# Chapter 8
## The distribution Pattern and the Habitat structure of Earthworm *Pheretima* sp. (Oligochaeta: Megascolecidae)

### Introduction

The Assembly State of animal of the lower order such as earthworm may correspond to "not organized aggregation" called by Morisita (1976). When density and or biomass become to be large compared with the quantity of food supply and the size of space, such animals may show the competition for food and space (Morisita 1976).

The mass emergence occurred on fine days after rain in early summer (Chapter 7). This phenomena was examined in relation to food shortage and biological conditioning of their habitat (Chapter 7). This may be an expression of the competition of earthworm for resource. A main purpose in this chapter is the following two. 1) The distribution pattern of *Pheretima* sp. (H-1) is examined. Distribution pattern as an important factor to bring the mass emergence or the background of animal's production process is clarified. 2) And, the seasonal change of distribution pattern is discussed in relating to the structure of habitat.

### Method

**1. Seasonal change of distribution pattern of field population**

Number frequency obtained in the quadrat survey was used for the study of distribution pattern. Two indices were used for this purpose. One index is the mean crowding (Iwao 1968, 1972 and Iwao and Kuno 1971) and other is the ratio of mean crowding to mean density. Later index is the appropriate equation of $I_\delta$ index (Morisita 1959, and Iwao 1968). Each index represents the different character of distribution pattern of a single population, respectively.

Mean crowding represents the mean number of other individual and is defined as

$$\overset{*}{m} = \sum_{j=1}^{q} xj(xj-1)/N$$

Where, q is the total number of quadrat in the area, $n_i$ is the number of individuals in the i th quadrat (i=1,2 ----q), N is total number of individual (Iwao 1968).

Another index ($\overset{*}{m}/\bar{m}$ ) is almost uninfluenced by the population density. It is suitable for measuring the dispersion of individuals over the area. The index is defined as

$$\overset{*}{m}/\bar{m} = q\sum_{j=1}^{q} xj(xj-1)/N(N-1)$$

The $\overset{*}{m}/\bar{m}$ index takes the value of unity, if individuals distributed at random. It takes the value smaller or larger than unity, if the distribution is uniform or contagious correspondingly (Morisita 1959, Iwao 1968, Iwao and Kuno 1971).

**2. Regression coefficient between number of individuals and depth of wormcast layer**

The presence of wormcast related to the mass emergence of earthworm on fine days after rain and then the decrease of population density. The water content of wormcast was higher than that of soil litter mixture (Chapter 7). The high water holding capacity of wormcast might act an important role as shelter for earthworm to avoid drying. Then, It seems that the existence of the wormcast influences earthworm's distribution pattern. The correlation between number of individuals and thickness of wormcast was examined, to obtain the precise understanding for the relation between habitat structure and distribution pattern.

Soil profile was build along quadrat flame, the size of which was $25 \times 25$ $cm^2$. The thickness of wormcast layer was measured at each flame. The measurement was carried out on June 8, June 20, June 30 and July 15 in 1972, and April 28, May 10 and June 15 in 1973.

The moisture content of wormcast was examined. Several samples of wormcast was collected on May 10 and June 15, 1973. The wormcast thicker than 1 cm was divided into two layers above and below than 1 cm depth. The water content was the difference between wet and dry weight.

**3. The evaluation of earthworm to wormcast**

To obtain the knowledge on the habitat preference of earthworm *Pheretima* sp. (H-1), the habitat preference experiment was carried out. Figure 8-1 shows the schema of the instrument for the experiment. This enclosure consists of two rooms, one room contained fecal pellet and other room contained food-soil complex. Preceding the experiment, the fecal pellet was produced by *Pheretima* sp. (H-1) and preserved. The food and the soil were same materials used for the cultivation experiment (Chapter 4). There is a wood board barrier between each room. Test specimens (one or three individuals) was laid on the wood barrier, and number of individual in each room was recorded every day in the period from May 6 to May 15, 1972.

**4. The disappearance rate of wormcast**

The knowledge on the disappearance rate of wormcast is necessary to estimate the depth of wormcast in field and to evaluate the value of wormcast as the food for earthworm.

For this observation, the wormcast bag method as like the litter bag method was used. The bag was made by saran net and was 5 cm × 5 cm, and the mesh of saran net was 1 mm × 1 mm. A bag contained 14 g wet wt (10 g dry wt) of fecal pellets as wormcast. The fecal pellets used for the measurement was produced by the individuals of *Pheretima* sp. (H-1), each being one gram body wet weight. A particle of the fecal pellet produced by them was 4 mm in length and 2.5 mm in width, in average. 30 bags were prepared for this measurement. These pellets bags were weighed in wet and the wet weight of the pellet bags were converted to dry weight, using the data on the water content of the fecal pellet. These bags were laid on the soil surface of study area covered by ground vegetation ,the experimental field of Kyusyu University, on June 2, 1973. Three bags were collected at a week interval, dried at 105 ºC for five hours and re-weighed. The difference between the initial weight and the later weight was regarded as the disappearance weight of wormcast.

## Result

### 1. Distribution pattern of individuals

#### 1-1 The seasonal change of the value of $\overset{*}{m}/\bar{m}$ index

Figure 8-2 shows the seasonal change of the value of $\overset{*}{m}/\bar{m}$ index.

**The 1971 year population:**

The $\overset{*}{m}/\bar{m}$ of the 1971's population was calculated with the number frequency on 12 quadrats. The size of a quadrat was 50×50 $cm^2$ (Chapter 1). The $\overset{*}{m}/\bar{m}$ value on March 7was 3.112, showing the aggregated distribution pattern. The values once decreased to 1.385 on 7 April, and increased to 1.776 on May 8. In early May 1971, it was dry season and the soil was dry condition (Chapter 1). The enlargement of the aggregation may be due to the migration of worms to wetter soil to avoid drying. The value on June 10 was 1.292, showing the minimum through the life span of the 1971 year population. The mass emergence of earthworms occurred frequently in June (Chapter 7). It seems that the rapid decrease of the aggregation degree at this days related to the mass emergence of earthworms on fine days after rain (Chapter 1 and Chapter 7). The value on July 7 was the highest through the life span ($\overset{*}{m}/\bar{m}$ = 3.333). In the quadrat survey on July 7, 1971, a few earthworms were collected in only 5 quadrats.

**The 1972 year population**

The $\overset{*}{m}/\bar{m}$ of the 1972 year population was calculated with the number frequency on 25 quadrats. When, the size of a quadrat was 25×25 $cm^2$ (Chapter 1). The value on Feb. 23 was 1.774 showing the aggregated distribution. Afterwards, the value decreased slowly, and was 1.313 on May 10. It was low temperature and relatively wetter in late February - early May 1972 (Chapter 1). The value increased, and became 1.547 on May 23. This increase is the same as the case of 1971's population. In late May 1972, it was dry season and the soil was dry condition.

The period from June 1 to June 11 and the period from June 20 to the beginning of July were the days of rain. And, it did not rain between June 12 and June 20 (Chapter 1). Namely, the values were the lowest (1.260) on June 8. The value was 2.656 on June 18, and it was 1.587 on June 30. That is, the value was high in day when it rained little and the value was low in days when it rained much. The mass emergence on fine days after rain occurred also in 1972 (Chapter 7). After July 15, rainy season was end. The value increased to the highest of 3.910 on July 19.

#### 1-2 $\overset{*}{m}/\bar{m}$ index value and mean crowding index value ($\overset{*}{m}$)

Figure 8-2 shows the seasonal change of mean crowding. The values of $\overset{*}{m}/\bar{m}$ index and of mean crowding index ($\overset{*}{m}$) showed roughly a similar change with each other. However, there was some difference in the seasonal change between two indices. This small difference is based on the character of each index. The $\overset{*}{m}/\bar{m}$ index shows the bias of the dispersion of individuals over the area. Otherwise, the mean crowding index ($\overset{*}{m}$) shows the degree of aggregation (the mean number of other individual per quadrat).

The difference between two indices for the 1972 year population was as follow.

(a) The value of $\overset{*}{m}/\bar{m}$ index, continuously and slowly, decreased in the period from Feb. 23 to May 10. Otherwise, the value of mean crowding hardly changed in the period from Feb. 14 to March 28. After that, it decreased slowly in the period from March 28 to April 12 and rapidly in the period from April 12 to May 10. The change of later index shows that the mean number of other individual per quadrat per an individual did not changed. The change of earlier index shows that the distribution of individuals over the area became to be random gradually. Some newly individuals appeared in the period from early February to later March (Chapter 1). These results may mean that the cocoon presenting within each spots hatch out at same time, but the hatching time was different in different spots.

(b) The value of $\overset{*}{m}/\bar{m}$ index rapidly increased in the period from June 8 to June 19 and the period from July 7 to July 28. Otherwise, the value of mean crowding increased at slower rate compared with that of $\overset{*}{m}/\bar{m}$ in those periods. The difference was due to the contagion of small colony in a few quadrats on June 19 and July 28. (The size of colony was small but the number of the small colony was little. This distribution pattern induce a large value of $\overset{*}{m}/\bar{m}$ but a small value of $\overset{*}{m}$.

(c) The minimum value of $\overset{*}{m}/\bar{m}$ appeared on June 8, but that of mean crowding appeared on July 15. The minimum value of $\overset{*}{m}/\bar{m}$ on June was due to the random deposition of individuals by migration. However, the minimum value of m on July was due to the decrease of colony size as the result of density decrease.

**1-3 A common feature in distribution pattern of animals in field**

The $\overset{*}{m}/\bar{m}$ are higher than unity through all season. This means that the very patch distribution is typical of earthworm distribution. The distribution pattern of field populations can be summarized as below.

The spatial distribution passes from a highly aggregated phase in early spring. The population in early spring consists of immature being 20-50 mg fresh wt. Through the dispersed phase in late spring, the second aggregated phase follow in late spring-early summer. When wetter season come after short dry season, individuals violently disperse and the mass emergencies frequently occur on the surrounding bare area. The decreases of the population density follow on the mass emergence. The population in wetter summer consists of pre-matured or matured individuals being about 1600 mg fresh wt. The copulation of *Pheretima* sp. (H-1) was observed frequently on rainy days during the wetter season. After wetter-summer, individuals form an aggregated phase again, and all individuals disappeared till late July.

The $\overset{*}{m}/\bar{m}$ values of earthworm's cocoon were 1.603 in 1971 and 2.462 in 1972. Also, the values of mean crowing of cocoon were 10.544 in 1971 and 18.912 in 1972. The number of quadrats were 25 and the size of quadrat was 25×25 $cm^2$ (Chapter 1 and Chapter 2). These values show that the cocoons distributed in aggregately in both years. The aggregately distribution of cocoon is due to the aggregately distribution of parenthood individuals in dry-summer of earlier year. Then, the aggregation of cocoon generate the aggregately distribution of new individuals in early spring.

**2. The regression coefficient between number of earthworm and thickness of wormcast**

Figure 8-3 shows the relation ship between number of earthworm and thickness of wormcast. There are a linear relation between number of individuals and thickness of wormcast. These relation are represented by the equation of Y = AX + B as follow

| | | |
|---|---|---|
| On 8 June 1972 | Y = 0.2058 X + 0.4991 | (8-1) |
| On 19 June 1972 | Y = 0.1664 X + 0.7058 | (8-2) |
| On 30 June 1972 | Y = 0.1967 X + 1.1167 | (8-3) |
| On 15 July 1972 | Y = 0.1008 X + 0.8306 | (8-4) |
| On 28 April 1973 | Y = 0.0414 X + 0.0158 | (8-5) |
| On 10 May 1973 | Y = 0.0365 X + 0.2212 | (8-6) |
| On 15 June 1973 | Y = 0.1638 X + 0.6650 | (8-7) |

where, X is the number of individuals per a quadrat (0.25 × 0.25 $m^2$), and Y is the thickness of wormcast cm. The reversal value of A may represent the number of individuals which one centimeter of wormcast can maintain. Also, the value of B (cm) may represent the layer of wormcast near soil surface, in which earthworm did not inhabit. Table 8-1 summarizes the values of 1/A and B.

One cm of wormcast existing below 0.5 cm depth from the soil surface could maintained 4.86 individuals on June 8. The value is the lowest through observation (Table 8-1). On June 8, it was a fine day after rain. The mass emergence of earthworm frequently occurred in the period from June 1 to June 10, 1972 (chapter 7). Also, animals showed the dispersed phase of distribution pattern on this day (Fig. 8-2). Then, the lowest value of 1/A on June 8 may be caused by animal dispersion. On June 19, one cm of wormcast existing below 0.71 cm from soil surface could maintained 6.01 individuals. (*The population density decreased in the period from June 8 to June 19*). It had scarce rain and relatively high temperature in the period from June 12 to June 20 (Chapter 1). Also, the animal showed the aggregated phase on June 19 (Fig. 8-2). Then, the increase of 1/A in the period from June 8 to Jun 19 may be due to the aggregation of animals moving from thin wormcast to thick wormcast. It may mean, earthworm can avoid the drying in dry periods by moving from thin wormcast to thick wormcast. On June 30 and July 1, it was a fine day after rain. The mass emergence of earthworm frequently occurred in these days. It was heavy rain in several days before June 29. The soil nearly submerged on June 30 (Chapter 7). However there were, still, a linear relation ship between number of individuals and thickness of wormcast. The index of 1/A on this day takes a lower value (5.08). A large number of dead individual on bare area was observed from June 30 to July 1 (Chapter 7). Also, the animals showed the dispersed phase of distribution pattern on those days (Fig. 8-2). The lower value of 1/A index on those days might be due to the animal dispersion on fine day after rain. The relation between number of individuals and thickness of wormcast on July 15, 1972 was not obscure. This may be due to the low density on that day. On April 28, 1973, there was an obscure linear relation between the number of the individuals and the thickness of wormcast. One cm of wormcast presenting below 0.02 cm from soil surface should maintain 24.18 individuals per a quadrat ($0.25 \times 0.25$ $m^2$) on April 28, 1973. On May 10, 1973, one cm thick wormcast presenting below 0.22 cm could maintained 21.38 individuals. If making an exception of the highest value, the regression was represented by Y = 0.067 X + 0.143. This equation shows that one cm of wormcast existing below 0.14 cm from soil surface could maintained 14.9 individuals. On June 15, 1973, one cm wormcast presenting below 0.665 cm from the soil surface could maintained 6.10 individuals. The value of 1/A decreased in the period from April to June 1973. The distribution pattern of earthworm in same season of 1972 showed the slow dispersion (Fig. 8-2). The decrease of 1/A in the period from April 28 to June 15, 1973 may due to the slow dispersion of earthworms. The slow dispersion of earthworms in this season may be due to the weight increase and to the emigration of earthworms to gain newly food resource. The value of 1/A on June 15, 1973 was 6.11. This value was akin to that on June 20, 1972 and higher than those on June 8 and June 30. 1972. In the period from June 2 to June 20, 1973, there was scarce rain (Chapter 1). Then, the relatively higher value on June 15, 1973 mean that earthworm aggregated in thick wormcast to avoid drying.

Table 8-2 shows the humidity of wormcast on May 23, 1973 and June 24, 1973. It was rain on three day before May 20, 1973 and there is no rain on several days before June 24, 1973. The thin wormcast have the relatively high content of water on May 20, and lose water on June 24, (Table 8-2). However, the thick wormcast have a relatively higher content of water, even in dry season. These results make firm that the increase of aggregation degree and the higher value of 1/A in dry period was caused by the migration of earthworm from thin wormcast to thick wormcast to avoid drying.

**3. The habitat preference of earthworm**

Figure 8-4 shows the habitat preference of earthworm in experiment. On first observation time, many individuals chose the wormcast site. 60-70 % of test specimens used for the ‘one individual’ experiments and 65 % of test specimens used for ‘three individuals’ experiments preferred the wormcast site. On the second day, some specimens moved from the wormcast site to the food site. The number of individual preferring the food site attained to the peak on the fourth day for ‘one individual’ experiments and on the third day for ‘three individuals’ experiments. After, The food side came to be full of the new pellets which earthworm had exhausted. Then, test specimens began to move from the food site to the wormcast site. On the sixth day, the moving of specimens attained to the equilibrium point. After the equilibrium, 65 % of specimens stay in the food site in both experiments (One and three individuals). Test specimens were laid on the wooden barrier at beginning time of experiment. One individual lift the anterior part of him, touch the wormcast and the food site with the mouthpiece by turns. After, the earthworm penetrated the wormcast site. Several individuals laid the anterior part of them in the food site and leave the posterior part of them in another site. There were no difference in the habitat preference between ‘one individual experiment’ and ‘three individuals’ experiments.

The movement of test specimens from one site to another site may explain the decrease of $\overset{*}{m}/\bar{m}$ and $\overset{*}{m}$, and the decrease of 1/A in the period from March to May in field (Figures 8-2 and 8-3, and Table 8-1).

**4. The disappearance rate of wormcast**

Figure 8-5 shows the result of the fecal pellet bag experiment. Following equation can approximate the remaining rate of wormcast

$$D = 98.36 - 1.2359\,t \qquad r = -0.9789 \qquad (8\text{-}8)$$

The disappearance rate per a month was estimated as about 38.7 %. Bi-monthly accumulation of the wormcast were estimated from the fecal pellet production by two litter dweller species, *Pheretima* sp. (H-1) and *Pheretima* vittata (Goto et Hatai) in due consideration of the disappearance rate of the wormcast. Namely, bi-monthly accumulation of the wormcast can be estimated by following equation.

$$Tn = \sum_{i=1}^{n} FiDn - i \qquad (8\text{-}9)$$

i = 1, 2, and n (pass half month)

Fi = Fecal pellet production by two litter dwellers in i th half month

D(n-i) = The remaining rate of the wormcast produced at i th half month

Tn = The accumulated wormcast on the soil surface till n th half month.

The average thickness of the wormcast in field was calculated from the figure on the correlation between individual number and the thickness of wormcast (Fig. 8-3). The density of the wormcast was 0.4055 g dry wt $cm^{-3}$ on June 24, 1973 (Table 8-2). Then, the weight of wormcast observed in field can be calculated by integrating the average thickness and the soil density of wormcast. Figure 8-6 shows the estimated weight, and the observed weight of wormcast. The observed weight of wormcast is almost equal to the estimated weight of wormcast. On the other hand, total weight of the fecal pellet production by two litter feeder species attained to 15013.6 g dry wt $m^{-2}$ (Fig. 8-6). The figure was far larger than the maximum weight of the wormcast actually obtained in the field, 7441 g dry wt $m^{-2}$. These results show that the soil and litter passed through the earthworm intestine more than once in a year.

## Discussion

### 1. Structure of habitat and distribution pattern of earthworm

The life history of earthworm *Pheretima* sp. (H-1) can be distinguished to four developmental stages in relation to the distribution pattern of individuals and the structure of their habitat. Figure 8-7 shows the life history of *Pheretima* sp. (H-1) relating to their distribution pattern. Also, Figure 8-8 summarizes the life history of earthworms relating to the habitat structure.

**Young 1 stage:**

When a new individual of Pheretima sp. (H-1) gives birth at the early spring, these individuals forms the contageous distribution. This distribution pattern may be caused by the aggregately distribution of the cocoons (Fig. 2-3b, in chapter 2). The degree of aggregation reduced in the period from late Feb. to early May (Fig. 8-2). The relation between number of individuals and thickness of wormcast in April 24 and May 10, 1973 was the linear regressions intercepting nearly the origin (Table 8-1, Fig. 8-3). Soil and thin wormcast might be wetter in spring with the reason of relatively low temperature and of frequently rain. In fact, the thin wormcast collected on May 20, 1973 had yet high water content (Table 8-2). Then, earthworm might be able to live in thin wormcast and earthworm could be inhabited in the area in which no wormcast either. Small quantity of fecal pellet might be pile up in early spring, because young earthworms showed the small rate of metabolism. In early time of the experiments of habitat preference, many specimens preferred the wormcast site than the food site. After, some specimen moved from the wormcast site to the food site, laying the anterior part of their body in later site. These result mean that in early spring young individuals dispersed with the slow pace for searching newly food, remaining the posterior part of their bodies in the wormcast site (Fig. 8-2 and Fig. 8-4).

**Young 2 stage in dry season:**

Dry days occur, frequently, in the period from late May to middle June. Water content of soil near surface might be low with the reason of no rain and of relatively high temperature in these periods. In fact, the water content of the thin wormcast collected on June 15, 1973 was about 3.6 % (Table 8-2). In a week before this day, it was no rain. The $\overset{*}{\bar{m}}/\bar{m}$ and $\bar{m}$ in these period showed the higher value showing aggregated phase of earthworms (May 8, 1971, May 23 and June 19, 1972, in Fig. 8-2). Also, the relations between number of individual and thickness of wormcast showed the high slope linear regression intercepting a minus value (June 19, 1972 and June 15, 1973, in Fig. 8-3, Table 8-1). These results show there were a few individuals in the thin wormcast. Earthworm might move from thin wormcast to thick wormcast to avoid drying in dry days. New comer might pile up the large quantity of fecal pellets on the thick wormcast. Then, the thick wormcast might enlarge the water holding capacity. Where, earthworm comes to endure a drier situation. However, earthworm is exposed to heavier food shortage in these conditions.

**Matured stage:**

Clitellum appeared on the body surface of earthworms after June, showing that earthworms reached maturity in June. The abruptly dispersion (the mass emergence) of earthworm accompanying the death of individuals occurred frequently on fine days after rain in June and July (Chapter 7). The value of $\overset{*}{m}/\bar{m}$ and $\overset{*}{m}$ in wetter days of these months showed the low or minimum showing the dispersed phase of animal (June 10, 1971, June 8 and June 30, 1972, in Fig. 8-2). The relation between number of individual and thickness of wormcast in these wetter days showed the low slope regression intercepting near zero (June 8 and June 30, 1972).

The mass emergence of earthworm on fine days after rain was caused by the increase of $CO_2$ tension in soil air. The increase of $CO_2$ tension in soil air was due to the increase of microbial metabolism stimulated by wetter and high temperature condition in those days. The microbial population was more plentiful in wormcast than in other soil. Namely, the abruptly aggravation of habitat for earthworm in those days induced the mass emergence of earthworms (chapter 7). The individuals confirming aggregated phase in dry days of late May might be under severe food shortage. The decrease of density after the mass emergence of earthworm means the mitigation of food shortage for earthworm. The decayed rate of wormcast was 38.7 % per a month (Fig. 8-5). This result means that the surviving earthworm can gain another food resource from the decayed wormcast.

**Post matured stage;**

The population density decreased with the end of wetter summer. Earthworm begun to form aggregated phase to avoid drying again. The value of $\overset{*}{m}/\bar{m}$ and of $\overset{*}{m}$ after dry-summer were the higher or highest values showing the aggregated phase of earthworm (July 7, 1971 and July 29, 1972). The aggregated distribution of matured earthworms after dry summer may relate to the aggregated distribution of earthworm's cocoon. It may induce the aggregated phase of young earthworms in early spring of next year.

**2. Ecological meaning of wormcast relating to the life history of earthworm**

The significance of wormcast for earthworm can be summarized in three, 1) Good habitat through a life span of animal except fine days after rain, 2) Bad habitat on fine days after rain and 3) Food resource. Good habitats of wormcast for animal depend on their the moisture retentivity and of the porosity character of wormcast. In the porositic wormcast layer, earthworms can move easily and escape from drying or solar radiation easily. Wormcast became to be bad habitat for earthworms on fine days after rain, which induce an abruptly dispersion of animals. Bad habitat of wormcast depend on the high density of microbial population contained in cast material (Chapter 7). The role of wormcast as food resource was brought by the decaying part of wormcast.

Earthworm show a different behavior to each character of wormcast, each of which appear under a given weather condition. The linear regressions shown in Fig. 8-3 express the integrated evaluation of earthworm to various character of wormcast. The reciprocal value of the slope in equation (1/A) represent the number of individuals per one cm thickness of wormcast below the depth of B cm from soil surface. Morisita (1952, 1971) proposed a theory of the environmental density, by using which theory, we could replace the difference of habitat for animal with the difference of the population density. The environmental density consisted of the product of a constant value and the coefficients, each of which corresponded to a given condition of an environmental factor. Namely, Environmental density (E.D) is a.s.K or G.K. Where, “a” is the coefficient of partial environmental density of other factor, “s” the product of the coefficient of partial environmental density of other factors still unanalyzed, “G”, the product of the coefficient of environmental density of the unanalyzed factors and “K”, the value determined by the physiological condition of animal (Morisita 1952, 1971). Ono (1962) pointed out that the actual population density in the natural habitat might be proportional to the reciprocal of the value E (=1/E) at last when the density was low and the repulsive effect among individual was not prominent. Earthworm satisfies the condition that the repulsive effect among individuals was not prominent. Then, the linear regression (Y = Ax + B) in present study may have a similar content to the value E (=1/E). Morisita (1952, 1971) said that the value of physiological condition (K) might change with growth and activity. The decrease of 1/A value in the period from April to June is mainly due to the weight growth of earthworm. Also, the small change of 1/A between dry and wetter days was due to the change of the evaluation of earthworm to wormcast. However, as Morisita (1952, 1971) pointed out, it is difficult to separate G from K also for earthworm.

Still, the value of A and B inducing from the equations (8-1) - (8-7) was the results of the field observation. However, the environment density in Morisita theory was determined by the probability distribution of individuals in each of two habitats. Then, the theoretical relation between the value of A and B, and the value of 1/E was remained unknown.

The wormcast accumulated over soil surface reflect the result of the interaction between animal and environment. The difference of the thickness of the wormcast may express the difference of the integrated evaluation of earthworm to the various environmental factors such as litter type and soil condition.

The wormcast existing in field was total quantities of the resource used by earthworm. This means the possibility that the material-energy metabolism of earthworm in field is estimated by using the data on the quantities of wormcast existing in field. This consideration will be discussed in detail, in later paper.

**Summary**

1) The distribution pattern of *Pheretima* sp. (H-1) were studied in relation to the structure of habitat through a life span.

2) The spatial distribution passes a highly aggregated phase in spring. Through the dispersed

phase in later spring, the second aggregated phase followed in late spring-early summer. When the wetter season come, earthworms dispersed abruptly. After wetter season, earthworm distributed in patch.

3) There were linear relation ship between the population density and the thickness of the wormcast. This relation could be approximated by following equation $Y = AX + B$, where Y was the thickness of the wormcast and X was the number of individual per unit area. It was though that the values of 1/A represented the number of individual per one cm thickness of the wormcast. The value of 1/A decreased through a life span, in roughly. Still, there was tendency that the value of 1/A was high in dry days and low in wetter days.

4) The role of the wormcast as the shelter and as the food resource, for earthworms was examined. The fundamental significance of the wormcast to the life of earthworm could be summarized in three.

(a) Wormcast have a porosity character, by which earthworms can move easily in soil surface layer. Wormcast have a high water holding capacity. Then, wormcast become a good shelter for earthworms to avoid a drying in dry days.

(b) Wormcast have a plentiful flora of microbial population. These microbial population induce a high soil respiration and then bring about the mass emergence of earthworms on fine days after rain.

(c) The decaying wormcast become to the alternatively food resource or earthworm.

5) The value of 1/A inducing from the linear equations between the number of individuals and thickness of wormcast was regarded as the integrated evaluation of earthworm to wormcast as shelter and food resource.

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