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BIOLOGICAL PRODUCTION IN A WARM-TEMPERATE EVERGREEN OAK FOREST OF JAPAN

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3.2 POPULATION STUDY OF AN EARTHWORM, PHERETIMA SIEBOLDI

Y Sugi and M. Tanaka

The earthworm, *Pheretima sieboldi*, is a species restricted to upland areas of southwestern Japan and has the largest body size among all earthworm species in Japan. The maximum wet weight of a mature individual is as much as 40 g. The population density of this species is rather low, being on the order of about 1-2 individuals per 100 m^2 in the forest surrounding the city of Fukuoka, northern Kyushu. This may be one of the reasons why the ecology of this species has been paid little attention, except for study of its feeding habits by Watanabe (1974).

A large number of *Pheretima sieboldi* were once observed in the Minamata forest migrating from a small valley to upper slopes one hour after a heavy rain on April 15, 1969. After that time, the seasonal changes in their number, distribution and habits of hibernation were observed until October 1971. This section deals with the results of study of the population density, distribution and population metabolism of this remarkable earthworm species.

3.2.1 Methods

Counting In the period from April to November, *Pheretima sieboldi* lives in the ground surface litter layer with the anterior part of its body lying on the surface of the humus layer and the rest horizontally in the humus layer. When the litter layer is artificially disturbed, all individuals creep out from their resting places over the litter layer surface, quickly slipping down the slope. We can thus count the number of worms by removing fresh litter with a farmer's rake to expose the underlying humus layer in a quadrat area. The presence and number of *Ph. sieboldi* are then recorded.

The quadrat size used for population counts was 3 × 3 m^2. Nine or eighteen quadrats were placed on sampling site for counting. Three sites, which were presumably situated in

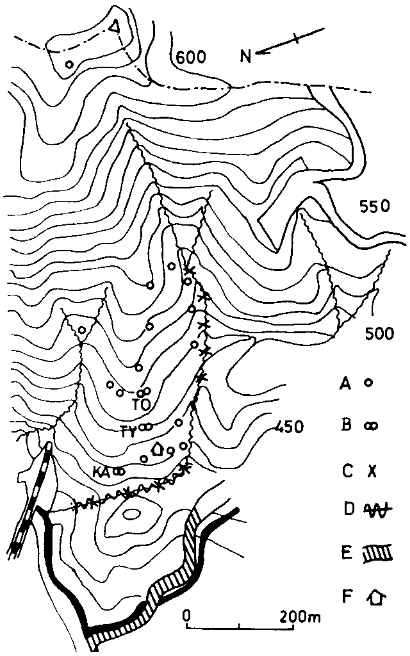

FIG. 3.2-1. Map of the Minamata forest, showing the location of quadrat sites and observation areas.

A: sites for population count. B: sites for monthly counting. C: area for population count of hibernating population. D: area for study of the behavior of hibernating worms. F: area for counting dead worms. F: field hut.

the distribution center for *Ph. sieboldi* in the Minamata forest, were chosen for monthly counts of the worm population from April 1969 to October 1971. In addition, 9-14 sites were also investigated to study of distribution. The location of the sites is shown on the map in Fig. 3.2-1.

Measurement of body weight For determination of individual wet body weight, 20-40 individuals were collected from around the field observation hut (Fig. 3.2-1), weighed and released to their original habitats. Measurements were continued at monthly intervals from March 1969 to July 1971.

Counting the number of dead worms Dead worms were frequently observed on bare ground every year in the summer months. They were counted throughout the observation period in order to determine the factors responsible for mortality. The location of the bare ground studied is also shown in Fig. 3.2-1.

Observations of hibernation Most of the population of *Ph. sieboldi* was found concentrated in the flat bottom of dried dingles during winter, as will be described later. Winter observation was, therefore, very important for study of population density and distribution. The number of hibernating worms was counted on a flat valley bottom on December 3, 1970, while hibernation behavior was observed in the same dingle during the period from December 1970 to April 1971, particularly on rainy days when hibernating individuals came up near the ground surface. The location and the direction of worms' reclining bodies were recorded upon observation.

Measurement of respiration rate Respiration rates were determined in 10 individuals each time, expressed as the rate of $C0_2$ expiration, with an infra-red gas analyzer (URAS). Test specimens were wrapped in moist filter paper and placed in a respiration chamber or a glass tube 3 cm wide and 30 cm long. The air flow rate through the chamber was maintained constant at 30 1 h^{-1}. Measurements were made at four different temperatures, 10, 15, 20 and 25° C, by placing the respiration chamber in a water bath in which the temperature was regulated within a range of ±0.25° C. The rate of $C0_2$ expiration was recorded every 12 minutes during a run of 72 minutes at a given temperature. The rates during the later half of a run were averaged and regarded as the mean respiration rate.

Body dry weight Only two individuals were available for determination of body dry weight. Worm specimens which had been kept in 10 % formaline for one day after narcotizing with alcohol for wet weight measurement, were dissected with a surgical knife to remove gut contents, dried for one day at 60° C and weighed. The dry weight/wet weight ratio was 0.0733. That for *Pheretima* sp. (H-l) was 0.0695 (Sugi, in preparation).

3.2.2 Some aspects of life

Figure 3.2-2 illustrates the distribution *of Ph. sieboldi* in the study area. The hibernating population was observed to come out of the dingle and migrate toward forest-covered slopes on spring days with heavy rainfall. At that time the number of individuals at each observation site varied greatly from day to day; *e.g.*, the observed number at site KA was 0.444 m^{-2} on the 15th and only 0.022 m^{-2} on the 16th of April 1969. Nevertheless, the numbers at sites TY and TO increased on April 16, 1969.

On June 27, 1970 and May 27, 1971, a high population density was found in an area between 440 m and 490 m in altitude, while the density was very low or even zero at higher altitudes. *Ph. sieboldi* in the active season is thus distributed mainly on more or less gentle slopes somewhat higher in elevation than its hibernating place, and is rarely found on higher slopes exceeding 490 m in altitude.

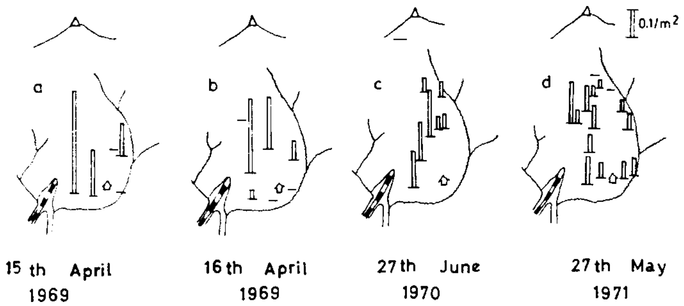

FIG. 3-2-3 Distribution of population in spring-early summer in different years.

The worms spend winter months in the soil or under stones in the dry flat bottom of the dingle except on rainy days, when they were observed to come up near the ground surface. Since their habitat supplies no leaf litter for food, feeding behavior was not observed on those rainy winter days.

The distribution of the hibernating population on a rainy day (December 3, 1970) is shown in Fig. 3.2-3. The population was concentrated at altitudes less than 490 m and a low density of hibernating individuals was found at higher parts of the same dingle, even where conditions were apparently the same. The distribution of hibernating worms seemed to reflect their distribution during the active season.

The direction of worm's body lying on the ground on rainy days seemed to indicate the direction of their movement. Individuals which were going to hibernate directed their

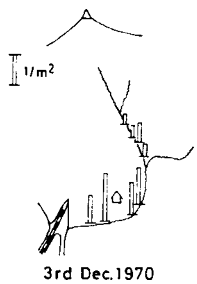

FIG. 3.2-3. Distribution of population during hibernation.

TABLE 3.2-1. Direction of worms' bodies lying on the ground and the number of dead worms observed during hibernation period.

	1970	1971							
	Dec. 22	Jan. 20	Jan. 21	Apr. 6	Apr. 8	Apr. 9	Apr. 28	May 4	May 19
Downhill direction	20	2	4	0	1	1	0	0	0
Uphill direction	3	0	0	0	1	6	2	3	1
Neutral	6	0	0	0	0	0	0	0	0
Number of dead worms	0	1	0	3	0	0	0	0	0

bodies downhill, while those emerging from hibernation pointed uphill (Table 3.2-1). The former phase lasted until the end of January in 1971. The hibernating population appeared from the dingle to migrate toward forest slopes on April 8, 1971, and were no longer found in the flat bottom of the dingle after May 19, 1971.

3.2.3 Seasonal changes in population density, individual body weight and number of dead worms

The seasonal change in the number of individuals observed at three main observation sites is shown in Fig. 3.24. The mean density of population was 0.172 rn^{-2} on April 16. 1969, and thereafter decreased gradually until July. Body weight, on the other hand, increased from 17 g (wet weight) to 30 g during the same period (Fig. 3.2-5b). The cliterium appeared on the body surface after May 1969, indicating that the worms reach maturity in May. Mature individuals seemed to die after oviposition.

The worms thereafter disappeared from the main observation sites until August 1969, while a large number of dead worms were observed on bare ground between June and August of the same year (Fig. 3.2-5c). The density of mature individuals in June and August was highest at site KA (0.0784-0.133 m^{-2}) and lowest at site TO (0.011-0.022 rn^{-2}) (Fig. 3.24).

During the period from August 1969 to May 1970, no individuals of this species could be observed in the study area. Cocoons were also not found in samplings of 50 $\times$ 50 cm^2 quadrats.

On June 27, 1970 immature worms were found, indicating the start of a new generation. The number of newly-appearing individuals reached a maximum density of 0.444 rn^{-2} on July 27, 1970 at site KA, of 0.222 rn^{-2} at TY and 0.200 rn^{-2} at TO, respectively (Fig. 3.24). The density at each site was, however, reduced to about one-half in the next month (September 1970). Corresponding to this decrease in population density, several dead bodies

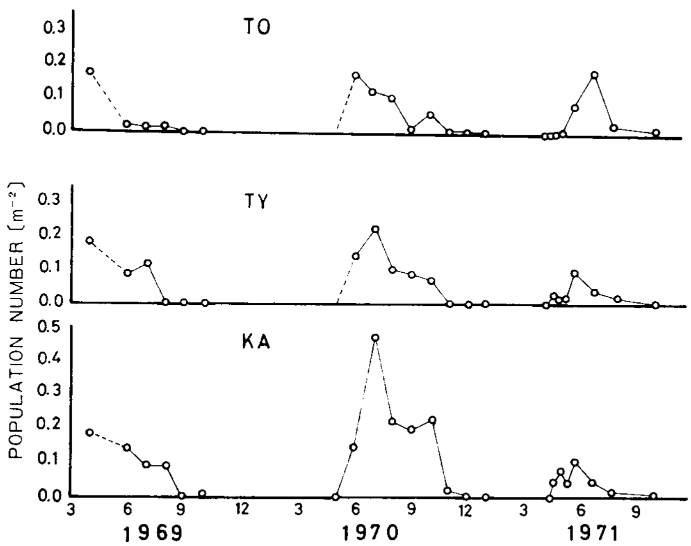

FIG. 3.24. Seasonal changes in the number of *Pheretima sieboldi* at the three main sites.

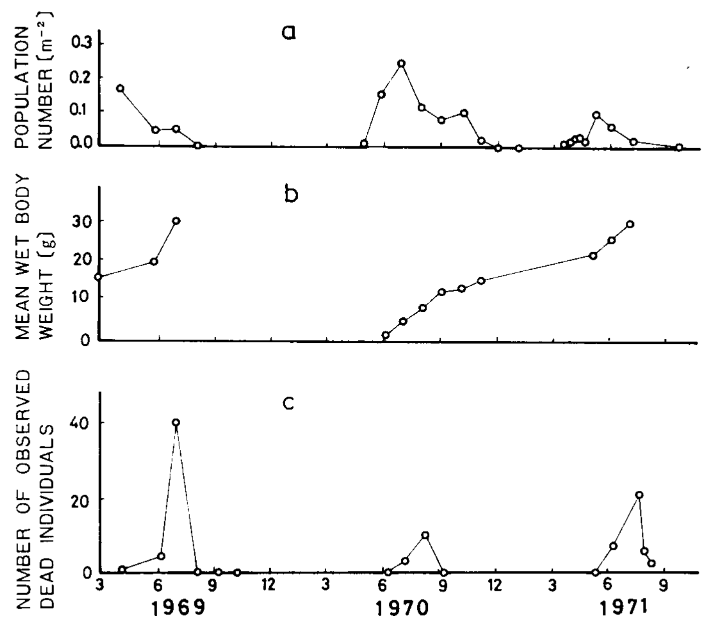

FIG. 3.2-5. Seasonal changes in average population density (a), mean body size (b) and number of dead worms observed (c).

of young worms were observed during the period from July to September (Fig.3.2-Sc). The mean body weight increased in the same period from 1.2 g (wet weight, June 27) to 12.0 g (October 25).

Through the winter from December 1970 to March 1971, the whole population hibernated in the dingle, not a single worm being found in the forest floor litter layer (Fig. 3.2-3). The number of individuals that emerged from hibernation in the spring of 1971 proved to be less than in the same season of 1969. A small number of worms were observed migrating into the forest every rainy day from April 8 to May 19, 1971 (Table 3.2-1). The population distribution and density after termination of spring migration are shown in Figs. 3.2-4 and 2d.

The population was then again distributed in a zone between 440 m and 490 m in altitude, with densities of 0.107 m^{-2} at site TO, 0.092 m^{-2} at KA and 0.074 m^{-2} at TY. The average density at the three main sites on May 27, 1971 was slightly lower than on October 24, 1970 (Fig. 3.2-5a). The body weight increase in the period between December 3, 1970 and May 27,1971 was from 14.8 g (wet weight) to 22.63 g (Fig. 3.2-5b). After the end of May 1971, the number of worms decreased gradually until they disappeared completely from the main sites in late August. Body weight attained a maximum of 30.5 g (wet weight) on July 29, 1971 (Fig. 3.2-5b). A large number of dead worms was also observed on bare ground in the summer months from the end of May to the end of August 1971 (Fig. 3.2-5c).

3.2.4 Seasonal changes in biomass and respiration rate

The rate of CO_2 expiration by *Ph. sieboldi* was estimated at 45.09 μl g^{-1} (wet wt) h^{-1} at

25° C, 29.29 μl $g^{-1}h^{-1}$ at 20° C, 20.71 μl $g^{-1}h^{-1}$ at 15° C and 13.92 μl $g^{-1}h^{-1}$ at 10° C in worms ranging between 12.61 g and 16.37 g (mean 14.67 g) in wet body weight.

The biomass and respiration of the population were then calculated based on the aver-age density at the three main sites (Fig. 3.2-5a) and the mean wet body weight (Fig. 3.2-5b) in each season. A dry weight/wet weight conversion factor of 0.073 and a caloric equivalent of biomass of 5.05 kcal g^{-1} (dry wt) (obtained for *Ph.* sp. H-I; Sugi, in preparation) were used in the calculation.

Caloric consumption associated with respiration was estimated assuming a respiratory quotient of 0.79 and using an oxycaloric coefficient of 4.775 kcal l^{-1}. The food of the earthworm consists of a mixture of organic debris, fungi, bacteria and probably protozoa, so that it may be safe to use the above oxycaloric coefficient quoted by O'Conner (1967). The RQ value was adopted following the proposal by Macfadyen (1963) for animals living on mixed foods. Since data on number and body weight during the hibernation period were lacking, these were estimated by interpolating the curves of Figs. 3.2-5a and b between October 27, 1970 and May 27, 1971.

The results of the calculation illustrated in Fig. 3.2-6 show that the biomass of *Ph. sieboldi* increased steadily from May 1970 to a maximum of 0.1568 g (dry wt) m^{-2} (0.792 kcal m^{-2}) on May 27, 1971, while the population density decreased from 0.24 m^{-2} to 0.09 m^{-2} The average biomass in the growing months from June 27, 1970 to July 27, 1971 amounted to 0.09 g (dry wt) rn^{-2} (0.47 kcal m^{-2}).

During the same period, the population respiration rate showed two peaks in August 1970 (6.2 cal $m^{-2}d^{-1}$) and at the end of May 1971(8.92 cal $m^{-2}d^{-1}$) and a minimum of 1.241 cal $m^{-2}d^{-1}$ on January 25, 1971. The high rates in these two seasons were caused either by an abundance of large individuals or by prevailing high temperatures. Total res-

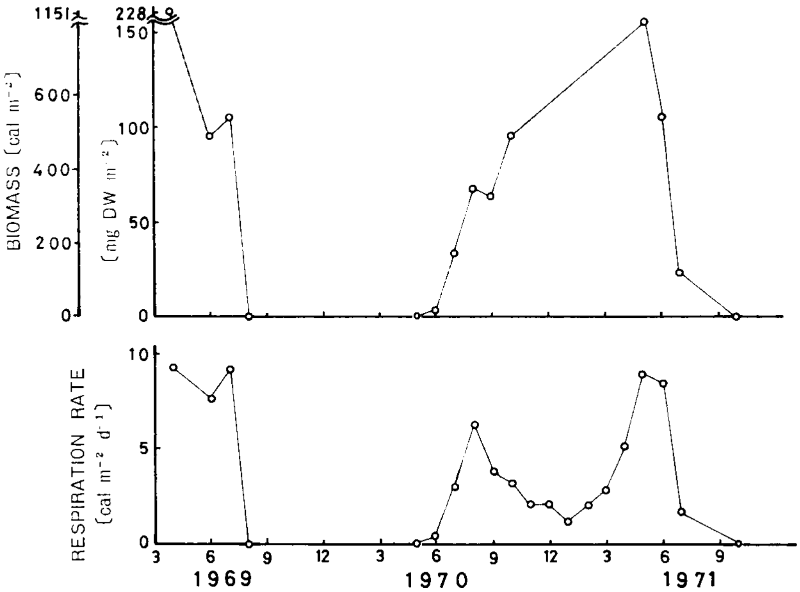

FIG. 3.2~6. Seasonal changes in the estimated biomass and respiration rate of a population of *Pheretima sieboldi.*

piratory consumption during the period from June 1970 to July 1971 was calculated at 1.561 kcal m^{-2}.

3.2.5 Discussion

Ph. sieboldi hatches out in early summer on the forest floor, reaching a size of Ca. 1.2 g (wet weight) in June. The worms spend the period from May to November in the litter or humus layer on the ground, and grow to a wet body weight of 12-14 g in November. Then they migrate to the dry bottom of a dingle on rainy days in late November to hibernate in the soil or under stones until April of the next year. In rainy weather in late April, they return to forest-covered slopes again and reach maturity there during late spring and early summer, attaining to a maximum body weight of 30 g (wet weight). The mature worms die and disappear before August.

Young worms were observed only in the summer of 1970, whereas adult worms were observed in the same season in 1969 and 1971. This suggests that the species requires two years for one generation to pass from egg to maturity and that the population remains in the egg stage for its first year. The active stage of a new generation may cover the remaining one year.

A large number of dead worms were found on bare ground every summer. The population number correspondingly decreased rather abruptly in summer months. High temperature during the summer seems to be harmful to the species.

The distribution of *Ph. sieboldi* in the growing season (April-November) was restricted to the lower part of the Minamata forest between 440 m and 490 m in altitude. The density of hibernating individuals in the dingle was also high at the same range of altitude and low at higher elevations. The distribution of this species in the growing season seems to depend largely on the distance from its hibernating places.

The production of a population during a time interval from t_1 to t_2 is given by the following equation, if the growth curves of population number and mean body weight are assumed to be linear.

$$P = (L_1 - L_2)(W_1 - W_2) \times 1/2$$

L_1 and L_2 are the number of survivals at t_1 and t_2, and W_1 and W_2 are corresponding mean body weights. Production up to the stage of maturity (from June 1970 to July 1971) is thus estimated at 0.248 g (dry wt) m^{-2} (1.255 kcal m^{-2}). Since the total respiration for the period was calculated at 1.561 kcal $m-^{2}$, the total energy assimilated by the population may be approximated by

Total assimilation *(A)* = Production *(P)* + Respiration *(R)* = 1.255 kcal m^{-1} *(P)* + 1.561 kcal m^{-2} *(R)* = 2.816 kcal m^{-2} *(A).*

Some important ecological ratios are calculated as follows.

P/A (production/average biomass) = 2.649
P/Bmax (production/maximum biomass) = 1.584
R/A (respiration/assimilation) = 0.554

These ratio values are close to those obtained for *Pheretima* sp. (H-l) and *Ph. vittata,* litter dwellers in the grasslands around Fukuoka City (Sugi, in preparation). This coincidence is to be expected since all of these *Pheretima* species are litter feeders, though the seasonal trend of population number is not the same among the three species.

Nishioka and Kirita (1978) estimated the mean annual fall rate of fine litter in the whole Minamata forest at Ca. 580 g (dry wt) m^{-2}. Daily litter consumption by *Ph. sieboldi* has been reported by Watanabe (1974) to be equivalent to Ca. 10% of its wet body weight. Litter consumption by the *Ph. sieboldi* population in the Minamata forest may thus be crudely estimated at 26.9 g (dry wt) m^{-2} for the period from June 1970 to July 1971. Considering the generation time of 2 years, this rate should be half as much on an annual basis (13.45 g $m^{-2}y^{-1}$). This is equivalent to only 2.3% of the annual litter supply on the forest floor.

Acknowledgements

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3.3
NUMBER AND BIOMASS OF EARTHWORM POPULATIONS

Y *Sugi and M. Tanaka*

The number of individuals and the biomass of earthworm populations were investigated during the period from June 30, 1970 to July 22, 1971 in the Minamata forest. This section describes the results together with a consideration of the role of earthworms as litter decomposers in the forest.

3.3.1 Methods

Several quadrat samples were taken monthly from a selected site (site A) which was located on a slope near plot P1 established for the study on primary production. The size of the quadrat used and the numbers of samples taken were changed monthly, and these are summarized in Table 3.3-1. A soil sample which was scooped out from a quadrat down to a depth of 20-40 cm was placed on a vinyl sheet, and earthworms were collected by hand sorting.

Ten quadrat samples were taken monthly from another site (site B) which was located on the southern slope of a ridge near plot P2 also for the study on primary production. The size of the quadrat used was 25 $\times$ 25 cm^2. Soil samples which were scooped out from the quadrats until a depth of 7 cm were taken to the observation hut for collecting earthworms by hand-sorting. The depth of litter layer was about 5 cm in both sites.

Collected earthworms were narcotized by adding drop by drop absolute alcohol to water, kept in 10 % formaline and preserved in 70 % alcohol for later studies. The body length and body width of the preserved worms were measured, and from this, body volume was calculated. The dry weight and the wet weight of each body were calculated by using the **regression coefficient between** the body dry weight and the body volume and that between the body **wet weight and** the body volume, of *Pheretima* **sp.** (H-1). These regressions for

TABLE .3-1-1 Size and Nunber of quadrats and the depth 0f soil samples

1970

Site A	30 June	28 July	24 Sept.	26 Oct.	1 Dec.	25 Dec	25 Dec
Size of quadrat (cm^2)	100	100	50	50	50	50	50
No. of quadrat	6	4	6	7	4	5	1
Depth of soil samples [cm]	20	20	20	20	20	20	40
Site B							
Size of quadrat (cm^2)	25	25	25	25	25	25	25
No. of quadrat	10	10	10	10	10	10	10
Depth of soil samples [cm]	7	7	7	7	7	7	7

1972

Site A	24 Jan.	12 Mar.	17 Apr.	24 May	22 June	22 July
Size of quadrat (cm^2)	50	50	50	50	50	50
No. of quadrat	4	4	6	9	10	6
Depth of soil samples [cm]	40	30	30	20	20	20
Site B						
Size of quadrat (cm^2)	25	25	25	25	25	25
No. of quadrat	10	10	10	10	10	10
Depth of soil samples [cm]	7	7	7	7	7	7

Pheretima sp. (H-1) were previously obtained in another study (Sugi, in preparation) and are represented by the following equations:

$$DW=0.0695\ BV+1.3304$$

$$WW=1.03338\ BV-2.1669$$

where *D W* denotes the earthworm body dry weight in mg without intestinal contents, *WW,* the body wet weight in mg, and *BV,* body volume in mm^3.

3.3.2 Growth pattern and life history of Pheretima sp. (M-3)

In the study area, six species of *Pheretima* and one species of *Allolobophora* were collected. The dominant species among them was *Pheretima* sp. (M-3) which was collected mainly in the litter layer throughout the year except in winter. The seasonal change in individual average body weight is shown in Fig. 3.3-1. The seasonal change in the vertical distribution of this species and other earthworms is shown for site A in Fig. 3.3-2.There was no large difference in the growth patterns of individuals of *Pheretima* sp. (M-3) between site A and site B (Fig. 3.3-1). On June 30, 1970, the consisted of small individuals, the body weight of which ranged from 60 mg to 200 mg WW. The average body weight increased suddenly and attained 800 mg WW by October 26, 1970. Then the body weight decreased slightly during winter from late November, 1970 to early March, 1971, and again increased to 1300-1600 mg in the next growing period from March to June in 1971. The earthworm moved from the litter layer to deeper soil layers in winter months for hibernation. The range of vertical distribution attained a depth of as much as 40 cm in January (Fig. 3.3-2). During the growing period all members reached full growth by May 1971. Thus the population after May 1971 was assumed to be a mature population and capable of producing cocoons. However, only two newly-born individuals were collected in June of 1971. A greater part of the next generation seemed to appear in June of 1972. The growing process of *Pheretima* sp. (M-3) showed a pattern similar to that of *Pheretima sieboldi,*

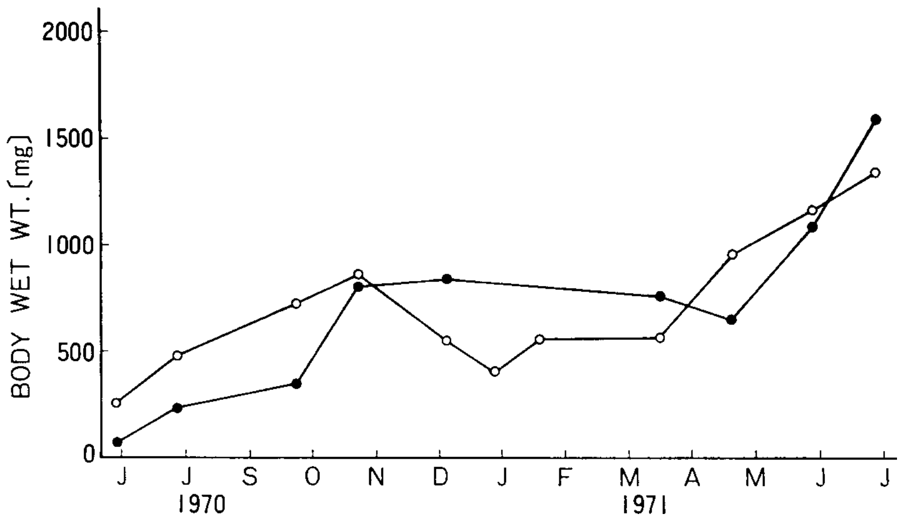


FIG. 3.3-l. Seasonal change in the body weight of ***Pheretima*** sp. (M-3). Open circles: individuals collected in site A. Closed circles: those collected in site B.

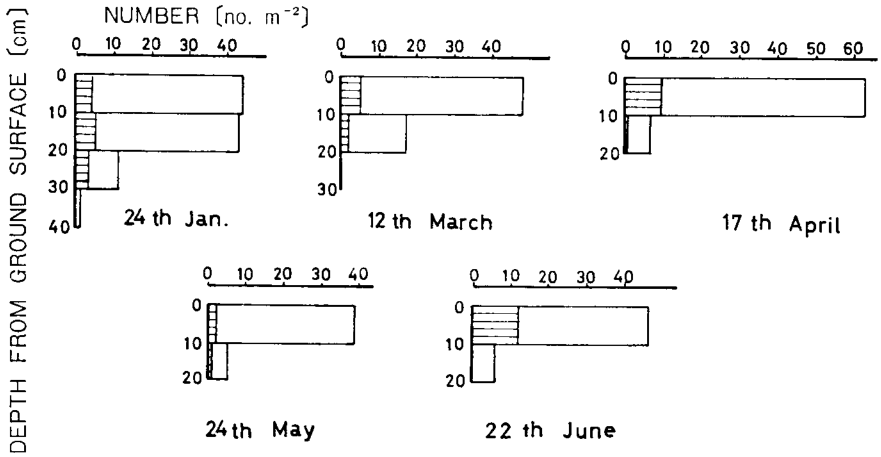


FIG. 3.3-2. Vertical distribution of earthworms in site A. Shaded areas indicate the contribution by *Pheretima* sp. (M-3).

which takes two years from egg to maturation, remains in the egg stage for the first year and the new generation grows in the next year (Sugi and Tanaka, 1978).

The seasonal change in the body weight of individuals for other species showed wide overlapping between different age groups and did not show a clear tendency which would make it possible to detect the growth pattern. These species were collected mainly in ground surface litter and in the A_1-layer throughout the observation period.

3.3.3 Number and biomass of earthworms

The seasonal change in number and biomass for *Pheretima* sp. (M-3) and other earthworms in site A are shown in Fig. 3.3-3, and those in site B are shown in Fig. 3.34. There were no large differences in number and biomass of *Pheretima* sp. (M-3) between the two study sites, in spite of the difference in the depth of soil sampled. This result indicates that *Pheretima* sp. (M-3) is a litter dweller. The density of *Pheretima* sp. (M-3) changed only slightly through the observation period except in winter in both sites (Figs. 3.3-3 and 4). The low density in winter reflects the vertical movement to deeper soil layers for hibernation (Fig. 3.3-2). The biomass of *Plieretima* sp. (M-3) attained a maximum of 1000 mg DW m^{-2} on June 22, 1971 on site A and 900 mg DW m^{-2} on May 24, 1971 in site B.

The total density and biomass of earthworms were larger in site A than in site B (Figs. 3.3-3 and 4). This result indicates that the greater part of dwellers in the litter and/or A_1-layer live in soil layer less than 7 cm in depth, where site B samples were collected. Total density in site A showed a minimum value in late November, 1970, and a maximum in late January, 1971. After the maximum, the density decreased with the lapse of time (Fig. 3.3-3). The minimum density in late November, 1970 was also caused by vertical movement for hibernation. The maximum density in late January in site A was caused by an abrupt increase of one species, and partly caused by deeper excavation down to a depth of 40 cm. On the other hand, total density in site B showed a peak in May, 1971. This difference in the peak month may be explained by upward movement of the humus and/or soil dwellers to a soil layer shallower than 7 cm in early summer (Figs. 3.3-2/4). Total biomass in site A

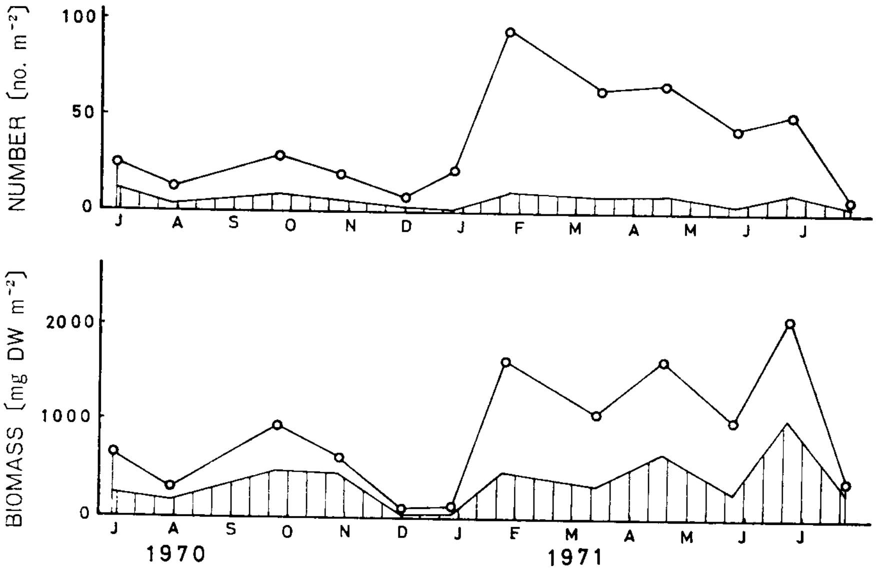


FIG. 3.3-3. Seasonal changes in the number and biomass of earthworms in site A. Shaded areas indicate contributions by *Pheretima* sp. (M-3).

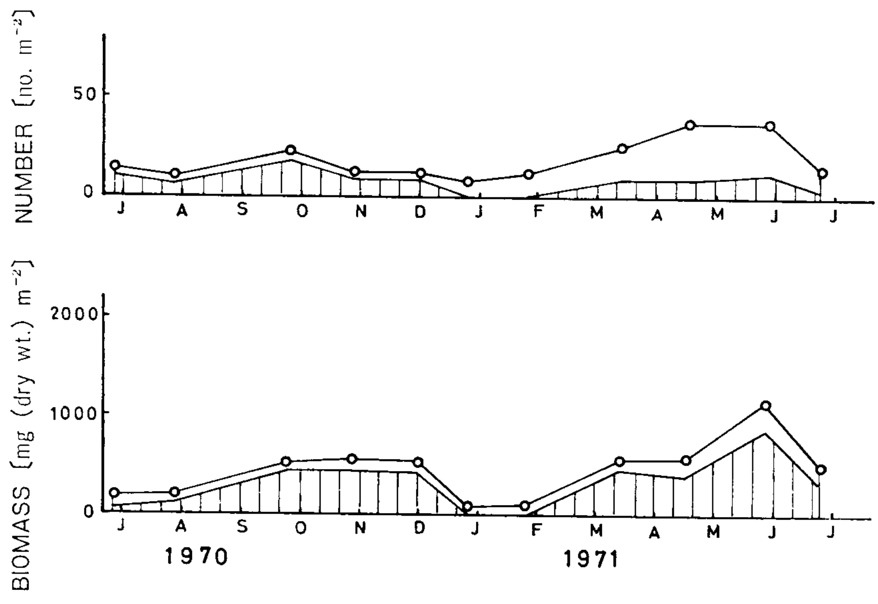


FIG. 3.3-4. Seasonal changes in the number and biomass of earthworms in site B. Shaded areas indicate the contribution by *Pheretima* sp. (M-3).

showed a larger value in 1971 than in 1970. This difference may be explained by the same reason as for the case of density. Total biomass was at a minimum, 127.0 mg DW m^{-2}, on December 25, 1970 and at a maximum, 2152 mg m^{-2}, on June 22, 1971. The maximum biomass in site A was partly due to the body weight increase of *Pheretima* sp. (M-3). Total biomass on site B depended largely on the biomass of *Pheretima* sp. (M-3) throughout the observation period.

3.3.4 Respiration of earthworms

Respiration of earthworms was estimated by using the data on $C0_2$ expiration rates of *Pheretima* sp. (H-1). The $C0_2$ expiration rate of *Pheretima* sp. (H-1), *r*[μl CO_2 h^{-1}], could be approximated by the following equations (Sugi, in preparation).

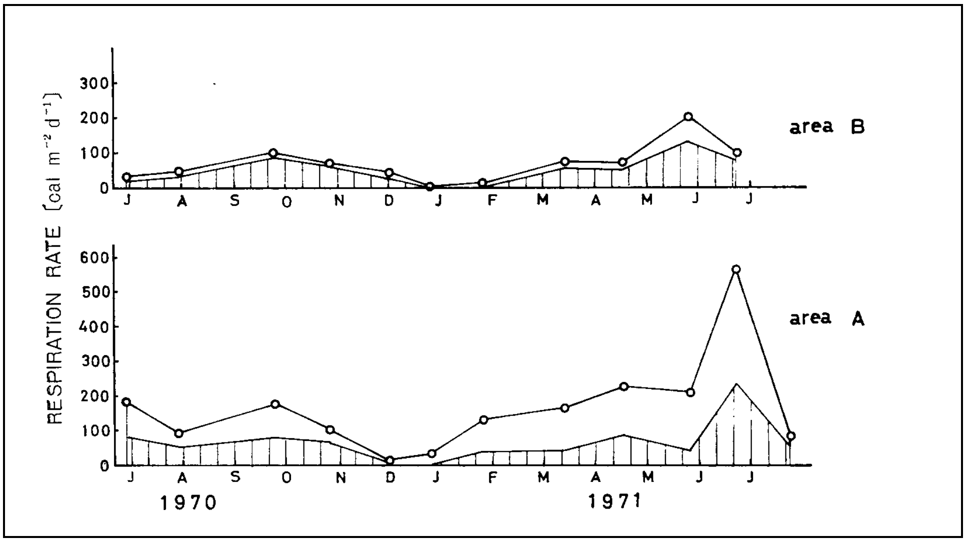
$$r= 111.23\ W^{0.69271} \quad \text{at } 25° \text{ C}$$

$$r= 76.5\ W^{0.69296} \quad \text{at } 20° \text{ C}$$

$$r= 58.5\ W^{0.73654} \quad \text{at } 15° \text{ C}$$

where *W* is the body wet weight [g]. Assuming that the earthworms' respiratory quotient is 0.79 and using the oxycaloric coefficient of 4.775 kcal l^{-1} of oxygen, caloric consumption for respiration of earthworms was estimated by using the data on CO_2 expiration. The diet of earthworms consists of a mixture of organic debris, fungi, bacteria and probably protozoa, and so it seems safe to use Heilbrunn's (1947) calorific equivalent of 4.775 kcal l^{-1} of oxygen. The value of RQ is assumed to be 0.79 following Macfadyen (1963) for animals feeding on mixed plant matter.

The seasonal change in earthworm respiration is shown in Fig. 3.3-5. Earthworm respiration in site A amounted to 100-180 cal $m^{-2}d^{-1}$ in summer 1970, then decreased gradually, reaching its minimum level of 8.8 cal $m^{-2}d^{-1}$on December 1, 1970. It rose gradually, attaining to a maximum of 567.3 cal $m^{-2}d^{-1}$on June 22, 1971. The higher



3.3-5. Seasonal change in the respiration rate of earthworms. Shaded areas indicate the contribution by *Pheretima* sp. (M-3).

respiration rate in the summer of both years was due to larger biomass and higher temperature. The minimum respiration in winter was due to the vertical movement of earthworms to a deeper Soil layer for hibernation and to lower temperature. Earthworm respiration in site B depended largely on the respiration of *Pheretima* sp. (M-3) throughout the period of observation.

Total respiration values in the period from July 1970 to June, 1971 were estimated at 61.65 kcal m^{-2} in site A and 23.45 kcal m^{-2} in site B. The contribution of *Pheretima* sp. (M-3) to total respiration was estimated at 22.342 kcal m^{-2} or 36% in site A and 17.92 kcal m^{-2} or 76% in site B.

3.3.5 Litter consumption by earthworms

Earthworm litter consumption can be approximately estimated by using the data on the litter consumption of *Pheretima* sp. (H-I), which is a litter-dwelling grassland species. The litter consumption rate of *Pheretima* sp. (H-1), c[g DW d^{-1}], was expressed by the following equations (Sugi, in preparation).

$$C = 377.56\ W^{0.5036} \quad \text{at } 25° \text{ C}$$
$$C = 341.02\ W^{0.5788} \quad \text{at } 20° \text{ C}$$
$$C = 239.14\ W^{0.8909} \quad \text{at } 15° \text{ C}$$

where *W* is the body wet weight [g].

Earthworm litter consumption in active months from July, 1970 to June, 1971 is estimated at 1451.7 g DW m^{-2} in site A and 648.27 g DW m^{-2} in site B. The contribution of *Pheretima* sp. (M-3) to litter consumption is estimated at 552.2 g DW m^{-2} in site A and 519.96 g DW m^{-2} in site B.

3.3.6 Discussion

Engelmann (1966) and Tanaka (1970) have proposed a calculation method for net productivity from maintenance metabolism (respiratory requirement). Using the value of *R/A* ratio, an approximation of net production and assimilation for the population or the community can be easily obtained (Tanaka, 1970).

The *R/A* ratio of *Pheretima sieboldi* was 0.55 (Sugi and Tanaka, 1978). The values of *R/A* ratio of three populations of *Pheretima* sp. (H-l) and one population of *Pheretima vittata* ranged from 0.520 to 0.691 (Sugi, in preparation). The average *R/A* ratio of these five populations was 0.60864 ± 0.065 which was utilized as a representative value for the *Pheretima* species. That is, total earthworm assimilation becomes 1.643 times as much as respiration. And accordingly, the total earthworm assimilation was estimated at 101.3 kcal m^{-2}1.643/61.65) in site A, and 38.53 kcal m^{-2}1.643 x 3.45) in site B. The assimilation of *Pheretima* sp. (M-3) is estimated at 36.71 kcal m^{-2}1.643 /22.344) in site A, and 29.44 kcal m^{-2} 1.643/17.917) in site B. Considering the two-year generation span of this species, the annual assimilation should be half the above values, 18.36 kcal $m^{-2}y^{-1}$ in site A, and 14.72 kcal $m^{-2}y^{-1}$ in site B. Other species were collected mainly in humus or in soil layers, and showed overlapping of growth stages throughout the observation period. Thus, earthworms except for *Pheretima* sp. (M-3) seem to have a constant annual life cycle in this area. The annual total earthworm assimilation should be evaluated as 82.95 kcal $m^{-2}y^{-1}$ (101.3-36.71/2) in site A, and 23.81 kcal $m^{-2}y^{-1}$ (38.53-29.44/2) in site B.

Annual total assimilation on site B amounted to 28.7% of that in site A. This value may mean that 28.7 % of the annual total assimilation was contributed by species living in the layers shallower than 7 cm in depth such as *Pheretima* sp. (M-3).

Nishioka et al. (1978) reported 752.3 g DW m^{-2} of annual litter fall on plot P2 (leaf litter 399.2 g DW m^{-2}, branch litter 316.5 g DW m^{-2} and others 36.6 g DW m^{-2}). As mentioned in the last section, earthworm litter consumption in site A was estimated at 1347.5 g DW m^{-2} and the contribution of *Pheretima* sp. (M-3) in site A was estimated at 552.0 g DW m^{-2}. The annual litter consumption of this species should be half as much as the above values for the same reason as in the case of respiration. Namely, the annual litter consumption of earthworms in site A is estimated at 1071.4 g DW $m^{-2}y^{-1}$. The annual litter consumption on the whole is 1.4 times as much as the annual litter fall. This may indicate that some part of the food resources for earthworms is provided by other materials such as worms' pellets, humus or soil other than litter fallen in the current year. The litter consumption in site B was contributed mainly by the species in layers shallower than 7 cm in depth. The greater part of the food resource for this species would be provided by the litter fall for the reason that the depth of the litter layer was 5 cm in the site. The annual litter consumption in site B is estimated at 376.5 g DW m^{-2} y^{-1} by the same method as for site A. The annual litter consumption of earthworms living in the layers shallower than 7 cm depth (in site B) amounted to 51.6% of the annual litter fall. This result may mean that the earthworm in the IBP Minamata area plays a very important role as a primary litter decomposer.

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[3.2]

MACFADYEN, A. (1963) Animal Ecology-Aims and Methods. Pitmann, London and New York. 344 pp.

Nismoka, M. and KIRITA, H. (1978) Litterfall. This volume, 231-238.

O'CONNER, F. B. (1967) The Enchytraeidae. In "Soil Biology" (ed. A. Burges and F. Raw), 213-257. Academic Press, London and New York.

SATCHELL, J. E. (1967) Lumbricidae. In "Soil Biology" (ed. A. Burges and F. Raw), 259-322. Academic Press, London and New York.

WATANABE, H. (1974) Consumption of leaf litter fed by the Megascolecid, *Pheretima sieboldi*, in a slash pine plantation and a natural mixed forest. *Bull. Kyoto Univ. For.* 46, 1~6.*

13.3]

ENGELMANN, M. D. (1966) Energetics, terrestrial field studies, and animal productivity. *Adv. Ecol. Res.* 3, 69-101.

GOLLEY, F. B. (1961) Energy values of ecological materials. *Ecology* 42, 581-584.

MACFADYEN, A. (1963) Animal Ecology-Aims and Methods. Pitmann, London and New York. 344 pp.
NISIOKA, M. and KIRITA, H. (1978) Litterfall. This volume, 231-238.
SUGI, Y. and TANAKA, M. (1978) Population study of an earthworm, *Pheretima sieboldi*. This volume, 163-171.
TANAKA, M. (1970) The bio-economics of the populations of *Isotoma (Desoria) trispinata* MacGillivray (Collembola; Isotomidae) and *Onychiurus (Protaphorura)* sp. (Collembola, Onychiuridae) in a grassfield. *Pub!. Amakusa Mar. Biol. Lab.* 2(2), 51-120.