table 1), a perennial flower strip was sown with a mixture of 42 native and mostly perennial species across a field to divide it into two parts. Each flower strip measured approximately 4–6 m wide and 200–800 m long. Strips were mown once per year in winter. The strips did not receive any chemical treatment or any intentional fertilisation, although some drift could have occurred despite the absence of observation. In spring 2021, winter cereals, oilseed rape, or lucerne were grown in the selected cropped fields (Table 1). Earthworms and enchytraeids were sampled in flower strips and in adjacent cropped fields 50 m from the strip (Fig. 1). All the sample points were located approximately 30 m from the grassy roadside.

### 2.2. Soil, earthworm and enchytraeid sampling

In spring 2020, for soil analysis (Table S1), three soil samples (0–20 cm depth) were taken from each field and from each flower strip (Fig. 1) using a 5-cm Ø soil auger. Then, they were combined to obtain one composite sample per site. Soil characteristics were measured at the Laboratoire d'Analyse des Sols, Institut national de recherche pour l'agriculture, l'alimentation et l'environnement (Arras, France). This laboratory's quality is certified by COFRAC (French accreditation committee) for soil characteristic analysis. Briefly, soils were dried at room temperature, disaggregated, homogenised and then sieved (2-mm-sieve). The following soil characteristics were measured: pH (by water suspension), organic matter and nitrogen contents (by dry combustion, in g $kg^{-1}$), grain size distribution (clay <2 µm, silt 2–20 µm, and sand >20 µm), total calcium carbonate ($CaCO_3$; in g $kg^{-1}$), and total

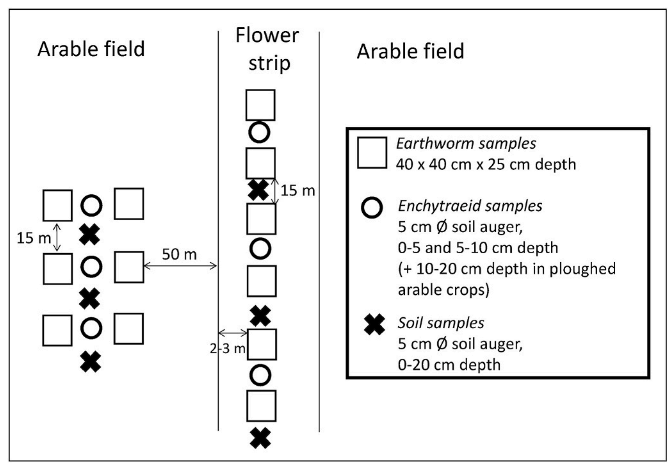


**Fig. 1.** Sampling at each of the ten studied fields. In each field, earthworms, enchytraeids and soil were sampled in the flower strip and in the adjacent cropped field.

**Table 1**
Description of the cropping systems implemented at the ten fields where earthworms and enchytraeids were sampled. TFI, Treatment Frequency Index is used for the assessment of pesticide pressure at different scales, from field to national level; it is defined as the mean number of treatments per hectare with commercial products, weighted by the ratio of the dose used to the recommended dose. As a reference, the average TFI for wheat in France was 4.9 in 2017 [28]. In France, organic agriculture follows the European standard n° 834/2007 (the use of synthetic pesticides and fertilizers is forbidden). Conservation agriculture is based on: i) the absence of soil disturbance other than sowing with a light tine or disc, ii) maximum soil coverage by intercropping and residues, and iii) diversification of cultivated species over time (rotation) and in space (intercrops). In conventional farming, tillage and synthetic inputs are used. The cropping fields were classified as conventional, conservation or organic in 2021, but some have recently transitioned to another system, thus explaining the TFI of 1.7 in a field classified as organic.

| Field number | Agriculture system | Agriculture system history | Crop in 2021 | Mean annual TFI (2018–2021) | Total number of moldboard ploughing operations (2018–2021) | Mean number of other tillage operations/year (2018–2021) |
|---|---|---|---|---|---|---|
| 1 | Conservation | 10 years | Winter wheat | 6.9 | 0.0 | 0.3 |
| 2 | Conservation | 10 years | Winter barley | 3.4 | 1.0[a] | 0.3 |
| 3 | Conservation | 5 years | Oilseed rape | 6.8 | 0.0 | 0.0 |
| 4 | Conventional | >30 years | Oilseed rape | 5.0 | 1.0 | 2.3 |
| 5 | Conventional | >30 years | Winter wheat | 5.9 | 2.0 | 1.3 |
| 6 | Conventional | >30 years | Winter barley | 6.2 | 2.0 | 2.5 |
| 7 | Organic | 2 years, after conventional | Lucerne | 0.0 | 2.0 | 4.7 |
| 8 | Organic | 2 years, after conservation | Triticale undersown to white clover | 1.7 | 0.0 | 4.0 |
| 9 | Organic | 20 years | Winter wheat | 0.0 | 4.0 | 5.5 |
| 10 | Organic | 20 years | Winter wheat | 0.0 | 4.0 | 5.7 |

[a] Exceptional intervention.

phosphorus ($P_2O_5$; in g $kg^{-1}$) by inductively coupled plasma mass spectrometry. The soil texture at the ten sampling locations was mainly silty loam composed of 61 % silt, 24 % clay and 15 % sand (Table S1). The pH at all sampling sites ranged between 7.2 and 8.2. Similar to all the measured soil parameters (Table S1), the mean (± standard deviation) organic matter content was similar in the flower strips (25.3 ± 7.2 g $kg^{-1}$) and in the cropped fields (25.6 ± 7.3).

Soil moisture was measured by weighing soil samples (0–20 cm depth, taken from the composite sample used for soil analysis, see above) before and after drying at 105 °C for 48 h. The mean soil moisture (n = 10) was 29.8 % (±4.6) in the flower strips and 29.6 % (±2.7) in the cropped fields.

Earthworms and enchytraeids were sampled in March 2021. At a depth of 10 cm, the minimum and maximum soil temperatures during the sampling period (5 days) were 6.5 and 8.0 °C, respectively (at the meteorological station of Thiverval Grignon, 50 km west of the sampling area). For the earthworms, six samples were taken from each cropped field and flower strip (Fig. 1) at the ten sampling locations. A 40 cm × 40 cm × 25 cm-deep block of soil was extracted. Earthworms were hand-sorted and preserved in 70 % alcohol before counting and weighing each individual without emptying the gut contents. The development stage of each earthworm was noted. Earthworms were considered sub-adults if they had full tubercula pubertatis but no clitellum and adults if they had a clitellum. They were considered juvenile if they had neither a tubercula pubertatis nor a clitellum. Sub-adults and adults were identified at the species level using the identification keys described by Sims and Gerard [29]. Juveniles were identified at the species level on the basis of the morphological characteristics of each species and the specific form they take in alcohol compared with adults. When identification at the species level was impossible, individuals were classified as 'unidentified'.

For the enchytraeids, three samples were taken from each cropped field and from each flower strip (Fig. 1) at the ten sampling locations. Sampling was carried out following the ISO 23611-3 method [30] with a 5-cm Ø soil auger at 0–5 cm and 5–10 cm depths in the flower strips and the non-ploughed fields (conservation agriculture, Table 1) because most enchytraeids generally stay in the uppermost soil layers [31]. In the ploughed fields (Table 1), samples were taken at 0–5, 5–10, and 10–20 cm depths because enchytraeids can be redistributed at different depths by soil tillage [32,33]. Each sample was transferred separately into a plastic bag and stored at 4 °C. Enchytraeids were extracted using wet funnel extractors under light from incandescent light bulbs [34,35]. All individuals were kept in Petri dishes with tap water and counted. Adult and sub-adult individuals were identified at the species level under a light microscope (up to 400x magnification) using the keys described by Schmelz and Collado [36].

### 2.3. Statistical analysis

At each site and for both flower strips and cropped fields, earthworm abundance and biomass were determined for the whole sample and for the three main ecological categories: epigeic, anecic and endogeic. For enchytraeids, the total abundance and abundance of r-strategists (i.e., life strategy, according to Graefe and Schmelz [37]) were determined. Abundance and biomass were expressed as individuals $m^{-2}$ and g $m^{-2}$, respectively. The effects of habitat (cropped field vs. flower strip) on earthworm and enchytraeid abundance, biomass and richness were assessed. Generalized linear mixed models and the glmmTMB package [38] were used, assuming a Gaussian error distribution or a negative binomial error distribution to account for data overdispersion, depending on the response variable. The models included replicate numbers nested within the habitat as a random effect to account for repeated measurements. The significance of the fixed effects (habitat and cropping system) was evaluated with type II analyses of deviance with the Wald chi-squared test and the ANOVA function of the car package [39]. Interactions between explanatory variables were not tested due to the insufficient size of the dataset. The distribution of model residuals (normality, homoscedasticity, outliers) was checked and confirmed with the DHARMa package [40]. To visualise how the cropping systems may have influenced the difference between flower strips and cropped fields, ratios of the total abundance and species richness in flower strip to cropped field were calculated for both earthworms and enchytraeids in all the fields, according to the cropping systems. Statistical analyses were performed with R software version 3.1.3 [41].

## 3. Results

### 3.1. Earthworms

The total earthworm abundance and total biomass were significantly greater ($1.81 \cdot 10^{-7}$ and $5.73 \cdot 10^{-8}$, respectively) in the flower strips than in the adjacent cropped fields (238.5 ± 143.8 individuals $m^{-2}$ *versus* 141.0 ± 74.8 individuals $m^{-2}$; and 93.6 g $m^{-2}$ ± 49.2 *versus* 54.5 g $m^{-2}$ ± 33.2, respectively) (Fig. 2a–b). The positive effect of flower strips on abundance and biomass was also significant when earthworms were divided into ecological categories, except for the mean abundance of epigeic earthworms (p = 0.06), although it was seven times greater in the flower strips than in the cropped fields (Table 2).

Overall, two epigeic species, three anecic or epi-anecic species (considered anecic), and six endogeic or epi-endo-anecic species (considered endogeic), were found at the ten sampling locations (Table 2). The most abundant species was *Aporrectodea caliginosa*, which represented 55 % of the total abundance in the flower strips and 50 % in the cropped fields across the ten sampling locations (Table 2). Two

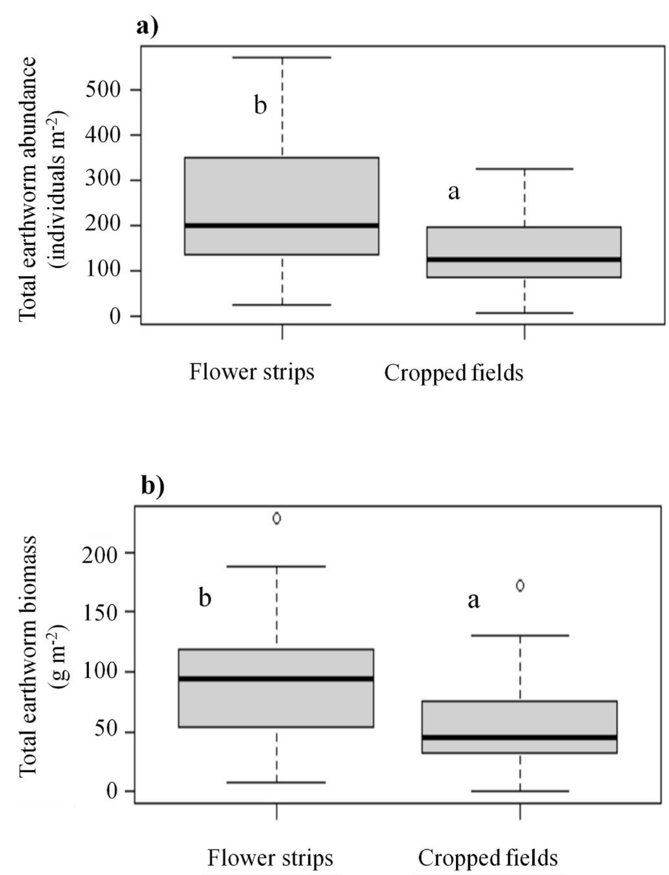


**Fig. 2.** Total earthworm a) abundance (individuals $m^{-2}$) and b) biomass (g $m^{-2}$) in flower strips and cropped fields (n = 60 observations in 10 fields for both). Significant differences between habitats (p = 0.05) are indicated with different letters.

**Table 2**
Effect of the habitat and of the cropping system on the abundance (individuals $m^{-2}$) and biomass (g $m^{-2}$) (standard-deviations in brackets) of the different species and on ecological categories of earthworms. The effect of habitat (FS: flower strips, CF: cropped fields) and cropping systems (conventional, conservation, organic farming) were tested with a generalized mixed effect model (n = 120 observations in ten fields); significant results are in bold.

| | | Abundance (ind·$m^{-2}$) | | Effect of habitat | Effect of cropping system | Biomass (g·$m^{-2}$) | | Effect of habitat | Effect of cropping system |
|---|---|---|---|---|---|---|---|---|---|
| Species | Ecological category(ies) | FS | CF | p-value | | FS | CF | p-value | |
| *Lumbricus rubellus* | epigeic | 0.3 (0.7) | 0.0 (0.0) | | | 0.2 (0.5) | 0.0 (0.0) | | |
| *Lumbricus castaneus* | epigeic | 14.8 (43.9) | 1.8 (4.3) | | | 2.5 (7.4) | 0.2 (0.6) | | |
| Epigeic indet. | epigeic | 0.0 (0.0) | 0.2 (0.7) | | | 0.0 (0.0) | 0.0 (0.1) | | |
| Total epigeic earthworms | | 15.1 (43.8) | 2.0 (4.3) | 0.0577 | 0.9705 | 2.7 (7.4) | 0.3 (0.6) | **0.0004** | 0.5815 |
| *Lumbricus terrestris* | epi-anecic | 7.7 (12.8) | 4.7 (5.6) | | | 3.8 (4.3) | 4.9 (5.8) | | |
| *Aporrectodea longa* | anecic | 11.3 (16.2) | 5.3 (10.2) | | | 18.6 (24.5) | 6.8 (7.9) | | |
| *Aporrectodea giardi* | anecic | 1.6 (2.7) | 0.7 (1.1) | | | 5.5 (8.6) | 2.6 (4.1) | | |
| *A. longa/A. giardi* (indet.) | anecic | 17.4 (19.8) | 15.5 (22.5) | | | 8.8 (8.4) | 8.6 (12.8) | | |
| Total anecic earthworms | | 37.9 (39.5) | 26.3 (26.1) | **0.0153** | 0.8447 | 36.7 (37.4) | 22.8 (18.5) | **0.0191** | 0.8412 |
| *Allolobophora chlorotica* | epi-endo-anecic | 13.1 (19.7) | 11.7 (18.4) | | | 2.8 (4.3) | 2.6 (4.2) | | |
| *Aporrectodea caliginosa* | endogeic | 131.8 (101.3) | 71.7 (51.3) | | | 37.5 (23.5) | 18.7 (13.6) | | |
| *Aporrectodea rosea* | endogeic | 6.5 (9.1) | 2.6 (2.2) | | | 1.4 (1.8) | 0.8 (0.7) | | |
| *Aporrectodea icterica* | endogeic | 33.3 (28.6) | 25.7 (26.2) | | | 11.9 (9.6) | 9.1 (9.1) | | |
| *Allolobophora muldali* | endogeic | 0.1 (0.3) | 0.0 (0.0) | | | 0.0 (0.0) | 0.0 (0.0) | | |
| *Octalasion cyaneum* | epi-endo-anecic | 0.2 (0.7) | 0.1 (0.3) | | | 0.5 (1.7) | 0.2 (0.5) | | |
| Endogeic indet. | endogeic | 0.5 (1.3) | 1.0 (1.4) | | | 0.0 (0.1) | 0.1 (0.1) | | |
| Total endogeic earthworms | | 185.5 (113.6) | 112.8 (51.0) | **6.51·$10^{-7}$** | 0.2277 | 54.2 (26.9) | 31.5 (17.7) | **3.83·$10^{-7}$** | 0.2117 |

species (*Allolobophora muldali* and *Lumbricus rubellus*) were present only in the flower strips (Table 2). For *Lumbricus castaneus*, the standard deviation was very high because its abundance was very high in one flower strip (i.e., 139.6 individuals $m^{-2}$, field 7; Table 1 and Table A1) and very low (≤5 individuals $m^{-2}$) in the other nine flower strips. The mean number of earthworm species was 3.7 ± 1.0 in the flower strips and 3.4 ± 1.1 in the cropped fields (p value = 0.23).

The ratios of the total abundance in flower strip to cropped field was higher in one organic field than in the other systems for earthworms (Fig. 3a), highlighting potential differences in the effect of flower strips depending on the agricultural system, although cropping systems effects were never significant (Table 2; Table A2).

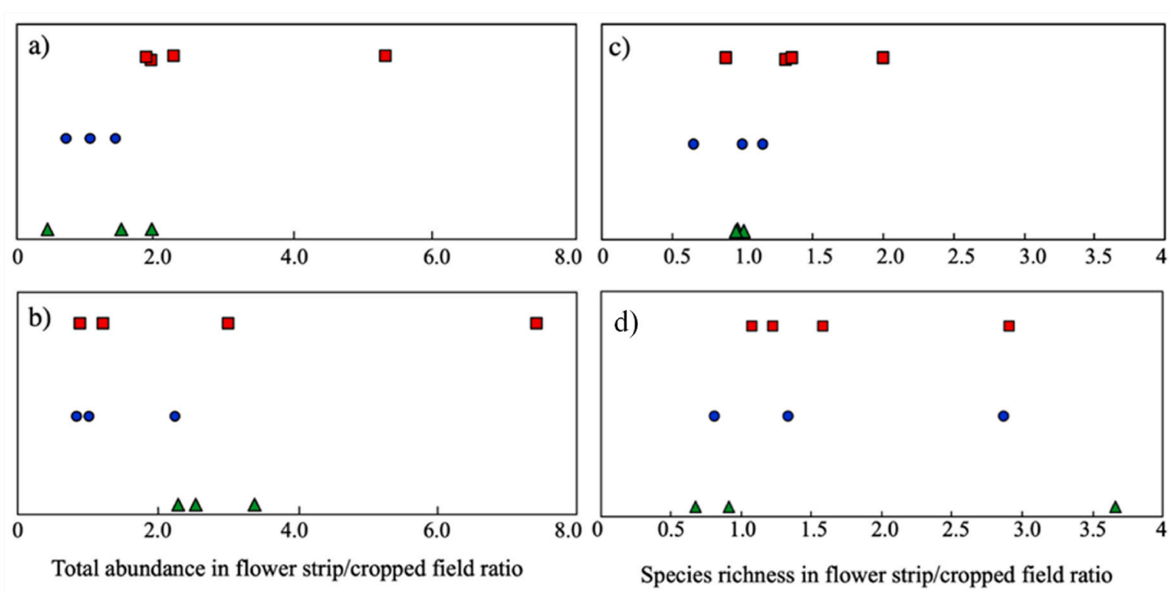


**Fig. 3.** Stripchart plots illustrating the ratio of the total abundance (a, b) or of species richness (c, d) in flower strip to cropped field for earthworms (a, c) and enchytraeids (b, d). Green triangles, blue circles and red squares for conventional (n = 3), conservation (n = 3) and organic agriculture (n = 4), respectively.

### 3.2. Enchytraeids

In total, 1475 and 913 individuals were found in wildflower strips and cropped fields, respectively. The total enchytraeid abundance and species richness were greater in the flower strips than in the cropped fields (25,041 ± 18,684 individuals $m^{-2}$ *versus* 15,466 ± 16,186 individuals $m^{-2}$, $p = 0.00228$; and 6.9 ± 2.5 species *versus* 5.1 ± 3.2 species, $p = 0.00536$, respectively) (Fig. 4a–b). Cropping system had no significant effect.

Seven different genera and 34 species of enchytraeids were recorded, as well as nine potentially new, undescribed species (1 from *Buchholzia*, 2 from *Achaeta* and 6 from *Fridericia*) (Table 3). The most abundant species were *Enchytraeus bulbosus* and *Enchytraeus buchholzi*, which represented 25 % and 20 % of the total enchytraeid abundance, respectively, followed by *Fridericia christeri* (7 % of the total abundance). These three species were found at all ten sampled sites. Three species were found at seven sites, but each represented less than 6 % of the total abundance (Table 3). The percentage of r-strategists was slightly lower ($p = 0.04$) in flower strips (40 % ± 24) than in cropped fields (50 % ± 28 %) (Table 3), without any cropping system effect ($p = 5.38 \cdot 10^{-9}$).

The calculated abundance ratios for enchytraeids were similar regardless of the farming system (conservation, conventional, or organic farming) (Fig. 3b). The dispersion was also greater between fields managed by organic agriculture than between those managed by conservation or conventional agriculture. The mean ratios of the species richness of enchytraeids and earthworms in flower strips to that in cropped fields were also very dispersed between fields (Fig. 3c–d) and were not significantly different. The mean ratio ($n = 10$) of the total abundance in flower strips to that in cropped fields was not different ($p = 0.46$) for enchytraeids (2.47 ± 1.99) and earthworms (1.88 ± 1.34).

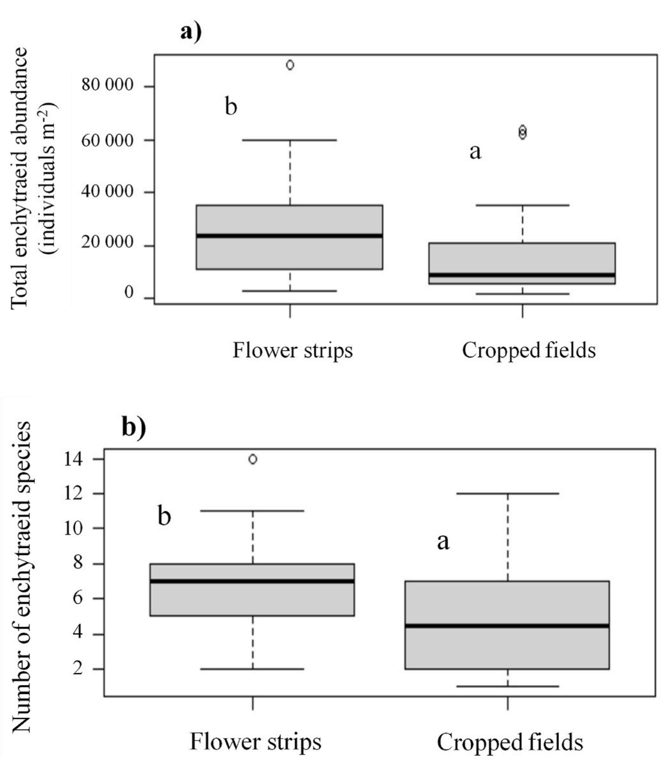


**Fig. 4.** a) Mean total abundance (individuals $m^{-2}$) and b) diversity (number of species) of enchytraeids in flower strips and cropped fields ($n = 30$ observations in 10 fields for both). Significant differences between habitats ($p = 0.05$) are indicated with different letters.

## 4. Discussion

At 2.5 years after sowing, flower strips increased the total abundance of earthworms and enchytraeids, favouring anecic and endogeic earthworms and also enchytraeid diversity compared with the adjacent arable cropped fields. This might be due to the decrease in physical and chemical disturbances and the suitable feeding conditions for Oligochaeta (Annelida) in the perennial flower strips [12,21]. These positive effects of flower strips were also found for above-ground biodiversity, with perennial and older flower strips being more effective than younger flower strips [42]. The increase in earthworm and enchytraeid abundance in flower strips is explained first by internal recovery, which depends on the individuals present in the original cropped field and originates from population increase through reproduction after the soil management changes [43]. External recovery may also have occurred through the immigration of individuals from neighbouring areas (e.g., adjacent grassy roadsides) by active or passive dispersal [44–46]. External recovery may explain why some species were found only in flower strips (e.g., *L. rubellus*) where individuals could settle due to suitable local conditions. As different earthworm species do not have the same dispersal and colonization capabilities [46], diversity can increase slowly in flower strips. Moreover, the seed mixtures (i.e., plant community species composition) used in the different studied flower strips can influence plant community development and consequently earthworm communities [21]. Therefore, it is important to assess the long-term effects of flower strips. Future studies could determine whether flower strips allow field colonization. This could be done by assessing whether a gradient of abundance appears after a few years between the flower strip and the cropped fields, as observed by Hof and Bright [47]. More generally, the dynamics of earthworm and enchytraeid populations should be regularly assessed in these less disturbed habitats to measure the speed (i.e., slope of the curve) of the increase in abundance and diversity and the change in carrying capacity (i.e., plateau of the curve that represents the maximum population size that can be sustained by the environment) of these preserved habitats.

In our cropped fields, the abundances of earthworms and enchytraeids were close to those generally found in agricultural systems: approximately 140 and 15,000 individuals $m^{-2}$, respectively [48,49]. Moreover, the most abundant earthworm (*A. caliginosa*) and enchytraeid (*E. buchholzi* and *E. bulbosus*) species are species typically found in cropped fields in temperate regions [23,50]. For earthworms, the combination of hand-sorting and a chemical expellant (i.e., ethological methods) is recommended, particularly to properly assess anecic earthworms [51]. However, Callaham and Hendrix [52] reported that the formalin extraction method was more effective than hand-sorting for the collection of *L. terrestris* but not for any other species. Moreover, liquid extraction involves a chemical (e.g., formalin or mustard oil) that is not necessarily allowed in organic farming. Here, we chose to use hand-sorting only, so the abundance of adult anecic and epi-anecic earthworms may have been underestimated and greater differences between flower strips and arable cropped fields potentially masked. This choice could also have underestimated their abundances under conservation agriculture with lower tillage intensity. Nine potentially new species of enchytraeids (not described so far) were found in the ten sampling sites near Paris. Enchytraeids have been less studied than earthworms, although they have functional roles similar to those of earthworms in soils (i.e., soil organic matter degradation and soil porosity dynamics) but at a smaller scale [53]. Therefore, more studies are needed to better describe the diversity of these soil animals and to assess the effects of anthropogenic activities on enchytraeids.

The studied cropped fields were managed differently, with either conventional, organic or conservation agriculture techniques. In all three agricultural systems, the abundance and biomass of all earthworm species and two-thirds of the enchytraeid species were greater in the flower strips than in the adjacent cropped fields. This positive effect of

**Table 3**
Number of individuals of the different enchytraeid species found in the 10 sampling sites at two (in flower strips and unploughed crops) or three (in ploughed crops) different soil depths in flower strips and cropped fields, and life strategy of the identified species (r or k, according to Graefe and Schmelz, 1999). *Fridericia* sp. indet. are juveniles that could not be identified at the species level. *Fridericia* sp. 1 to 6 are potentially new species (undescribed to date) that could not be named (but the individuals could be linked to a morphospecies).

| | | | | | Flower strips | | | Cropped fields | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Strategy | Number of sites | 0–5 cm | 5–10 cm | TOTAL | 0–5 cm | 5–10 cm | 10–20 cm | TOTAL |
| *Achaeta* | *bohemica* | Vejdovský, 1879 | k | 1 | 5 | 1 | **6** | 0 | 0 | 0 | **0** |
| *Achaeta* | *pannonica* | Graefe, 1989 | k | 1 | 1 | 1 | **2** | 0 | 0 | 0 | **0** |
| *Achaeta* | sp. 1 | | – | 3 | 0 | 1 | **1** | 0 | 0 | 3 | **3** |
| *Achaeta* | sp. 2 | | – | 1 | 0 | 0 | **0** | 0 | 1 | 1 | **2** |
| *Buchholzia* | *appendiculata* | Buchholz, 1862 | r | 5 | 24 | 5 | **29** | 1 | 0 | 0 | **1** |
| *Buchholzia* | *fallax* | Michaelsen, 1887 | r | 3 | 6 | 3 | **9** | 0 | 1 | 1 | **2** |
| *Buchholzia* | sp. 1 | | – | 1 | 0 | 0 | **0** | 0 | 1 | 3 | **4** |
| *Enchytraeus* | *buchholzi* | Vejdovský, 1879 | r | 10 | 191 | 58 | **249** | 131 | 63 | 30 | **224** |
| *Enchytraeus* | *bulbosus* | Nielsen & Christensen, 1959 | r | 10 | 177 | 184 | **361** | 115 | 97 | 22 | **234** |
| *Enchytraeus* | *coronatus* | Nielsen & Christensen, 1959 | r | 1 | 1 | 0 | **1** | 0 | 1 | 0 | **1** |
| *Enchytraeus* | *lacteus* | Nielsen & Christensen, 1959 | r | 1 | 0 | 4 | **4** | 0 | 1 | 0 | **1** |
| *Enchytronia* | *christenseni* | Dózsa-Farkas, 1970 | k | 7 | 26 | 50 | **76** | 6 | 25 | 20 | **51** |
| *Fridericia* | *bulboides* | Nielsen & Christensen, 1959 | k | 2 | 20 | 0 | **20** | 0 | 0 | 0 | **0** |
| *Friderica* | *christeri* | Rota & Healy, 1999 | k | 10 | 94 | 42 | **136** | 14 | 24 | 3 | **41** |
| *Friderica* | *connatiformis* | Dózsa-Farkas, 2015 | k | 2 | 10 | 2 | **12** | 5 | 5 | 0 | **10** |
| *Fridericia* | *dozsae* | Schmelz, 2003 | k | 3 | 2 | 3 | **5** | 2 | 0 | 0 | **2** |
| *Friderica* | *galba* | Hoffmeister, 1843 | k | 7 | 18 | 7 | **25** | 10 | 4 | 6 | **20** |
| *Friderica* | *isseli* | Rota, 1994 | k | 5 | 16 | 8 | **24** | 1 | 10 | 11 | **22** |
| *Friderica* | *nix* | Rota, 1995 | k | 5 | 1 | 16 | **17** | 1 | 0 | 10 | **11** |
| *Friderica* | *paroniana* | Issel, 1904 | k | 2 | 7 | 0 | **7** | 5 | 3 | 0 | **8** |
| *Fridericia* | *rendsinata* | Dózsa-Farkas, 1972 | k | 1 | 6 | 0 | **6** | 1 | 0 | 0 | **1** |
| *Friderica* | *sylvatica* | Healy, 1979 | k | 3 | 1 | 2 | **3** | 12 | 16 | 0 | **28** |
| *Friderica* | *tuberosa* | Rota, 1995 | k | 3 | 5 | 2 | **7** | 4 | 4 | 0 | **8** |
| *Friderica* | sp. 1 | | – | 7 | 0 | 11 | **11** | 1 | 1 | 3 | **5** |
| *Fridericia* | sp. 2 | | – | 4 | 1 | 2 | **3** | 0 | 5 | 4 | **9** |
| *Fridericia* | sp. 3 | | – | 1 | 0 | 0 | **0** | 0 | 1 | 0 | **1** |
| *Fridericia* | sp. 4 | | – | 1 | 2 | 0 | **2** | 0 | 0 | 0 | **0** |
| *Fridericia* | sp. 5 | | – | 1 | 8 | 9 | **17** | 0 | 1 | 0 | **1** |
| *Fridericia* | sp. 6 | | – | 1 | 1 | 0 | **1** | 0 | 0 | 4 | **4** |
| *Friderica* | sp. indet. | | – | 10 | 186 | 119 | **305** | 80 | 78 | 26 | **184** |
| *Henlea* | *perpusilla* | Friend, 1911 | k | 4 | 7 | 8 | **15** | 10 | 6 | 0 | **16** |
| *Henlea* | *ventriculosa* | d'Udekem, 1854 | k | 4 | 65 | 1 | **66** | 2 | 0 | 2 | **4** |
| *Marionina* | *brendae* | Rota, 1995 | k | 1 | 0 | 3 | **3** | 0 | 0 | 6 | **6** |
| *Marionina* | *hoffbaueri* | Möller, 1971 | k | 1 | 0 | 1 | **1** | 0 | 0 | 0 | **0** |
| *Marionina* | *mendax* | Rota, 2013 | k | 2 | 19 | 32 | **51** | 1 | 8 | 0 | **9** |
| TOTAL (Σ of individuals) | | | | | 900 | 575 | **1475** | 402 | 356 | 155 | **913** |

flower strips on earthworm abundance could be related to the agricultural system, but here the low number of fields per system makes it difficult to conclude properly on the effects of these three systems.

Our findings showed that the enchytraeid and earthworm communities were similarly favoured by flower strip sowing. Beylich et al. [49] stated that conditions favouring soil organisms can result in increased activity of these two Oligochaeta groups. Similar to earthworms, enchytraeids are bioindicators of land use and agricultural practices [15, 18], and they can take advantage of the decrease or suppression in soil tillage and pesticide use [54]. As enchytraeids live at the soil surface and consume high quantities of organic matter [33], they could have been more favoured by the supply of organic matter in flower strips (decomposing senescent plants, especially in fall). Last, as enchytraeids have a relatively short life cycle compared with that of earthworms, their populations can increase rapidly when the available resources increase.

## 5. Conclusion

Perennial habitats, such as flower strips, promote aerial and soil organisms, but few studies have investigated their effects on Oligochaeta. The present study showed that in a short period of time (2.5 years), flower strips could increase the abundance and biomass of earthworms and enchytraeids and also increase enchytraeid diversity. As these soil organisms are involved in key functions related to soil fertility and are prey for higher trophic levels, the implementation of such linear habitats in the landscape could constitute a source of biodiversity and provide other ecosystem services in agricultural landscapes.

## CRediT authorship contribution statement

**C. Pelosi:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **M. Bertrand:** Writing – review & editing, Methodology, Investigation. **A. Gardarin:** Writing – review & editing, Resources, Project administration, Funding acquisition, Formal analysis, Conceptualization.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Data availability

Data will be made available on request.

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ejsobi.2024.103644.

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