

Chapter One

Number and biomass of Earthworms in Several Types of vegetation in the suburb of Fukuoka City of Kyushu Japan

Introduction

Since Darwin (1881) published the book about the role of earthworm in the soil formation, many papers have been written about its ecology. The population ecology of earthworm have been studied, mainly, on Lumbricidae species (Cuendet 1984, Satchell 1963, 1967, Nakamura 1971, 1972, Gerard 1967, Nowak 1975, Lakhani and Satchell 1970, and Phillipson et al 1978), and Acanthodridae and Eudrilidae (Lavelle 1973, and Lavelle and Mayer 1976). The species group of *Pheretima* Megascolecidae characterizes the earthworm in West Japan. However, the ecology of *Pheretima* is hardly studied except some papers (Watanabe 1974, 1975, and Sugi and Tanaka 1978 a, b).

This chapter reports on the faunas and abundance of earthworm in the suburb of Fukuoka City Kyushu Japan.

Study Area

The populations of earthworm were researched in two groves of Hakozaki shrine and Kumano shrine, and two old grass fields. Four areas are located in the suburb of Fukuoka City Kyushu Japan. Figure 1-1 shows the situations of four areas. Figure 1-2 shows precipitation, air temperature and soil temperature. The laboratory of Agricultural Meteorology of Kyusyu University kindly allowed the author to use meteorological records of its observatory. It was situated at 33° 37' 26" N and 130° 25' 45" E. The figures of precipitation, air temperature and soil temperature were obtained from their records.

The area for the sampling in Hakozaki shrine (area H) was 30 x 40 m². The area was predominantly covered by the dicotyledon such as *Artemisia vulgaris* L. var. *indica* Maxim., *Achyranthes japonica* Nakai and *Erigeron annuus* L. with deciduous trees. The thickness of A₀ horizon was about 5-40 cm (14 cm in average). Soil pH in H₂O was 6.16.

In Kumano shrine (area K), the territory was covered with dense evergreen forest and with poor undergrowth vegetation except a few shrubs. The area for sampling was 40 x 50 m². The thickness of A₀ horizon was 5-10 cm (5 cm in average). Soil pH in H₂O was 4.72.

Two grass fields adjoined each other in the experimental field of the department of Biology of Kyushu University, Fukuoka City Kyushu. One grass field (area D) was covered densely with the dicotyledon such as *Vicia hirsuta* Koch, *A. vulgaris*, *Solidago altissima* L. and *Medicago denticulata* Willd., and the A₀ horizon in area D was 3.0-12.3 cm (6.64 cm in average). Soil pH in H₂O was 6.05. Another field (area G) was covered with Monocotyledon such as *Imperata cylindrica*, *Cyperus rotundos* and *Carex* spp. . The A₀ horizon in area G area was 1.7-4.2 cm (3.36 cm in average). Soil pH in area G was 5.56. The areas for sampling were 783 m² in area D and 256.5 m² in

area G.

The litter supply to ground surface must be an important environment factor determining the population sizes of earthworms. The annual primary production was determined only on area D in 1972. The above ground vegetation on quadrat areas were collected with half month interval from January to late August 1972 in area D. (The vegetation in the experimental field was mown in early September for sanitary reason.) Twenty-five quadrats per a sampling were used. A size of quadrat was $25 \times 25 \text{ cm}^2$. As for the collected plants, it was dried for five hours at 105°C and that was weighed. Figure 1-3 shows the seasonal change of standing crop of each species. The net production of above ground vegetation was estimated by the summation of each species maximum standing crop. The estimated primary production was $1176.5 \text{ g (dry wt) m}^{-2}$.

The standing crop of the vegetation in area G was measured by using ten quadrats on July 1972. The standing crop in area G on July 1972 was 251.2 g m^{-2} . That in area D on same day was 549 g m^{-2} . Then, the net primary production in area G seems to be less than half of that in area D. Nishioka and Kirita (1978) estimated the annual fall rate of whole litter in evergreen forest (IBP Minamata) at 844 g m^{-2} . The litters supply in area K may be approximated by the rate in IBP Minamata with the reason of similar vegetation type between two forests. The annual litter supply in area H may approximated to the median rate between area D and IBP Minamata, because the vegetation in area H was the intermediate phase between old grass field (area D) and ever green forest (IBP Minamata). Then, the rate in area H was estimated at $1010 \text{ g m}^{-2} = (1176.5 + 844.0)/2 \text{ g m}^{-2}$. Table 1-1 summarizes the environmental factors of four areas.

Method

1. Sampling

1.1. Sampling of earthworm

The maps of two groves (area H and area K) which recorded the position of the tree larger than 5 cm in DBH were made. The line of 1m interval was written on the map. This line becomes a sign to choose the sampling point. In 1968, sixteen sampling points were chosen in each occasion, using the random numbers table. This sampling were continued from March to November in one month interval. In these sampling, the size of a quadrat was $50 \times 50 \text{ cm}^2$.

In two grasslands (area D and area G), the bamboo piles of 50 cm were driven in the ground at 3 m intervals. The map which recorded the position of the bamboo piles, vegetation and other marks was made. The grid line of half-meter intervals was drawn on the map. Sampling points were chosen using the random numbers table. The size of quadrat used and the number of sample taken were changed monthly. The details on the size and number of the quadrat were shown in Table 1-2.

In sampling, a quadrat area was excavated with a shovel to the depth of 20 cm from the surface. Soil samples were divided to several small masses, each mass was thinly expanded on a

large board and earthworms were collected with sorting. The worms collected were moved to the room and were put into water. They were anesthetized by adding drop by drop absolute alcohol slowly. The earthworm anesthetized was put between the glass sticks, and was fixed with 10% formalin solution for a day. Later, the specimens were kept in 70 % alcohol. The specimens were identified, and their body length and body widths were measured. The body volumes of the specimens preserved in formalin were calculated from the body width and the body length, under the assumption of the cylindrical body form of earthworm.

The specimens were identified according to “Oligochaeta” (Ohfuchi 1957), in Illustrated Encyclopedia of the Fauna of Japan ed. by Uchida et al, about the literatures on the taxonomy of Oligochaeta in Japan and surrounding regions (Goto et Hatai 1898, 1899, Kobayashi 1938, 1941a-b, Yamaguchi 1962, Son and Paik 1970 a-c, 1971). The undescribed species was shown by the first character of the name of the region where the earthworm had been collected first. The nomenclature follows Sims and Easton (1972).

1-2. Sampling of earthworm's cocoon

Samplings of earthworm's cocoon were made in area D in late August, 1971 and 1972. Twenty-five sampling points per a sampling were chosen, using the random number table. The size of the quadrates used was $25 \times 25 \text{ cm}^2$. A soil sample was scooped out from a quadrate down to a depth of 20 cm. Soil samples were filtered through the sieve of 1 mm mesh with washing. The cocoons of most earthworm species were larger than 3-4 mm in diameter. The cocoons on sieve were collected. Collected cocoon was weighed and the shape and the color were recorded.

Pheretima sp. (H-1) (Oligochaeta: Megascolecidae) produced cocoons under the cultivating condition (chapter 4). The cocoon is a ball with a small projection and the color is yellow brown. The weight of cocoon is 10-30 mg fresh wt. Only the cocoon of such shape was able to identify the species.

2. The regression coefficient between weight and body volume

The earthworms collected in sampling were preserved in alcohol. Then, the weight of the earthworm preserved in alcohol was calculated by using the regression coefficient between the weight and the body volume. The regression coefficient only of *Pheretima* sp. (H-1) was made. Two hundred fifty specimens adopted for this determination were collected in the surrounding of area D between March and June 1972. The fresh weights of the earthworms collected were measured one by one. After there, the earthworms were anesthetized by adding drop by drop absolute alcohol slowly, were placed between the glass sticks and were fixed with 10 % formalin solution for a day. Later, the specimens were preserved in 70 % alcohol. The body length and width of the specimens were measured. The specimens were dissected with a surgical knife and its guts content was removed. After, the specimens were dried for a day at 60 °C and the dry weights of specimens were measured. Figure 1-4 show the results. The relation between body volume and fresh weight and the relation

between body volume and dry weight can be represented by the following equations.

$$W = 1.033378 \times V - 2.16689 \quad r = 0.9562 \quad (1-1)$$

$$D = 0.0695 \times V + 1.3303 \quad r = 0.9461 \quad (1-2)$$

W is the fresh weight in mg, V, the body volume in mm³, and D, the dry weight in mg. These coefficients were quoted to estimate the weight of other species, in spite of different coefficient of different species.

3. Weight distribution of earthworms

The calculated values of earthworm's fresh weight are from 10 to 5000. The frequency histograms of the earthworm's fresh weight were not a normal distribution in many cases. To make the histogram of regular distribution, the 1/3 power root was converted into earthworm's fresh weight. The frequency histogram on the cube root of fresh weight showed a normal distribution in most populations. Thus, the weight distribution of earthworms in this paper is given as the frequency histogram of the 1/3 power root weight.

The fresh weight was approximated by the following equation: $WW = a \times BL \times BW^2$, where WW denotes the fresh weight, a, constant, BL, the body length and BW, the body width. This is same to the following equations: $WW = a' \times BL^3$ or $WW = a'' \times BW^3$, assuming that the body width and the body length are proportional with each other. Then, the normal distribution of the 1/3 power root of weight means the normal distribution of body length or body width.

The average weight in this histogram is calculated as three power of the average of the cube root of the weight. As a natural result, this average value is different from the arithmetic average value. The earlier value is lower than the later one in always. In later chapters of present study, the arithmetic average will be employed for the future comparative study on weight of earthworms. To avoid the above confusion, the weight of earthworms in the figure will be expressed by the 3 power of the upper and the lower range of the standard deviation of cube root of weight (av. \pm). (The average between the upper range and the lower range was almost same to the arithmetic average value. In most case, the difference was within 1 % of the arithmetic average value.)

4. Growth analysis on the population having a bi-modal distribution of weight

Some species showed a bi-modal histogram of weight, each of which represents a different generation. The populations having many generations were separated to several generations by Cassie's Method (Cassie 1954). The density of each generation was calculated as a quantity surrounded by an estimated normal curve.

Result

1. Population densities and weight distributions of earthworms in area H

In area H, there were collected six species of Pheretima group Megascolecidae, and two species of Lumbricidae. *Pheretima* sp. (H-1), *Pheretima vittata* (Goto et Hatai) and *Pheretima micronaria* (Goto et Hatai) were abundant, and *Pheretima s. schmardae* (Horst) was moderately

abundant, in area H. *Pheretima phaselus* Hatai, one unknown species of *Pheretima* group, *Allolobophora japonica* (Savigny) and *Bimastus parvus* (Eisen), these were collected at times. There were collected several earthworms having clitellum, but lacking male opening on male segments. These have a same feature of internal anatomy to that of *Pheretima* sp. (H-1). Then, these were determined as *Pheretima* sp. (H-1).

Ph. schmardae, *Pheretima* sp. (H-1) and *Ph. vittata* were sampled from litter layer or the worm cast layer which were build up by earthworm themselves. *Pheretima micronaria* was sampled from deeper zone, 0-20 cm.

The seasonal change of the population densities in area H was shown in figure 1-5. The weight distributions of earthworms in area H was shown in figure 1-6. The density and growth pattern of these abundantly population are seen bellow.

1-1. *Pheretima s. schmardae*

A small number of *Ph. schmardae* ($2-3 \text{ m}^{-2}$) was collected only in three months from May to July 1968 (Fig. 1-5). Most worms were collected at young stage on May 19, and A clitellum appeared on the body surface of the earthworms collected on 3 August 1968. The appearance of clitellum shows earthworm's maturity. The weight of the earthworms collected on 3 August was 425-808 mg fresh wt (Fig. 1-6). This species was founded abundantly in wetter habitat such as a heap (Sugi unpublished). Then, migrants might compose the temporary population of this species in area H.

1-2. *Pheretima* sp. (H-1)

The density of *Pheretima* sp. (H-1) showed a peak (23.8 m^{-2}) on March 20, 1968 (Fig.1-5). Most member of the population in this month was at juvenile stage of 34-70 mg fresh wt (Fig. 1-6). The population density decreased considerably in the following month, and in contrast, the individual gained the more weight growth in these months. It attained to 1828-3578 mg fresh wt on July 6. Most earthworms reached at sexual maturity by July 6. After that, the weight decreased slightly (1270-2766 mg fresh wt on August 3). Most adults disappeared by late August. A few earthworms remained till late autumn in 1968. Copulation was frequently observed on the rainy days of June 1968 in this area. Most of the specimens collected on August 3 were bearing the white spots on the body surface due to the parasitization by ameba which was assumed to be the mortality factor in summer as was pointed by Ohfuchi (1947).

1-3. *Pheretima vittata*

The seasonal change of the density of *Ph. vittata* was similar to the change of *Pheretima* sp. (H-1). *Ph. vittata* showed the maximum density of 8.5 m^{-2} on April 15, 1968 (Fig. 1-5). Individuals grew up from 39-112 mg fresh wt on March 20 to 3910-9135 mg on July 6. All the earthworms collected on July 6, 1968 were at mature stage. A slight decrement of weight and of density was seen in summer. The weight of surviving individuals increased again in autumn

(6510-10835 mg fresh wt on October 6, in Fig. 1-6).

1-4. *Pheretima micronaria*

Ph. micronaria have slender body shape and relatively small body size. The weight frequency shows that the population is composed of two or more generations (Fig. 1-6). The weight and the density of an individual generation were analyzed by using the Cassie's method. Figure 1-7 shows the result.

The weight of old generation which started in 1967 grew up from 97-158 mg on March 20 to 1197-1815 mg on August 3, 1968. The density was below 1.0 m^{-2} . This generation disappeared by Sept. 2 1968.

The new generation first occurred in May. The fresh weight of new generation on May 19 was 38-94 mg. They grew up to 367-888 mg fresh wt on October 6. Some individuals of 1968's summer population attained to sexual maturity by that day. The density of this generation showed a peak of 13.0 m^{-2} on August 3, 1968. After, it had decreased to 1.0 m^{-2} by Nov. 7, 1968. A small individual was collected in the autumn. However, the number of individuals was insignificant. These results show that majority of *Ph. micronaria* hatch out in early summer, spent winter at pre-matured or matured stage, grow steeply in spring and oviposit the cocoon in early summer.

2. Population densities and weight distribution of earthworms in area K (Kumano shrine)

The species in area K were three of genera of *Pheretima* group and two of family Lumbricidae. Earthworms in area K were poor. Relatively abundant species in this area were *E. japonica*, *Pheretima irregularis* (Goto et Hatai) Ohfuchi, *Pheretima heterochaeta* (Kinberg 1867) and *Ph. micronaria*. *B. parvus* was collected at times. *Ph. irregularis* was collected in litter layer, and *Ph. heterochaeta*, *Ph. micronaria* and *E. japonica* were collected in deeper soil layer.

The seasonal change of the population densities in area K was shown in figure 1-8. The weight distributions of earthworms in area K was shown in figure 1-9. The density and growth pattern of these abundantly population in area K are seen bellow.

2-1. *Pheretima irregularis*

The number and growth pattern of *Ph. irregularis* in area K showed a similar change with those of *Pheretima* sp. (H-1) and *Ph. vittata* in area H. *Ph. irregularis* was collected after March 23, 1968. The weight of earthworm was 16-142 mg fresh wt on March 23, 1968. After, earthworms grew up and attained to 1441-2777 mg fresh wt on July 3. The majority of individuals reached maturity by July 3. Summer decrement of the weight was seen also in this species (Fig. 1-9). The density showed a peak of 5.8 m^{-2} on June 6. Some matured earthworms remained till October 22, 1968 (Fig. 1-8). Still, the matured earthworms of *Ph. irregularis* have not a male pore. However, there are unknown on the fertility of this species (Kobayashi 1938).

2-2. *Pheretima heterochaeta*

Ph. heterochaeta in area K appeared after June 1968. Its density showed the maximum of

6.5 m⁻² on August 15. Afterwards, the density became 3.3 m⁻² on Oct. 22 (Fig. 1-8). The weight of individuals has scattered within the range of 21-3209 mg fresh wt through the investigation period. This means the overlapping of various stages. Still, there were a lot of young individuals in August (Fig. 1-9).

2-3. *Pheretima micronaria*

The density of *Ph. micronaria* in area K was one-five of those in area H. Maximum density was 2.8 m⁻² on Sept. 15, 1968 (Fig. 1-8). The weight of individuals scattered in the wide range from 5.4 to 1077 mg fresh wt through the investigation period (Fig. 1-9).

2-4. *Allolobophora japonica*

Allolobophora japonica was a very small species. The weights of most individuals ranged between 5.4 and 562 mg fresh wt, and of the 'even' largest one was less than 1150 mg fresh wt. *E. japonica* was the most abundant species in area K (Fig. 1-8). The density in area K fluctuated between 1.3 and 16.0 m⁻². The pre-matured individuals were abundant in autumn and the matured individuals were abundant in spring. Nakamura (1972) reported that *Allolobophora japonica* in Hokkaido northern Japan hatched out in spring, attained to pre-matured stage by autumn and matured in next spring. The present result mean, there was no difference of the life history of this species between two regions.

3. Population densities and weight distribution of earthworms in area D

Earthworms in area D were very rich. There were collected 8 species of *Pheretima* group, and 3 species of Lumbricidae. *Pheretima* sp. (H-1) and *Ph. heterochaeta* were abundant. *Ph. schmardae*, *Ph. vittata* and *Allolobophora caliginosa* (Savigny) were moderately abundant. *Pheretima hupeiensis* (Michaelson), *Eisenia foetida* (Savigny), *B. parvus* and three-unknown *Pheretima* group were collected scarcely. Still, there were several matured earthworms lacking the male pore on male segment. These earthworms were determined as *Pheretima* sp. (H-1) by the reason of same feature of internal anatomy. *Ph. schmardae*, *Pheretima* sp. (H-1) and *Ph. vittata* were collected in litter layer or wormcast layer. *Ph. heterochaeta*, *Ph. hupeiensis* and *A. caliginosa* were collected in deeper zone 0-20 cm than above species.

Figure 1-10 show the seasonal changes of the population densities and Figure 1-11 show the weight distributions of earthworms in area D. Seasonal changes in density and growth pattern of abundantly population are seen as bellow.

3-1. *Pheretima schmardae*

The population of *Pheretima schmardae* in 1971 appeared only in three months of May, June and July. The density in area D 1971 was low (1.7-5.3 m⁻²) (Fig. 1-10). The individuals collected before June was an immature individual. And, the individual collected in July was a maturity individual (Fig. 1-11). The weight of the individuals collected on July 7, 1971 was 372-634 mg fresh wt. The 1972's population of *Ph. schmardae* appeared after March 28. They maintained the

low-density level ($1.3-11.5 \text{ m}^{-2}$) till July 15. The maximum density appeared on July 29 (20.5 m^{-2}) (Fig. 1-10). The weight of earthworms showed a maximum (206-443 mg fresh wt) on July 29, 1972 (Fig. 1-11). A clitellum appeared on the body surface of the most individuals collected on July 29. Population disappeared by late August. The population change indicated that *Ph. schmardae* was a temporary population also in area D.

3-2. *Pheretima* sp. (H-1)

The density of *Pheretima* sp. (H-1) was 63.0 m^{-2} on March 7, 1971 (Fig. 1-10). Most member of the population was juvenile stage. Its weight was 22-70 mg fresh wt (Fig. 1-11). After that, the density increased and attained to the maximum of 95.3 m^{-2} on May 8. The individuals of 20 mg-1900 mg fresh wt compose the population in May. (The range calculated from the cube root of standard deviation was 148-737 mg fresh wt). Small individual was observed to be born from cocoon when the earthworm was sampled in March and April 1971. Therefore, it is thought that a considerable part of newborn in 1971 appeared after March. After, the density decreased from 37.5 m^{-2} on June 10 to 9.3 m^{-2} on July 7. The weight of the earthworms collected on July 7, 1971 was 1155-2532 mg fresh wt. The majority of individuals reached maturity by July. Copulation was frequently observed on the rainy days of June. The population disappeared till August 9, 1971. On fine day after heavy rain of June 1971, mass emergency of earthworm was observed frequently on the bare area of the experimental field. The rainy season of this year had ended and the soil of the experimental field had dried up till early June. A few mummified earthworms were detected in the dry soil of the area at the sampling time of July 7.

Small earthworms were collected on Feb. 14, 1972. It is shown that a new generation appeared (Fig. 1-10). Its density was 60.8 m^{-2} . The weight of individual on Feb. 14 was 38-100 mg fresh wt (Fig. 1-11). Afterwards, the densities increased, and it reached the highest density of 108.8 m^{-2} on March 28. The density decreased slowly in the period from March 28 to May 23, 1972. The density decreased rapidly from May 28 to August 28 except between June 19 and June 30. The clitellum appears on the body surface of all individuals collected after June 30. This shows that most individuals of *Pheretima* sp. (H-1) reached maturity by the end of June. The earthworms collected on June 19 showed the maximum weight of 1019-2589 mg fresh wt. Copulation was frequently observed on rainy days of June and early July 1972. After word, the weight decreased slightly and was 552-1431 mg fresh wt on July 29. All earthworms disappeared by late August. Mass emergence were observed on bare ground surrounding the experimental field on fine days after heavy rain between May and June 1972. And, several dead individuals were detected on bare ground after mass emergence.

Number of yellow brown cocoon belonging to *Pheretima* sp. (H-1) was 102.5 m^{-2} in 1971 and 122.9 m^{-2} in 1972 in area D. The density of cocoon were equivalent to 1.75-2.74 times of the densities of the earthworms in June: $102.5/37.45$ in 1971 and $122.9/\{(76.8 + 68.0 + 66.0)/3\}$ in 1972.

This shows that the maturity individual produces 2-3 cocoons. The density of cocoon in 1971 was equivalent to 1972's maximum density of *Pheretima* sp. (H-1) (108.8 m^{-2}). *Pheretima* species produced one individual in many cases but two individuals rarely (Ohfuchi 1947). Then, the above result may mean that most of the cocoon deposited in early summer survive through winter, and hatch out in spring of next year. The weight of cocoons ranged between 12.0 and 34.0 mg fresh wt (19.57 mg in av.) in 1971 and between 9.0 and 29.0 mg fresh wt (18.97 mg in av.) in 1972. Still, two among the yellow brown cocoons collected in 1972 hatched out after 2-3 day of keeping in vinyl bags. The weights of the emerging earthworm were 25.7 mg fresh wt and 23.0 mg fresh wt, respectively.

3-3. *Pheretima vittata*

Ph. vittata in area D appeared after March in both years: 1971 and 1972. The density through the active month from March to July were $0.7 - 1.7 \text{ m}^{-2}$ in 1971 and $0.6-5.8 \text{ m}^{-2}$ in 1972 (Fig. 1-10). The individual grows up rapidly for these periods, and will reach maturity by July (Fig. 1-11). The weight showed a peak in early summer (5276-8629 mg fresh wt on July 7, 1971 and 6045-8720 mg fresh wt on June 30, 1972). All earthworms disappeared by late August in both years.

3-4. *Pheretima heterochaeta*

The weight frequency of *Ph. heterochaeta* indicates bi-modal distributions through the investigation period (Fig. 1-11). Figure 1-12 shows the weight frequency and the density of each generation, which were estimated with Cassie's method.

In early March 1971, the individuals belonging to old generation were at pre-matured or matured stage. The weight of individuals of an old generation was 164-376 mg fresh wt on March 7. Most individuals of an old generation were mature by July 7, 1971. They grew up to 617-972 mg fresh wt on Sept. 7, 1971. On the other hand, the density of the old generation increased even after March 7, 1971. It showed a peak (29.0 m^{-2}) on June 10, 1971. The old generation disappeared by October.

New generation appeared after April 1971. The replenishment of the individual of a new generation continued until September. The weight of the individual of a new generation was 12-37 mg fresh wt on May 8. The weight has grown up to 702-751 mg fresh wt by November 5. Before winter, a clitellum appeared on the body surface of some individuals. The weight once decreased in winter months. It increased to 639-1258 mg fresh wt on June 30, 1972. Most individuals of this generation reached maturity at that day. On the other hand, the density of 1971 year's generation showed a maximum (24.0 m^{-2}) on Oct. 5, 1971. After there, it decreased gradually and maintained a low density ($7.0-14.1 \text{ m}^{-2}$) in spring of 1972. However, the density increases again, as like the 1970's generation. It showed a peak (21 m^{-2}) on June 19, 1972. After that, the density of the 1971's generation decreased rapidly, but A part of maturity individual was survived until January 1973. Still, the figure on the weight frequency show that the 1971's generation was composed by two sub

generations, one sub generation was starting in summer and another was starting in autumn, respectively (Fig. 1-11). However, The weight and the density of every sub generation could not be estimated by the reason of the low density of sub-generation for the analysis of Cassie's method.

The individuals belonging to the 1972's generation appeared from May 23 to August 28. The weights of the new generation's individual were 28-48 mg fresh wt on May 23, 1972. The weight has increased to 298-844 mg fresh wt by March 22, 1973. The density of the 1972's generation showed a maximum of 72.2 m^{-2} on August 28, 1972. Its maximum density was equivalent to 2.5 times of that of the 1971's generation. The 1972's generation once disappeared from the 0-20 cm soil layer on Jan. 3, 1973. But it recovered the original density of 68.5 m^{-2} till Jan. 28, 1972 (Fig. 1-12). Still, total density more increased after Feb. 1973. This was due to the 1973's generation (Fig. 1-11 and Fig. 1-12).

From the above results, the life history of *Ph. heterochaeta* in area D can be inferred as bellow. The hatching occur through a year except winter. But, most of hatching occurs in summer. Majority attains to middle size of weight till autumn and once moves to deeper soil layer in winter month. After hibernation, these earthworms return to shallower soil layer again. They mature by early summer and may oviposit the cocoon in summer. Also, the dynamics of every generation can be inferred as bellow. A new generation starts in summer-autumn. Then, each generation show a maximum density in late summer or autumn. Some individuals disappear just after hatching and in winter months. The number of the matured individuals increased in June of both year 1971 and 1972 (Fig. 1-12). This result may be due to the moving of matured individuals from deeper zone to shallower zone for copulation and oviposition. After oviposition, many matured individuals disappear but some remain till late autumn.

The maximum density was 3 times higher in 1972 than in 1971. This result might be due to the much rain fall of summer of 1972 than that of 1971 (Fig. 1-2).

3-4. *Allolobophora caliginosa*

The density of *A. caliginosa* in area D fluctuated between 0.0 and 13.4 m^{-2} through the investigation period (Fig. 1-10). The population was composed by various stages through a year. The weights of individuals were distributed between 5 mg to 2073 mg fresh wt. However, The majority of populations in July - August 1971 and the end of August 1972 were composed by a small individual (Fig. 1-11).

4. Population densities and weight distributions of earthworms in area G

In area G, there were collected 7 species of *Pheretima* group and 3 species of Lumbricidae. Dominant species in this area was *Ph. heterochaeta*. *Pheretima* sp. (H-1) and *A. caliginosa* were moderately abundant. Other species: *Ph. vittata*, *Ph. hupeiensis*, and three unknown species of *Pheretima* group, *E. foetida* and *B. parvus* were collected scarcely.

Figure 1-13 and Figure 1-14 showed the density and the weight frequency of the

population in area G. The densities and the growth pattern of the abundantly populations are as follow.

4-1. *Pheretima* sp. (H-1)

The majority of *Pheretima* sp. (H-1) in Area G was collected in the place which was adjacent to Area D through the investigation. This species appeared after Jan. 21, 1972. The maximum density was 22.4 m⁻² on March 25, 1972. Afterwards, the density has decreased gradually. The population disappeared by July 19, 1972 (Fig. 1-13). The growth pattern of this population was similar to that of same species in area D 1972. The weight of individuals was 28-54 mg fresh wt on Jan. 21, 1972, and the earthworm collected on June 1, 1972 showed the maximum of 465-1667 mg fresh wt (Fig. 1-14). The weight of individuals in area G was smaller than that of same species in area D.

4-2. *Pheretima heterochaeta*

Pheretima heterochaeta consists of some generations through year as shown in Figure 1-14. The weight frequency and the density of every generation were analyzed with Cassie's method. Figure 1-15 shows the result of analysis. An old generation, which had started in 1970, disappeared by September 1971. The weight of new generation, which had left in the summer of 1971, was 53-154 mg fresh wt on August 9, 1971. Afterwards, the weight reached 337-1420 mg on Nov. 7, 1971. Several individuals had reached maturity before winter. The weight once decreases slightly in winter. The weight increased again, and it reached 528-1196 mg in June 1972. On June 1, 1971, most individuals of this generation were at matured stage. On the other hand, the density of the 1971's generation showed a maximum (72.0 m⁻²) on Sept. 7, 1971. After, it decreased gradually till Jan. 21, 1972. It fluctuated around the low density level (17.4-25.6 m⁻²) during Jan. 21 and April 24, 1972. However, the density of the 1971's generation increased again after April 1972. It showed a peak of 62.5 m⁻² on June 1, 1972. The density of peak was equivalent to 86.8 % of the maximum density of this generation on Sept. 7, 1971. After that, this generation decreased their density gradually and disappeared by Nov. 11, 1972.

The individuals belonging to the 1972's generation in area G appeared in the period from June to August. The weights of individual of 1972's generation were 11-61 mg fresh wt on June 1, 1972. The weight has increased to 436-950 mg fresh wt on Jan. 3, 1973. The weight of this population's individual decreased temporarily in the winter, too. They showed a maximum density (128.0 m⁻²) on Oct. 1, 1972. Its maximum was two times of that of same species in area D 1972. Afterwards, the population disappeared from the layer of 0-20 cm in the winter (Fig. 1-15).

The population change and the weight frequency of *Ph. heterochaeta* in area G were almost similar to those of same species in area D, except the density level. The life history of the population in area G, inferred from the above results, was almost same as those of the area D population. The population density in area G was twice of that in area D. This result may mean that

Ph. heterochaeta is more adaptable in area G than in area D.

4-3. *Allolobophora caliginosa*

The density of *A. caliginosa* fluctuated between 2.4 and 16.0 m⁻² (Fig. 1-13). The population was composed by various developmental stages, the weight of individuals was ranged from 0.4 to 1622 mg fresh wt. Still, the weight frequency on August 9 and Oct. 5, 1971, June 1, 1972 and July 19, 1972 show the recruitment of new born (Fig. 1-14).

Discussion

1. Faunas of earthworms in the suburb of Fukuoka city Kyushu Japan

Kobayashi (1941) suggested that the number of species of terrestrial earthworms in Japan is about 190, but only 80 of them had been recorded. In present study, 10 species of *Pheretima* group and 4 species of Lumbricidae were collected. Most abundant species was *Pheretima* sp. (H-1) and secondary abundant species was *Ph. heterochaeta*. Moderately abundant species were *Ph. schmardae*, *Ph. vittata*, *Ph. irregularis*, *Ph. micronaria*, *A. japonica*, and *A. caliginosa*. Other species were founded rarely. Besides, *Pheretima hilgendorfi* (Michaelsen), *Pheretima agrestis* (Goto et Hatai), *Pheretima sieboldi* (Horst) and several unknown *Pheretima* group were founded in the suburb of Fukuoka city Kyushu (Sugi unpublished). Then, the number of *Pheretima* species in the suburb of Fukuoka city may be attained to several time of the number of *Pheretima* species collected in present study. This means that a rich fauna of *Pheretima* group characterizes the earthworm in West Japan.

The variability in some characters of taxonomic value, as seen in *Ph. hilgendorfi* (Kobayashi 1938) and *Pheretima divergens divergens* (Michaelsen) (Yamaguchi 1962), was observed in some species of *Pheretima* group collected in present study such as *Pheretima* sp. (H-1) and *Ph. irregularis*.

2. Life history and growth pattern

Among *Pheretima* species collected abundantly in the suburb of Fukuoka City, *Ph. schmardae*, *Pheretima* sp. (H-1), *Ph. vittata* and *Ph. irregularis* are litter dwellers, and *Ph. heterochaeta* and *Ph. micronaria* are soil dwellers. Four litter dweller species are mutually similar concerning the seasonal change of the number of individuals and growth. A young individual appears in the spring, and grows up from spring to early summer rapidly. The individual will reach maturity, and produce cocoon by June of rainy season. After an oviposition, a slight decrement of weight was seen in summer and many earthworms disappeared by late August. The weight decrement after oviposition may show that the reproductive load besides the drying and high temperature condition in summer is very severe for the survival and the growth of individual earthworm. There were small, but noticeable differences in the degree of summer density decrement of litter dwellers between different habitats. *Pheretima* sp. (H-1) disappeared almost by early July in area G 1972 and disappeared by August in area D 1971 and 1972. But several

individual of this species remained till November in area H 1968. *Ph. vittata* was scarce in area G and area D, but relatively abundant in area D. *Ph. vittata* in area G 1972 appeared only in spring. This species remained till August in area D 1971 and 1972 and remained till November in area H 1968. *Ph. irregularis* in area K 1968 remained till November. These results show that the activity period of the litter dweller becomes long as the cover of the vegetation of habitat increases from area G to area-K. The scarce cover of above ground vegetation would allow a penetration of solar radiation and then would induce a higher temperature near soil surface in summer. This may mean that the activity periods of litter dwellers after summer depend on the temperature and the dryness near soil surface in summer.

Ph. schmardae and *Pheretima* sp. (H-1) were scarcely founded after summer, and *Ph. vittata* and *Ph. irregularis* were founded abundantly in late autumn in present study and in my occasional observation (Sugi un-published). This may mean that As for resistance to the high temperature and the dryness in summer, *Ph. vittata* and *Ph. irregularis* was stronger than *Ph. schmardae* and *Pheretima* sp. (H-1).

Soil dwellers: *Ph. heterochaeta* and *Ph. micronaria*, showed an overlapping of various developmental stage through a year against one age composition of litter dwellers. Two soil dwellers showed a similar life history with each other. Most individuals were born in summer though several small individuals are observed through year. Most individuals will reach pre-matured stage before winter. They once moved to deeper soil layer for hibernation in winter. Most individuals reached sexual maturity and perhaps oviposit cocoons in summer of next year. Then, the maximum densities of soil dwellers appear in summer or autumn. The deaths of soil dwellers seem to occur at young stage after summer peak of density, at pre matured stage after hibernation and at matured stage after oviposition.

Sugi and Tanaka (1978 a, b) reported that the abundantly species in ever green oak forest IBP Minamata area were *Ph. sieboldi* and *Pheretima* sp. (M-3) (Oligochaeta: Megascolecidae), both of which were founded frequently also in the mountain site of the suburb of Fukuoka city. They reported that these species had a generation per two year and spent in the litter layer through a year except winter, all of individual hatched out in June-July and matured in May-June of next year. The results from the present study, considered together with that reported by Sugi and Tanaka (1978 a, b), may indicate that the member of *Pheretima* species founded in the suburb of Fukuoka city can be divided into three or four groups with regarded to their life history. The first type is litter dweller and its populations are composed by one generation. Young individuals of this type appear in spring, and they mature in summer. *Ph. schmardae*, *Pheretima* sp. (H-1), *Ph. vittata* and *Ph. irregularis* belong to this type. As mentioned in above, *Ph. schmardae* and *Pheretima* sp. (H-1) disappeared by August, but *Ph. vittata* and *Ph. irregularis* are survived until late autumn. Therefore, the first group can divide into two sub-groups further according to the difference at the activity period, although the

difference is essentially related to the difference of the condition of each habitat. Namely, *Ph. schmardae* and *Pheretima* sp. (H-1) appear in spring, mature and oviposit a cocoons in early summer and disappear by late summer (1a type). Otherwise, *Ph. vittata* and *Ph. irregularis* appear in spring, mature in summer, and disappear before winter (1b type). Perhaps *Ph. hilgendorfi* and *Pheretima communissimus* (Goto et hatai) may belong to later sub type (Ohfuchi 1947, Hino 1929, Ogawa 1934). The second type is also litter dweller. Its population is composed by one age generation. The young individual of the second type appear in summer and they pass winter at pre-matured stage, mature and deposit the cocoon in summer of next year. *Ph. sieboldi* and *Pheretima* sp. (M-3) belong to the second type. Last type is soil dweller. Individuals of various developmental stages compose its population through year. Many younger appear in summer, pass winter at pre-matured or matured stage, and mature and produce a cocoons in summer of next year. *Ph. heterochaeta* and *Ph. micronaria* belong to last type. Watanabe (1975) reported that *Ph. hupeiensis* hatched out in May, grew rapidly and hibernated in immature or matured stage. And, its size distribution showed an overlapping of various sizes. Then, *Ph. hupeiensis* may belong to the third type.

Most individuals of all species of *Pheretima* mature in early summer. This result may mean that the warm and wetter condition in early summer is suitable for the metabolism of all species of *Pheretima*. There were a large difference in life history between soil dwellers and litter dwellers. The litter dweller is always composed by one stage, but the soil dweller has various developmental stages through year. The litter dweller *Pheretima* that are exposed to heat and drought may adjust their life cycle to the change of external environment. On the other hand, the maturity and oviposition of soil dweller are defended from the dryness and high temperature on the soil surface.

3. Biomass of earthworm

The biomass of earthworm populations was calculated by summing up the weight of each individual. Table 1-3 summarizes the maximum biomass of the representative species. In this table, the areas are arranged in the cover degree of above ground vegetation. The order may show the direction of plant succession. Also, various earthworms have been brought together according to the life history. The biomass of *Pheretima* species is different according to vegetation. *Ph. schmardae* was distributed in old grass field (area D) and the shrine forest having a rich ground flora (area H). It was most abundant in area D (6.65 g fresh wt m⁻²). This species was a temporary population in both areas. This species was most frequently found in compost and the meadow around the rice field. *Pheretima* sp. (H-1) was distributed in younger glass field (area G), old glass field (area D) and shrine forest (area H). It was most abundant in area D (123.0 g fresh wt m⁻²). The population in area G may be a part of the population in area D. *Ph. vittata* have the same distribution areas as *Pheretima* sp. (H-1), but was most abundant in area H (29.24 g fresh wt m⁻²). *Ph. irregularis* appeared only in shrine forest, soil surface of which was scarcely covered by shrub (area K). The

maximum biomass was 10.6 g fresh wt m⁻². *Ph. sieboldi* and *Pheretima* sp. (M-3) appeared only in the forest on the mountain site (IBP Minamata). Sugi and Tanaka (1978 a, b) reported that the maximum biomass of these species were 157 mg dry wt m⁻² (2.3 g fresh wt m⁻²) and 1153 mg dry wt m⁻² (16.8 g fresh wt m⁻²) respectively. Among soil dweller *Pheretima*, *Ph. heterochaeta* was distributed in younger vegetation (area G, area D and area K) and was most abundant in youngest vegetation (area G) (60.5 g fresh wt m⁻²). Another soil dweller: *Ph. micronaria* was distributed in more old vegetation (area H, area K and IBP Minamata), and was most abundant in area H (5.11 g fresh wt m⁻²). The distribution area of Lumbricidae were narrower than those of soil dweller *Pheretima*. Namely, *A. caliginosa* appeared in area G and area D, and *E. japonica* appeared in area H and area K. The biomasses of Lumbricid were very small compared with those of *Pheretima* group.

The above result may indicate that the biomass of each earthworm species was related to the vegetation type of their habitat. *Ph. schmardae* and *Pheretima* sp. (H-1), these species were litter dweller and their life time was six months, were most abundant in old grass field (area D). *Ph. vittata* was litter dweller and its life time was about nine month. This was most abundant in shrine forest having rich ground flora (area H). *Ph. irregularis* with the same life history as *Ph. vittata* appeared only in woods (Area K). *Ph. sieboldi* and *Pheretima* sp. (M-3) were litter dweller and their activity period were one year. These appeared only in the forest of mountain site (IBP Minamata). Among two soil dwellers, *Ph. heterochaeta* appeared in younger vegetation and was most abundant in the youngest vegetation (area G). Another soil dweller: *Ph. micronaria* appeared in older vegetation but was scarce in their habitats. The relation between the vegetation type and the abundance of animals will be discussed in next paper.

Summary

1) The population studies of earthworms were performed in four areas in the suburb of Fukuoka city Kyushu Japan.

2) Ten species of *Pheretima* and 4 species of Lumbricid were founded in present study. Among them, six *Pheretima* and two Lumbricid were abundant.

3) *Pheretima* species founded in the suburb of Fukuoka city could be grouped into three or four groups with regard to their life history, in discussion together with the result on IBP Minamata area (Sugi and Tanaka 1978 a, b). *Ph. schmardae* and *Pheretima* sp. (H-1) were founded in litter layer, all the earthworms appeared in spring, matured in early summer and most disappeared till late summer (Ia type). *Ph. vittata* and *Ph. irregularis* were founded also in litter layer, all the earthworms appeared in spring, matured in summer but remained till autumn (Ib type). *Ph. sieboldi* and *Pheretima* sp. (M-1) were founded in litter layer except winter, all the earthworms appeared in summer, hibernate at pre-matured stage and matured in summer of next year (Second type). *Ph. heterochaeta* and *Ph. micronaria* were founded in deeper zone and had a various stage through a year but most younger appeared in summer, hibernate at pre-matured stage and matured in early

summer of next year (third type).

4) The biomass of each species changed with the difference of vegetation type. *Ph. schmardae* and *Pheretima* sp. (H-1) were most abundant in old grass field. *Ph. vittata* was most abundant in forest having a rich ground flora. *Ph. irregularis* was founded only in small forest. *Ph. sieboldi* and *Pheretima* sp. (M-1) were founded only in forest on mountain slope. *Ph. heterochaeta* was most abundant in the youngest vegetation and *Ph. micronaria* was most abundant in the forest having a rich ground flora.

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PartOne Chapter One

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