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Seasonal population dynamics of *Eisenia fetida* (Savigny, 1826) (Oligochaeta, Lumbricidae) in the field

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Abstract

In order to assess the response of epigeic earthworms to seasonal changes we monitored the population dynamics of *Eisenia fetida* (Oligochaeta, Lumbricidae) in a manure heap in the field during a year. Earthworms were hand-sorted from five 0.25 × 0.25 × 0.20 m blocks around the heap in November (autumn) 1999 and in January (winter), April (spring) and August (summer) 2000 to determine earthworm population dynamics. Earthworms of each block were classified into different age classes: mature, preclitellate, juvenile, hatchling and cocoon, and afterwards counted and weighed. Seasonality had a strong effect on the density, biomass and reproductive activity of the population. The population of *E. fetida* was characterized by a high density of individuals and the predominance of mature individuals throughout the year. Maximum density, mating activity and size of cocoons were achieved in spring, but there were not changes in the number of cocoons per mature earthworm throughout the year. Unexpectedly, the smallest cocoons were produced in winter by the largest individuals. These results suggest that *E. fetida* is able to allocate resources to growth and/or reproduction in response to environmental fluctuations. ***To cite this article: F. Monroy et al., C. R. Biologies 329 (2006).***

Keywords: Earthworms; Seasonal effects; Mating activity; Population dynamics; Age classes

1. Introduction

Soil fauna is influenced by environmental factors and changes in soil physical and chemical properties influence their number and local distribution patterns [1–3]. Some of these changes, such as seasonal variations, are time-related, affecting animal life cycles and their annual population dynamics. Moreover, differences in resource availability also play an important role to determine some life history traits such as growth, size at maturity, number and size of offspring and length of life [4].

Earthworms represent a major group into the soil fauna and seasonal factors play an important role in explaining changes in size and biomass of their populations [5]. Because earthworm species exhibit different ecological preferences, the influence of environmental factors on population dynamics differs among earthworms of different ecological categories [6]. Since the two soil conditions that affect earthworm activity most are temperature and moisture [5], epigeic earthworms (earthworm species that live and feed in the litter layer)

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are probably much more affected by the season than endogeic or anecic species (those that inhabit permanent or semipermanent burrow systems into the soil). *Eisenia fetida* (Savigny, 1826) is an epigeic species associated to environments with high organic matter content and their natural populations live at high densities in patchy distributions [7]. The basic aspects of the life cycle of *E. fetida* are relatively well documented due to the importance of this species in waste management. The growth and reproduction of this earthworm species is affected by several factors such as food quality, moisture, temperature and population density, as showed under laboratory conditions (see [8] for a review). Moreover *E. fetida* is an iteroparous earthworm, with continuous and high reproduction rates, and it should respond to adverse environmental conditions modifying those rates.

Partly due to the particular distribution of this species, mainly associated to compost and manure piles [9], there is only one study regarding its seasonal cycle [10]. The present work was undertaken to study the effect of seasonality on the changes of density, biomass and reproductive activity of the earthworm *E. fetida* in a field population.

2. Materials and methods

Individuals of *E. fetida* were collected in a temporary heap of cow manure from a small farm near the University of Vigo (42°9′N, 8°41′W), in the northwest of Spain. Average annual rainfall and temperature in the zone range between 2500–3000 mm and 11–12 °C respectively, with lower rainfall and higher temperatures reached in the summer [11,12]. Nevertheless, during the sampling period, the total precipitation was 1820 mm, as is referred in Table 1. The population of *E. fetida* was limited to the manure heap, since this epigeic species is scarce or absent in soils without direct presence of organic amendments [7]. Earthworms were hand-sorted from five $0.25 \times 0.25 \times 0.20$-m blocks around the heap in November (autumn) 1999, January (winter) and April (spring) 2000 to determine earthworm population dynamics. Summer samples were collected in August 2000 using only two blocks, since most of the manure heap was removed as every year in late spring to use it as source of organic matter in agricultural fields. In order to know the age distribution of the population, earthworms collected from each sample were separated in the laboratory into mature (with well-developed clitellum), preclitellate (with *tubercula pubertatis*), juvenile, and hatchling (<0.01 g) stages. Earthworms were counted and weighed during each seasonal sampling. Cocoons were also counted and weighed from a subsample of 100 g of substrate. Average cocoon deposition per earthworm was estimated for each season from densities of cocoons and mature individuals. Mature earthworms were checked in the laboratory, using a dissecting microscope, for the presence of spermatophores, which indicates a recent mating [13]. Therefore, mating activity was estimated as the percentage of mature individuals with spermatophores.

Statistical analyses of earthworm data were done using SPSS (version 11.0.1) for Windows. Prior to the analysis, sampled values were normalized using a $\log(x + 1)$ transformation. The effect of the season was analyzed by one-way ANOVA with the GLM procedure of SPSS. Post hoc comparisons between the different seasons were performed using the Tukey HSD test.

Table 1
Total rainfall and average temperature in the study area on sampling dates

	Rainfall (mm)	Temperature (°C)
Autumn 1999	600	9.1 ± 1.6
Winter 1999	200	8.1 ± 1.7
Spring 2000	770	12.1 ± 2.7
Summer 2000	250	16.0 ± 0.3

3. Results

The density of *E. fetida* in the field population across all seasons was 4950 ± 690 individuals m^{-2}, with a biomass of 1040 ± 130 g live weight m^{-2}. Most of the biological traits of this population strongly changed through the year (Table 2). The number of earthworms increased significantly from autumn to spring, when the population showed its maximum density. In summer, the earthworm population density decreased until the lowest numbers. Earthworm biomass followed a similar seasonal trend, with the highest value in spring and the lowest in summer (Table 2). The density and the average weight of the cocoons were significantly higher in spring and lower in winter (Table 2).

The age structure of the population also changed over time. The mature-to-juvenile ratios were 11.4, 1.4, 1.7 and 0.1 for autumn, winter, spring and summer, respectively. The proportion of mature earthworms was almost constant during autumn, winter and spring and was very low during the summer, when almost 80% of the individuals were juveniles; the highest numbers of hatchlings were found in spring (Table 2). Mature, preclitellate and juvenile earthworms were larger in winter and autumn than in spring and summer (Table 2). Mature earthworms bearing spermatophores were present in the population during the whole year and were more

Table 2
Effect of the season (GLM test) on the density, biomass and reproductive activity of a field population of the earthworm *Eisenia fetida* (Oligochaeta, Lumbricidae)

	Autumn	Winter	Spring	Summer	Seasonal effect		
					df	F	P
Total earthworms (No. m^{-2})	2450 ± 250[a]	3965 ± 490[a]	8460 ± 1000[b]	4888 ± 1528[ab]	3	14.04	<0.001
Mature (No. m^{-2})	1680 ± 380[a]	1760 ± 370[a]	3810 ± 480[a]	432 ± 224[b]	3	10.00	0.001
Preclitellate (No. m^{-2})	540 ± 90[a]	540 ± 110[a]	790 ± 150[a]	504 ± 24[a]	3	0.47	0.710
Juvenile (No. m^{-2})	150 ± 55[a]	1250 ± 280[b]	2280 ± 680[b]	3488 ± 1552[b]	3	18.34	<0.001
Hatchling (No. m^{-2})	Not sampled	410 ± 160[a]	1650 ± 500[a]	464 ± 224[a]	2	2.01	0.190
Cocoon (No. m^{-2})	Not sampled	850 ± 400[a]	3970 ± 1090[b]	184 ± 24[a]	2	15.40	0.001
Total biomass (g live weight m^{-2})	775 ± 150[a]	980 ± 180[ab]	1570 ± 240[b]	527 ± 31[a]	3	4.60	0.021
Mature weight (g individual^{-1})	0.33 ± 0.02[ab]	0.40 ± 0.02[a]	0.32 ± 0.01[b]	0.29 ± 0.01[b]	3	5.87	0.009
Preclitellate weight (g individual^{-1})	0.28 ± 0.03[a]	0.25 ± 0.01[ab]	0.21 ± 0.01[b]	0.22 ± 0.02[ab]	3	3.36	0.052
Juvenile weight (g individual^{-1})	0.15 ± 0.02[a]	0.10 ± 0.01[a]	0.09 ± 0.01[a]	0.08 ± 0.01[a]	3	3.49	0.047
Cocoon weight (mg unit^{-1})	Not calculated	12.03 ± 1.36[a]	22.57 ± 1.37[b]	19.12 ± 0.01[b]	2	17.03	<0.001
Mating activity (%)	10.5 ± 4.1[ab]	3.8 ± 1.5[a]	22.1 ± 1.6[b]	4.9 ± 4.9[ab]	3	5.20	0.014
No. cocoon adult^{-1}	Not calculated	0.4 ± 0.1[a]	1.1 ± 0.3[a]	0.6 ± 0.4[a]	2	2.72	0.119

Values are means ± SE ($n = 5$ for autumn, winter and spring; $n = 2$ for summer). Different letters indicate significant differences (Tukey HSD test, $\alpha = 0.05$).

abundant in spring (Table 2). Mating activity was significantly higher in spring and autumn. The number of cocoons per mature earthworm was similar throughout the year (Table 2).

4. Discussion

Seasonality had a strong influence on the growth and reproduction of *E. fetida* and consequently on the age structure of the population. This population was characterized by a very high density and biomass with a high proportion of mature individuals throughout the year. This resulted in an unusual population structure where the young earthworms were not the most abundant stage, as in other earthworm species [5]. High densities are common in *E. fetida* populations when large quantities of organic matter are available, supporting up to 14 600 individuals m^{-2} [7]. Moreover, *E. fetida* lives in environments where the food and the living substrate usually are the same [9] and this resource availability should improve the conditions for earthworm growth and reproduction, and promote the occurrence of high numbers of mature individuals.

In our study, the average size of the mature earthworms ranged between 0.30 and 0.40 g, as it was reported by Watanabe and Tsukamoto [10], although *E. fetida* can reach nearly 1.6 g in laboratory conditions [14]. The low mean annual temperature in the study area (11–12 °C) could explain the observed size of the mature earthworms [15]. Furthermore, the high population density likely had a strong effect on mature weight, since Neuhauser et al. [16] and Reinecke and Viljoen [17] reported a weight of adult individuals below 0.40 g for population densities equivalent to 2000 and 2700 individuals m^{-2}, respectively.

Unexpectedly, maximum mean weight of adult earthworms was achieved in winter, at the lowest temperatures, but these large-sized earthworms showed the lowest mating activity. Temperature regimes below 15 °C cause low growth rates [18], but also affect to reproduction diminishing cocoon production and increasing incubation time [15,19]. The low reproductive activity found in winter could lead to weight gain due to decrease of reproductive costs and reallocation of resources toward growth [4]. According to this, the mean weight of the mature earthworms decreased in spring with the increasing reproductive activity. Similar results for resource reallocation to growth were reported by Cluzeau et al. [20] when adult individuals of *E. fetida* were isolated or reared in groups after mating.

The decline of the mature stage in summer was another feature of the population of *E. fetida*. The marked decrease in density of mature earthworms was probably caused by the strong disturbance caused by the removal of most of the manure in late spring. After this event, small juvenile and newly hatched individuals became the most abundant stages in the summer population.

Mating processes and production of cocoons in the population of *E. fetida* occurred throughout the whole year, indicating that there were some favourable and stable conditions to reproduction, even in winter. According to this, in the studied population there was not seasonal effect in the number of cocoons relative to the number of adult earthworms, although the highest mating activity occurred in spring. This mating peak could be due either to the optimal environmental conditions that lead to a maximum in the population traits measured or to an increase in the number of available mates. In fact, the availability of mates is one of the factors involved in the size-assortative mating of earthworms [21,22].

Changes in the density of cocoons over time seem to be related with the density of mature earthworms, despite the lack of significance in their density between winter and spring. These results agree with those of Watanabe and Tsukamoto [10], who found that cocoons were recorded mainly in autumn and spring, being affected by both the high and low temperatures in summer and winter, respectively. We found that cocoons were smaller in winter and larger in spring, and it is interesting to note that the smaller cocoons were produced by the heavier mature earthworms. Then our data suggest that *E. fetida* is able to regulate cocoon size in response to environmental factors. Currently, it remains unclear whether the size of earthworms is the only factor governing cocoon size [14,23,24], but in *E. fetida* the weight of the cocoon influences the number of progeny per cocoon [10,23,25]. We suggest that this ability to regulate the size of the cocoons has important implications in the development of the population. Thus, although in our study there are no significant differences in the number of cocoons in relation to the number of adult individuals between seasons, changes in offspring production and population growth rates can occur anyway.

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