Interaction of animal with its environment

1 Structure of earthworm community in the suburbs of Fukuoka City

Distribution of environments under study
Maximum biomass of earthworm in various vegetation
Eco-morphological feature of representative Pheretima

Unsettled problem

a. Growth analysis on the population having a bi-modal distribution of weight, b. the individual without the male pore,
b. The function of intestinal coeca
c. Taxonomy problem of Pheretima of Fukuoka outskirts and Minamata

2. Population ecology of representative species *Pheretima* sp.(H-1) population

1. The earthworm is born, lives, and dies
   a Number of individuals and weight distribution b. Population metabolism
   c. Daily fecal pellet production rate, daily food ingestion rate digestive efficiency and assimilation efficiency
2. Relations between individuals of the same species（Movement and dispersion）
   a mass emergence of *Pheretima* sp. (H-1) on fine day after rain b The structure of habitat and the distribution pattern
3. **Interaction of animal with its environment**
   a Resource utilization and energy balance b The bio-economic life table
   c Interaction of animal with its environment

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(Slide 1) Contents

Table 1-1 Distribution of environments under study

	Area G	Area D	Area H	Area K	IBP minamata
Tree vegetation			*Celtis sinensis*	*Quercus glauca*	
Cover degree			ca 40 %	100%	
Ground surface vegetation	*Imperata cylindrica*	*Solidago altissima*	*Artemisia vulgaris*	*Damnacanthus indicus*	
	Carex spp.	*Vicia hirsuta*	*Achyranthes japonica*	*Trachelosperum asiaticum*	
Cover degree	ca 50 %	100%	ca 70 %	ca 20 %	
Litter layer (cm)	0	0.1 - 1.5	2.0 - 4.0	3.5 - 5.0	
A_0 horizon (cm)	1.7 - 4.2	3.0 -12.3	5.0 -40.0	5.0 -10.0	
pH in H_2O	5.56	6.05	6.2	4.7	
Primary production	540. ?	1176.5	1010 ?	844	
study year	1971-72	1971-73	1967-68	1967-68	1969-1971

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(Slide2) Table 1-1 Distribution of environments under study

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. 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.. Another field (area G) was covered with Monocotyledon such as *Imperata cylindrica*, *Cyperus rotundos* and *Carex* spp. . The area of Hakozaki shrine (area H) was predominantly covered by the dicotyledon such as *Artemisia vulgaris* L. var. *indica* Maxim., *Achyranthes japonica* Nakai and *Erigeron annuus* L. with deciduous trees. In Kumano shrine (area K), the territory was covered with dense evergreen forest and with poor undergrowth vegetation except a few shrubs. IBP minamata area, which are located in Kumamoto Prefecture, are ever green oak forest.

Table 1-3 Species composition and maximum biomass of earthworm in various vegetation

g fresh wt m-2

Area	Area G	Area D	Area H	Area K	**IBP Minamata**
Pheretima schmardae		6.648	1.877		
Pheretima sp. (H-1)	11.045	122.964	43.945		
Pheretima vittata	0.679	24.912	29.24		
Pheretima irregularis				10.552	
Pheretima sieboldi					2.312
Pheretima sp. (M-3)					17.122
Pheretima heterochaeta	60.512	34.39		3.762	
Pheretima micronaria			5.111	0.471	2.809
Allolobophora caliginosa	7.298	11.14			
Allolobophora jaoinica			0.182	2.494	
Other fewer species	*Pheretima hupeiensis* Two unknown Pheretima *Bimastos parvus*	*Pheretima hupeiensis* Two unknown Pheretima *Bimastos parvus*	*Bimastos parvus*	*Bimastos parvus*	Four unknown Pheretima One unknown Lumbricidae

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(Slide3) Table 1-3 Species composition and maximum biomass of earthworm in various vegetation

In present study, 10 species of Pheretima group and 4 species of Lumbricidae were collected. Most abundant species was *Pheretima* s. *schmardae, Pheretima* sp. (H-1), *Pheretima vittata, Pheretima irregularis, Pheretima* sp. (M-3), *Pheretima heterocheata Pheretima micronara, Allolobophora caliginosa and Allolobophora japonica.*

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. *A. 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}).

1972 population of *Pheretima* sp.(H-1) in Area D is the main object in the following consideration. The average and maximum biomass of earthworms were abundant in old grass field (area D), moderately abundant in the forest having a rich ground flora (area H) and younger grass field (area G), and scarce in evergreen forests.

Table 2-3 Eco-morphological feature of representative Pheretima

Species	*Pheretima schmardae*	*Pheretima* sp. (H-1)	*Pheretima vittata*	*Pheretima irregularis*	*Pheretima sieboldi*	*Pheretima* sp. (M-3)	*Pheretima heterochaeta*	*Pheretima micronaria*
Life history	**Newly born hatch out in spring, mature in summer and disappear till August .**		**Newly born hatch out in spring, mature in June and some remained till November.**		**Newly born hatch out in summer, mature till next summer, and disappear till August.**		Many younger appear in summer, mature till next summer, and some remain till winter.	
Life time	6 months		8 months		12 months		over 12 months	
age composition	One generation						Two or three generation	
Main habitat	**Compost**	**Old grass field**	**Old grass edge of**	**Edge of forest**	**Ever green forest in mountain site**		**Younger vegetation**	**Older vegetation**
Inhabit layer	Litter						**Litter - A -Soil**	
Hibernate site					Dry dingle	Deeper soil layer		
Body pigmentation	**yellow green**	**dark reddish brown**	**dark brown with yellow band**	**dark reddish brown**	**deep black purple**		**light grey brown**	**light purplish brown**
Number of pair of	two				three	two	four	
Activity	Active						sluggish	
Body form	Plumply						slenderly	
Body size	474	1922	6006	2206	30500	1434	799	564
Intestinal coeca	5	6-7	8	6	Most complex	Simple showing a conical form		
	pairs of finger projection							
Composition of gut content	**Organic rich matter**	**Small raw humus**	**Large raw humus**	**Organic rich matter with small raw humus**	**Litter from tree leaves**	**Organic rich matter**	**Organic rich soil and mineral soil**	

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(Slide 4) Table 2-3 Eco-morphological feature of representative Pheretima

Some eco-morphological feature such as body size, body form mobility and the developmental degree of intestinal coeca, and feeding habit were investigated on seven representative Pheretima species: *Ph. s. schmardae*, *Pheretima* sp. (H-1), *Ph. vittata*, *Ph. irregularis*, *Pheretima* sp. (M-3), *Ph. heterocheata* and *Ph. micronaria*.

Soil dweller: *Ph. heterocheata* and *Ph. micronaria* had in a small body size and slender body form, and showed a sluggish mobility compared with those of litter dwellers.

Among litter dwellers, *M. schmardae* had the smallest body size, and *Pheretima* sp. (M-3) had the slenderest body form. It was discussed that the eco-morphological feature of each species were largely reflected on their life history, their hibernating behavior and distributions, in relation to the structure of their habitats. There was large difference between every species in the gut material. The main component of gut material were large particle of raw humus in *A. vittata*, of small particle of raw humus in *Pheretima* sp. (H-1), of small particle of raw humus and organic rich material in *A. irregularis*, of organic rich material in *M. schmardae* and *Pheretima* sp. (M-3), and or organic rich soil and mineral material in *A. micronarius* and *Ph. heterocheta*. There were observed a linear relation between the decayed degree of gut material and the developmental degree of intestinal coeca, of each species. The feeding habit of each species was discussed in relation to the quantity and quality of the food resource presenting in their habitats.

It was discussed that Pheretima species found in suburb of Fukuoka city had a different niche with each other, along three axes: life history, habitat preference and food preference. The genera of Pheretima in Japan lack the well-developed calciferous gland. However, this problem is unsettled.

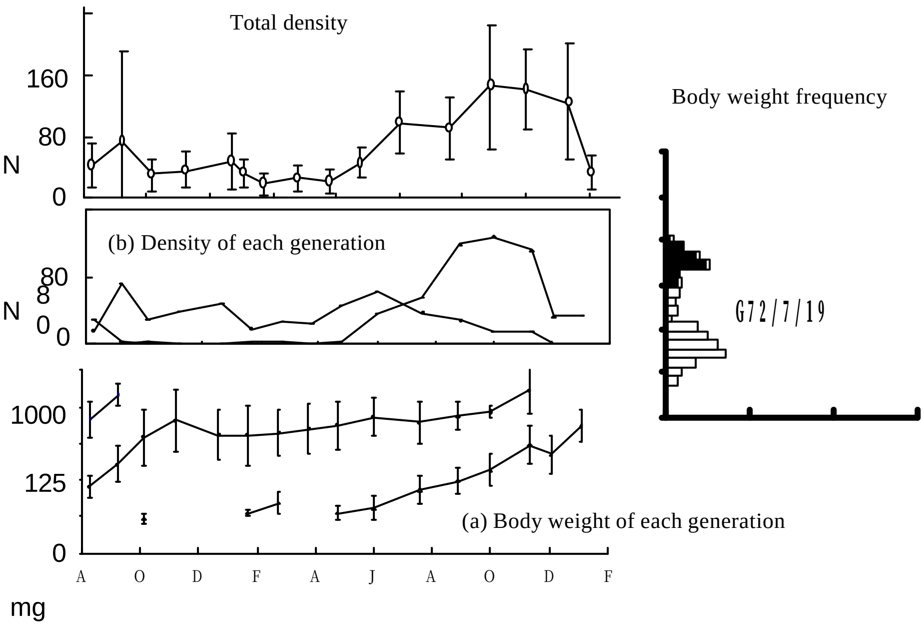

Fig. 1-15. Seasonal change in (a) body weight and (b) density of each generation of *Pheretima heterochaeta* in area G. Vertical lines in upper figure indicate one standard deviation.

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(Slide5) Growth analysis on the population having a bi-modal distribution of weight

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.

Soil dweller earthworm 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.

Table 7 - 1 Microbial density in gut materials of *Pheretima* sp. (H-1)

coeca 6-7 finger shape litter dweller

4-5 individuals per a measurement

The average of 5 measurement (1972/5/ 1 5 - 6/25)

Body weight	D	Fore gut × 10	Mid gut × 10	Hind gut × 10
Average weight	5	2.9	6.1	9.4
2722.6	6	4.0	7.6	11.2
GWW	7	7.7	15.4	27.9

Table 7 - 2 The number of observed colonies in gut materials of *Pheretima heterochaeta*

coeca conical form soil dweller

4 individuals per a measurement

The average of 5 measurements (1971/10/21-12/8)

Body length	D	Fore gut	Mid gut	Hind gut
10cm	3	13.1	12.3	21.7
から	4	3.6	3.1	6.6
12cm	5	0.9	0.9	1.7

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(Slide6) Function of intestinal coeca

Ishizuka assumed the intestinal coeca to be the most important character for the classification of Pheretima. In my research, the shape of the intestinal coeca correlated to the quality of the eaten food. Ishizuka described the following forecasts (private letter) The intestinal coeca might help the activity of the bacterium in intestines. I examined the microbaial density in the intestine of Pheretima (Pheretima) sp. (H-1) by the process of the research of earthworm's mass emargence.

Parle (1963a) reported that bacteria and actinomycetes were up to 103 time in gut of *Lumbricus terrestris* L. than in surrounding soil. Otherwise, bacteria increased to 3-5 time during the passage of material through the gut of *Pheretima* sp. (H-1). The difference in the increasing rate of microbial population between two species may be caused by the difference in passing time of material through the gut of each earthworm species. The material remains in the gut of L. terrestris for about 20 hr. (Parle 1963a) and in the gut of *Pheretima* sp. (H-1) for about 4-5 hr. Parle (1963a) considered that the length of time the food remains in the gut of *L. terrestris* would not allow the break down of cellulose by microbial action and the organism present did not helped earthworm to ingest its food. It is equally impossible for the bacteria in *Pheretima* sp. (H-1) to help the digestion of earthworms because of shorter time of the food remain of this species than that of *L. terrestris*.

I had examined the microbial density in gut material of Pheretima heterochaeta as a practice before. The number of bacteria has decreased once by mid gut in Pheretima heterochaeta. However, the investigation time is different. It is not understood whether this result depends on working of coeca.

(Gut material is not weighed for (Ph. heterochaeta). Therefore, the number of observed colonies was not able to be converted into microbial density.)

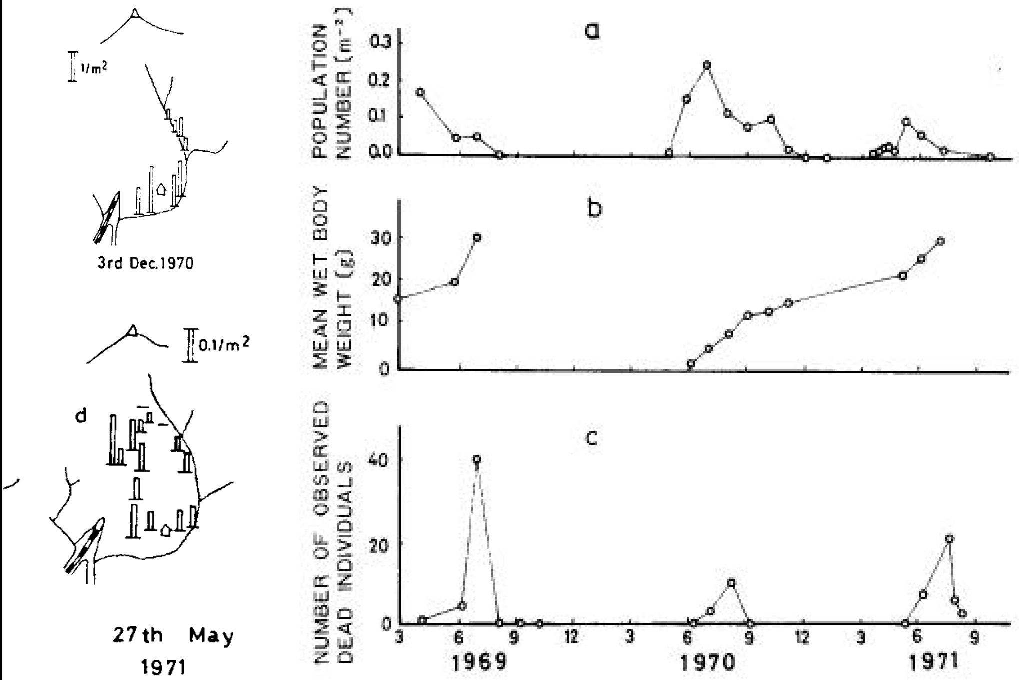


FIG. 3.2-5. Seasonal changes in average population density (a), mean body size (b) and number of dead worms observed (c).

(Slide7) Pheretima sieboldi in Minamata

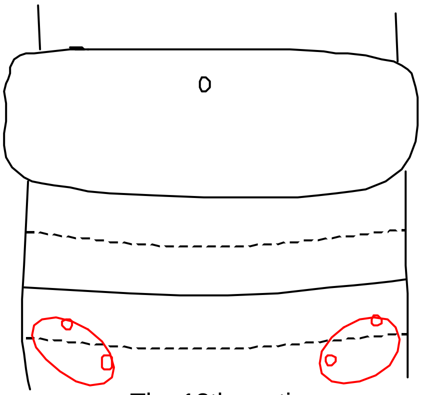
Ph. sieboldi hatches out in early summer on the forest floor, reaching a size of Ca. 1.2 g (wet weight) in June. The worms spend the period from May to November in the litter or humus layer on the ground, and grow to a wet body weight of 12-14 g in November. Then they migrate to the dry bottom of a dingle 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.

In Minamata, the species requires two years for one generation to pass from egg to maturity. However, this species appears in Mt, Houman (Fukuoka) every year. Moreover, the Individual number of this species is a little in Mt, Houman (Fukuoka). In Mt, Houman (above sea level 829m), I keep observing the number of appearance of these earthworms now. The result is shown in this homepage.

Taxonomical problem of earthworm collected in Fukuoka pref.

- Young earthworm cannot be identified.
- All of *Pheretima vittata* and the majority of *Pheretima* sp.(H-1) have the male pore.
- In Fukuoka and Minamata, there are **a lot of nameless earthworms.** . .



Rough sketch of *Pheretima* sp.(H-1)

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(Slide 8)Taxonomy problem of Pheretima of Fukuoka outskirts and Minamata

Earthworm's young individual can be essentially identified only by intuition. However, earthworm's ecology cannot be done without identifying a young earthworm. In addition, earthworm's species cannot be identified in the field. The earthworm was fixed by the formalin solution for 24 hours, and it preserved it in alcohol afterwards. The specimen was identified under the microscope. Still, a young earthworm cannot easily distinguish Pheretima heterochaeta and Pheretima micronaria. When this two species appeared at the same time, the young individual was arranged under the microscope, and distinguished as follows. The specimen with red was identified with Pheretima micronaria. Moreover, a greyish specimen was identified with Pheretima heterochaeta. It was said by the resercher of spider's taxonomy that a young spider was not able to identify it.

Mature Pheretima vittata collected in Fukuoka has all male pores. In Tokyo, the male pore possession rate of mature Pheretima vittata is several percent (Ishizuka 1999). 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. Pheretima sp. (H-1) is intuitively like to Pheretima hilgenndorfi well. Moreover, I observed the copulation of the individual with the male pore and the individual without the male pore. On the other hand, Pheretima hilgendorfi and agrestis are most in the edge of a small woods in Fukuoka outskirts.

Right figure shows Pheretima sp.(H-1).

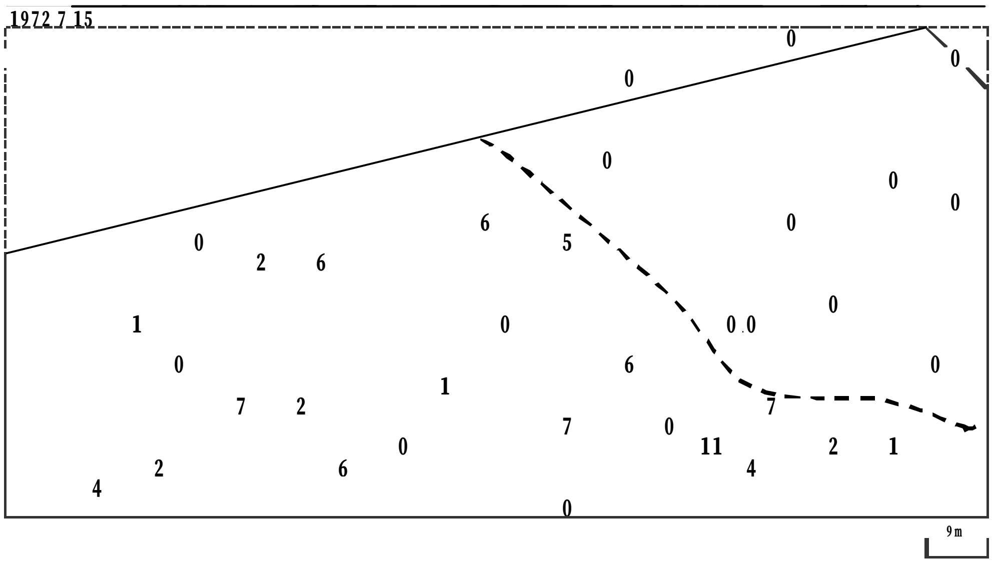

Fig. 2-3a. Distribution maps of earthworm in the experimental field.

Black letter indicate the density of Pheretima sp. (H-1) (25 x 25 cm-2)

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(Slide 9) Fig. 2-3a. Distribution maps of earthworm in the experimental field.

A part of the experimental field (area D) was covered densely by the dicotyledon、The remained part of the experimental field (area G) was covered with the monocotyledon、In the soil of Area D, the organic was rich, the ratio of fine particle was high and the density was low. The A_0 horizon in area D was thick. On the other hand, in the soil of area G, the organic material was poor, the ratio of coarse sand was high and the soil density was high. The A_0 horizon in area G was thin.

The distribution of *Pheretima* sp. (H-1) which is the litter dweller is corresponding to the distribution of the dicotyledon and the distribution of *A. vittata* and *M. schmardae* were restricted within the area D, the soil surface of which were covered with the dicotyledon. *Ph. heterocheta* was scattered over the experimental field regardless of vegetation type. As mentioned, the area covered by the dicotyledon (area D) had plenty ground flora and thick A_0 horizon, and the area covered by monocotyledon (area G) had not. These results may mean that *Pheretima* sp. (H-1), *Ph.. vittata* and *Ph. schmardae* require a plenty flora and thick A_0 horizon for their distribution, and *Ph. heterocheta* can live in either condition. *Pheretima* sp.(H-1) and *Ph. vittata*:This two species live in the litter layer of same vegetation.

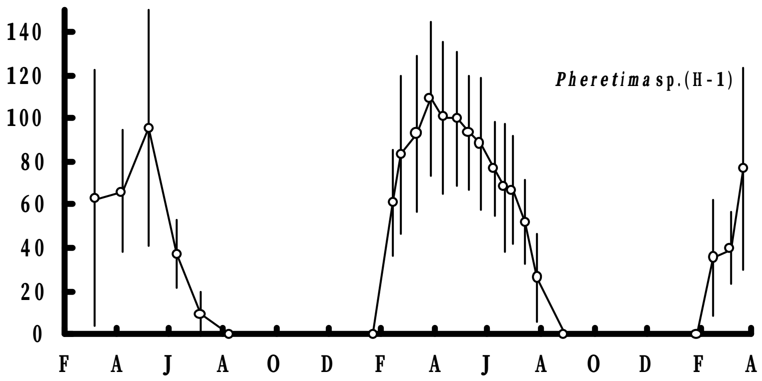

Fig. 1-10. Seasonal change in population density of *Pheretima* sp.(H-1) in area D. **Vertical lines indicate one standard deviation.**

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(Slide10) Seasonal change in population density of *Pheretima* sp.(H-1) in area D.

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}. 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. All earthworms disappeared by late July.

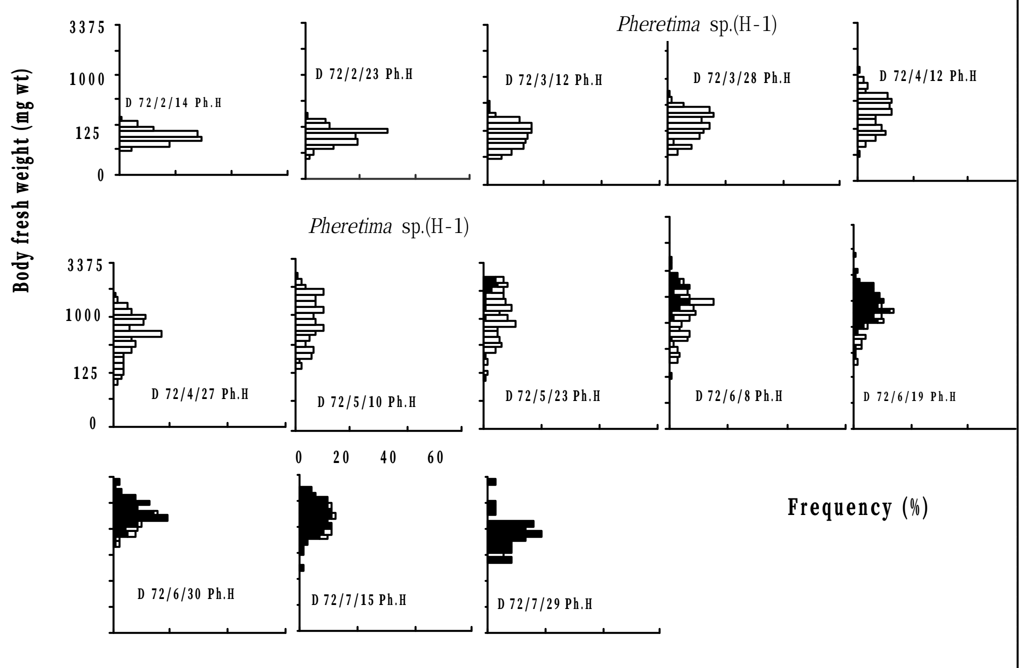
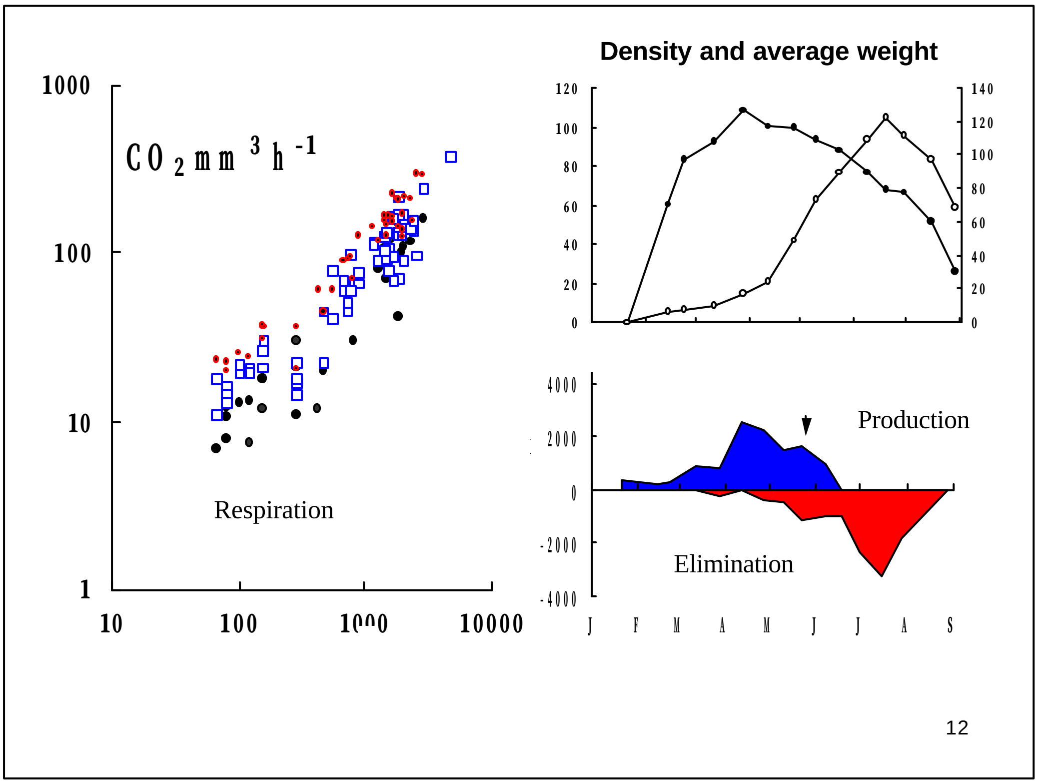


Fig. 1-11. Seasonal change in body weight frequency of Pheretima sp. (H-1) in area D（1972）

Open bars indicate the frequency of immature and black bars indicate the frequency of mature. 11

(Slide11) Fig. 1-11. Seasonal change in body weight frequency of Pheretima sp. (H-1) in area D（1972）

The weight of individual on Feb. 14 was 38-100 mg fresh wt (Fig. 1-11). 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.



(Slide12) Respiration, production and elimination of Pheretima sp. (H-1)

Consumption is a total of production and respiration. The production of *Pheretima* sp.(H-1) is calculated from the number of individuals and the average weight shown in the foregoing paragraph. However, it is necessary to measure the amount of the respiration.

Figure 3-1 shows the respiration rate of *Pheretima* sp. (H-1). The CO_2 expiration rate can be represented as follow

$CO_2\ h^{-1} = 111.23\ W^{0.69271}$ at 25 °C (3-1)

$CO_2\ h^{-1} = 76.50\ W^{0.69296}$ at 20 °C (3-2)

$CO_2\ h^{-1} = 58.50\ W^{0.73654}$ at 15 °C (3-3)

W is the weight of the earthworms in g fresh wt.

***Pheretima* sp. (H-1) in area D 1972:**

The biomass of *Pheretima* sp. (H-1) in area D 1972 increased after Feb., reached a maximum level on May 23. This highest level has been maintained for the period of the rainy season (Fig. 3-4). The maximum biomass was 8.378 g dry wt m^{-2} (177.067 KJ m^{-2}) on June 8, 1972. The average biomass was 4.368 g dry wt m^{-2} (92.299 KJ m^{-2}). The production was estimated at 11.489 g dry wt m^{-2} (242.672 KJ m^{-2}). The density of cocoon was 128.6 m^{-2} and the average weight of cocoon was 18.97 mg fresh wt. These mean 8.648 KJ m^{-2} of cocoon production. The respiration rate increased after Feb., reached a maximum level on June 19 and maintained the level for June. The maximum rate of respiration was 6.510 KJ m^{-2} d^{-1} on June 30, 1972. Total respiration was calculated as 589.275 KJ m^{-2}.

The assimilation (P+R) of *Pheretima* sp. (H-1) 831.917 KJ m^{-2} in area D 1972

Table 3-1 Production, respiration, assimilation and ecological ratios

Species	*Pheretima* sp. (H-1)					*Ph. Vittata*	*Ph.irregularis*	*Ph. sieboldi*	*Ph. Heterochaeta*	
Year	1968	1971	**1972**	1972	1972	1968	1968	1970 1971	1971 1973	1971 1972
Area	Area H	Area D	**Area D**	Area G	Clay sand	Area H	Area K	IBP	Area D	Area G
Net production										
g dry wt m^{-2}	4.075	7.688	**11.489**	1.174	6.368	3.217	0.827		1.59762	4.7243
KJ m^{-2}	85.772	162.339	**242.642**	24.686	134.575	68.199	17.573	5.23	33.765	99.839
Cocoon production										
g dry wt m^{-2}	0.0018	0.0021		0.0022						
KJ m^{-2}	0.007554	0.008648		0.009205						
Respiration KJ m^{-2}	138.239	193.669	**589.275**	44.124	263.885	126.566	43.639	6.527	234.467	659.465
Assimilation KJ m^{-2}	224.011	356.008	**831.917**	68.81	398.46	194.765	61.212	11.757	268.232	759.304
Average biomass g dry wt m^{-2}	0.779	1.729	**4.368**	0.268	1.72	0.883	0.226	0.09	0.695	1.632
Maximum biomass g dry wt m^{-2}	2.982	3.324	**8.378**	0.76	4.352	1.964	0.725	0.157	1.368	2.889
R/A	0.617	0.544	**0.708**	0.641	0.662	0.65	0.713	0.555	0.874	0.869
P/B	5.218	4.446	**2.63**	4.381	3.702	3.643	3.659	2.649	2.3	2.895
P/B_{MAX}	1.363	2.313	**1.371**	1.545	1.463	1.638	1.141	1.584	1.168	1.635

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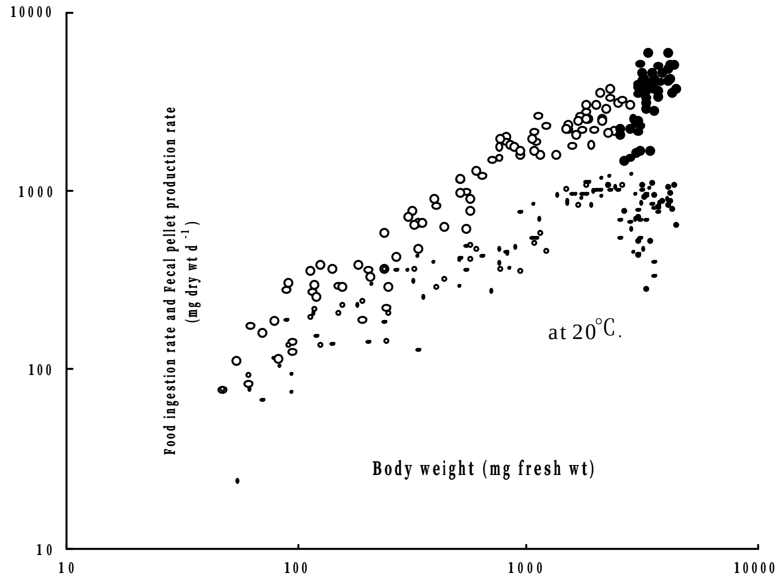
(Slide13) Table 3-1 Production, respiration, assimilation and ecological ratios

***Pheretima* sp. (H-1) in area D 1972:**

The maximum biomass was 8.378 g dry wt m^{-2} (177.067 KJ m^{-2}) on June 8, 1972. The average biomass was 4.368 g dry wt m^{-2} (92.299 KJ m^{-2}). The production was estimated at 11.489 g dry wt m^{-2} (242.672 KJ m^{-2}). The density of cocoon was 128.6 m^{-2} and the average weight of cocoon was 18.97 mg fresh wt. These mean 8.648 KJ m^{-2} of cocoon production. The maximum rate of respiration was 6.510 KJ m^{-2} d^{-1} on June 30, 1972. Total respiration was calculated as 589.275 KJ m^{-2}.

The R/A ratio of Pheretima were ranged between 0.544 and 0.713 for litter dweller Pheretima and 0.869-0.874 of soil dweller Pheretima. The values of litter dweller Pheretima were slightly smaller than those of Lumbricidae species.

P/B ratio, and P/B_{max} of litter dweller Pheretima were ranged between 2.631 and 5.218, and between 1.141 and 2.313, respectively. Also, the values of soil dweller Pheretima were 2.300-2.895 and 1.168-1.635, respectively. The values of litter dweller Pheretima were larger than those of Lumbricidae species.



food consumption rate | **fecal pellet production**

Y = 545.15 W 0.4382 at 25 ºC | F = 1419.12 W 0.7015 at 25 C

Y = 481.55 W 0.5280 at 20 ºC | F = 1405.93 W 0.9594 at 20 ºC

Y = 338.13 W 0.8764 at 15 ºC | F = 986.86 W 0.92840 at 15 ºC

Y:Food consumption per day W:Body weight F:Fecal pellet production per day 14

(Slide14) food consumption rate, fecal pellet production

1) *Pheretima* sp. (H-1) were cultivated under three temperature condition, and fecal pellet production, food consumption rate and growth rate were determined.

2) The cultivated earthworms required 34 - 64 days for their maturation against to 100 days of maturation period for the field earthworms. Also, the maximum weight of the cultivated earthworms was attained to 4 - 4.5 g fresh wt against 1.7 - 2.5 g fresh wt of the field earthworm.

3) Fecal pellet production of the cultivated earthworms were 1054 - 1540 mg dry wt for an individuals having one gram body wet weight.

4) Litter consumption of the cultivated earthworms were 374 - 590 mg dry wt for an ndividuals having one gram body wet weight. Still, the litter consumption rate of mature earthworms was smaller than the rate of immature earthworms.

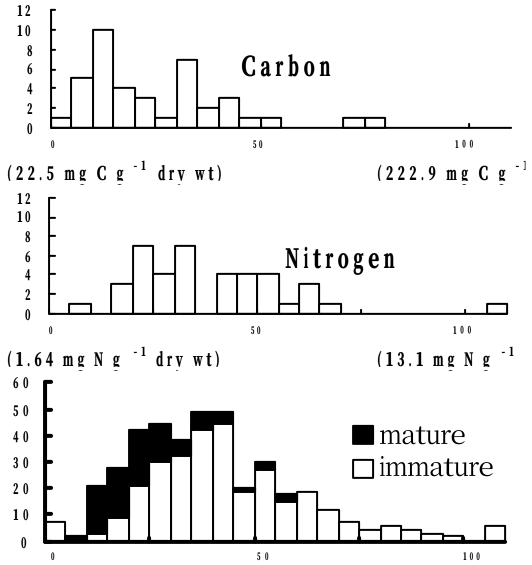


Fig.4-6. Nutrient contents of the materials in alimental canal of the pre-mature worms collected in field.

a, Carbon content; b, Nitogen content; c; The ratio of food consumption to fecal pellt production, of the reared worms. In Lowest figure, the open area indicates the contribution by immature worms and the black area indicates the contributionby mature worms.

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(Slide15) Fig.4-6. Nutrient contents of the materials in alimental canal of the pre-mature worms collected in field.

5) The carbon content in gut material of the field individuals was 72.15 mg g^{-1} dry wt in *Pheretima* sp. (H-1) and 116.83 mg g^{-1} dry wt in *Ph. vittata*. These were equivalent to 77.03 % in *Pheretima* sp. (H-1), and 91.71 % in *Ph. vittata*, of the estimated carbon contents of the cultivated earthworms, respectively. The litter feeding ratio of the *Pheretima* sp. (H-1) field populations can be presumed from the data of the content of the carbon of the field population by the next expression.

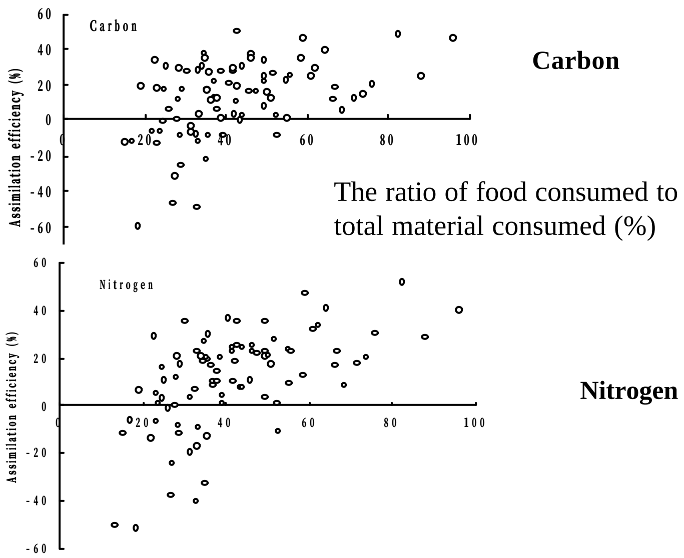


Fig. 5-2a. The relation between the assimilation efficiency and the ratio of food consumed to total material consumed.

16

(Slide16) The relation between the assimilation efficiency and the ratio of food consumed to total material consumed.

1) The digestive efficiency of the cultivated earthworms was estimated with the difference in the quantity of nitrogen and carbon between consumed minus ejected. The estimated efficiency was in wide range from -200 % to 80 %.

2) The relation between the digestive efficiency and the quality of the material consumed was approximated by following equation A = 0.58028 X - 12.624, where X is the ratio of the food consumed to total material consumed. The average ratio of the food consumed to total material consumed was estimated as 35.5 % in cultivation condition. The digestive efficiency of the cultivated earthworms was calculated at 7.397 %.

Table 5-1 Digestive efficiency of *Phererima* sp. (H-1)

		Efficiency (%)	Food consumption / Pellet production (%)
Reared worms (A=C-F)	Carbon	8.124	35.5
	Nitrogen	7.392	
Reared worms (A=P+R)	25℃	2.31	35.5
	20℃	1.98	
	15℃	2.22	
Field Population	Carbon	1.895	24.77
	Nitrogen	9.559	38.86

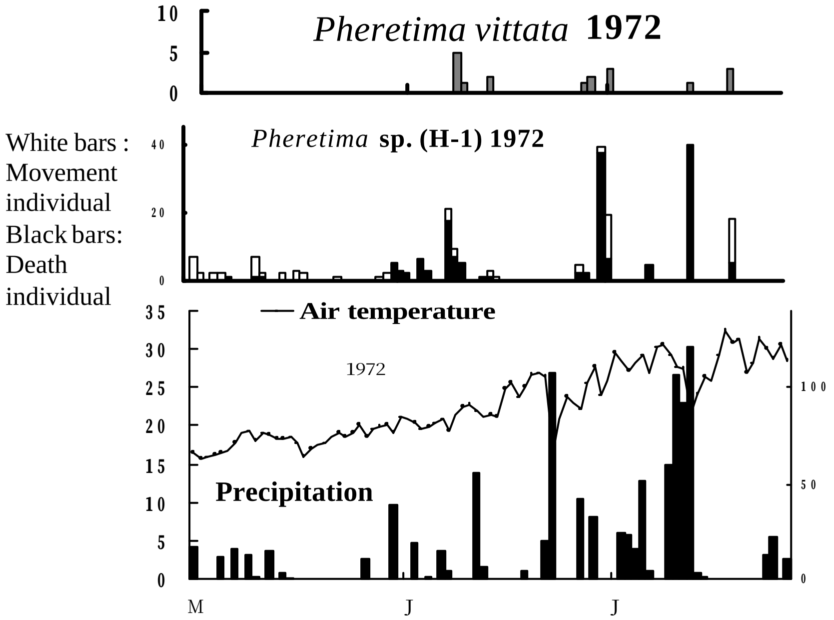
17

(Slide17) Table 5-1 Digestive efficiency of *Phererima* sp. (H-1)

The digestive efficiency of the cultivated earthworms was calculated at 7.397 %.

Assimilation efficiency of the cultivated earthworm can be estimated another process {A = (P+R)/C}. Average efficiency from (P+R)/C was calculated at 2.17 %. The values from (C-F)/C were far larger than that from (P+R)/C. Particularly, the excess absorption (total absorption minus basal metabolism) was larger in younger earthworm than in elder earthworm. It was discussed that the excess energy assimilated by younger earthworms must be expended for their mobility and their specific dynamic action to gain the larger weight increase.

The digestive efficiency of the field earthworm (A=(C-F)/C) could be estimated at 1.895 %, the value of which was deduced from Carbon content in the gut material of the field earthworms. This value was far lower than the average value of the cultivated earthworm. It was discussed that the lower digestive efficiency of the field earthworms than that of the cultivated earthworms might be another reason why the weight and the growth rate were far lower in field than in cultivation.

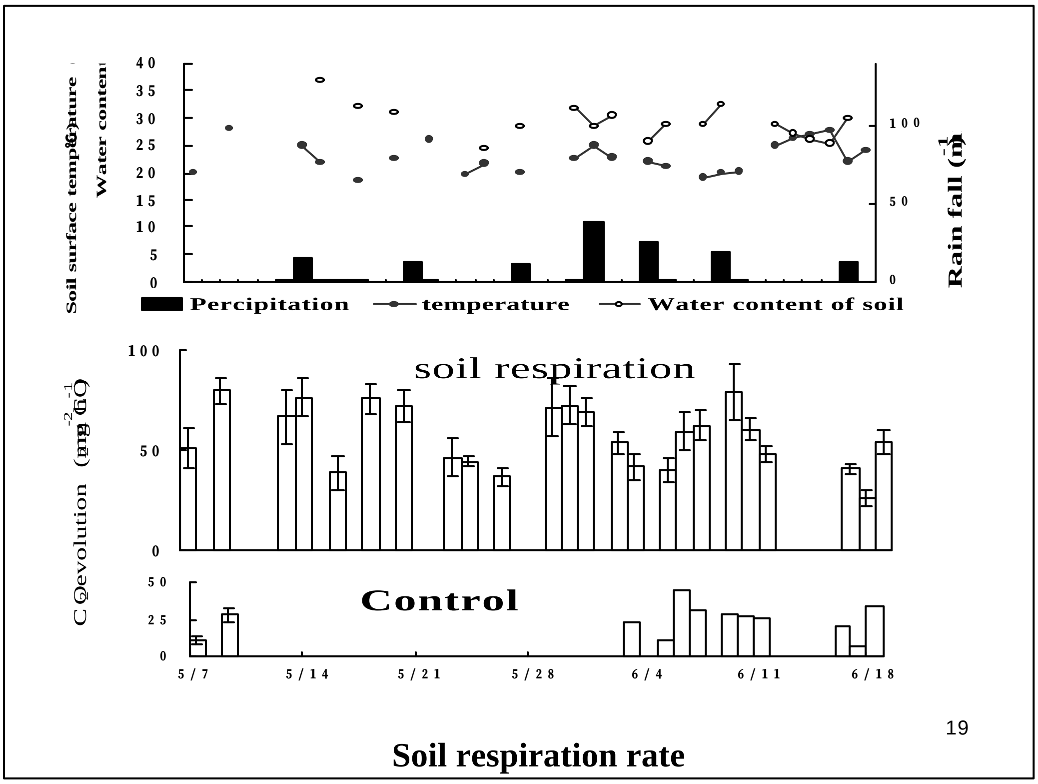


Mass movement of earthworm on fine after rain 18

(Slide18) Mass movement of earthworm on fine after rain

The daily change of the number of death earthworms that had died on the bare ground was shown in Figure 7-3

The observation on mass emergence of *Pheretima* sp. (H-1) were carried out on the bare land in the experimental field of Department of Biology Kyushu University in the period from May to July for two years 1971 and 1972. The mass emergence of *Pheretima* sp. (H-1) occurred frequently on fine day after rain. Several individuals was killed by solar radiation on bare land. Few individuals died on other days.



(Slide19) Figure7-4 Soil respiration rate

The soil respiration rate on fine day after rain was two fold of the rate on rainy days or dry days. The increase of soil respiration rate in soil air on fine days after rain was the factor inducing the creeping our behavior of earthworm.

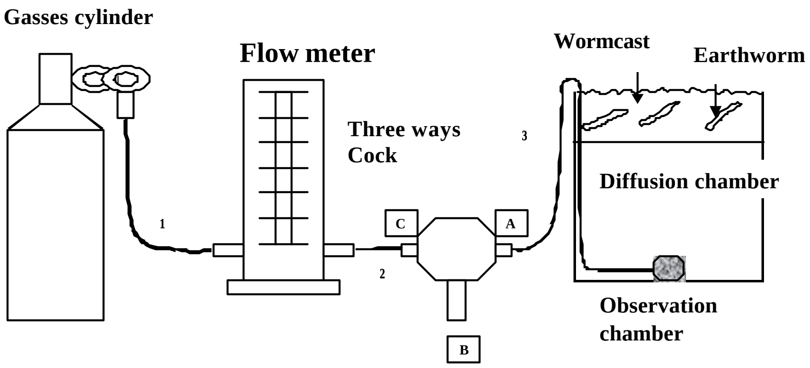


Fig.7-2 Shema of the response box

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This work follows the responses of the earthworm to CO_2 gas and N_2 gas. Figure 7-2 shows the apparatus for observation. The apparatus was composed of gas cylinder, flow meter, three way cock and response box. The response box was made up of two parts. One part was the gases diffusion chamber, the volume of which was 1250 ml, and other part was the observation chamber. To prevent the sudden gust of gas, the plastic boll which was porous was settled at the end of polyvinyl chloride tube in the gas diffusion chamber. The observation chamber was filled up with the fecal pellet which was used as the habitat of earthworm like wormcast in field. By filling up the chamber with fecal pellet, various gases can flow from the plastic boll to outside of the chamber through the layer of fecal pellet. As earthworm could move easily in the fecal pellet, the behavior of earthworm could be observed exactly.

The procedure of experiment was presented as bellow. (1) Three-way cock was turned open to A site and the valve of gas cylinder was open for a sometime. Then, the gas flowed through the tube 1, 2, 3 and the plastic boll. (2) Three-way cock was handled to C site. After, the response box was sweeping by the stream of O_2 gas. (3) The fecal pellet was placed on the surface of wormcast layer. The specimens were laid on the surface of wormcast layer. They creep into wormcast layer and came to a standstill there. (4) Five minute after the standstill of earthworm in wormcast layer, a three way cock was handled to B site, the valve of gas cylinder was open. The flow was settled at an appointed rate using a flow meter, a three way cock was handled to A site, the object gases flowed into the gas diffusion chamber for a settled time. Then, an appointed volume of gases flow into the box. After that, a three way cock was handled to B site (then, the excess gases flowed out from the observation system to an open air), and immediately the valve of gas cylinder was closed.

The observation on behavior of earthworm was begin just after the inflow of object gas into the diffusion chamber and continued for 22 minute.

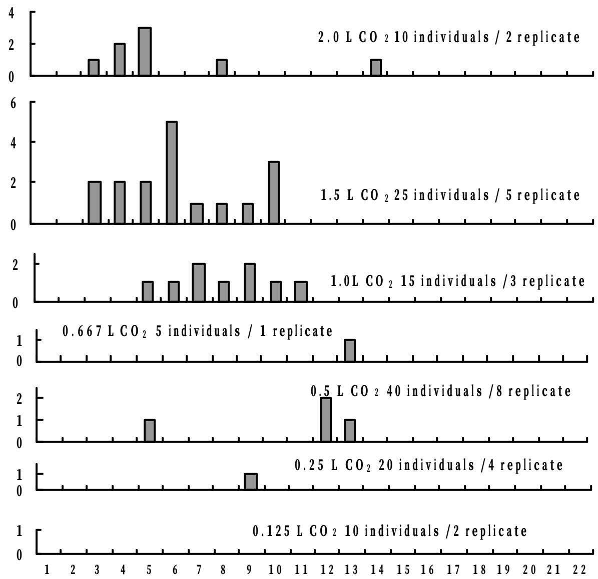

Fig. 7-7a Number of earthworm showing the rashing out behavior to various concentration of Carbon dioxide gases.

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(Slide21) Fig. 7-7a Number of earthworm showing the rashing out behavior to various concentration of Carbon dioxide gases.

The response of *Pheretima* sp. (H-1) to harmful gases was examined under experimental condition. Earthworm showed the abruptly creeping out behavior even to the small increase of CO_2 tension. They showed no behavior response by the continuously exposing of pure Nitrogen gas.

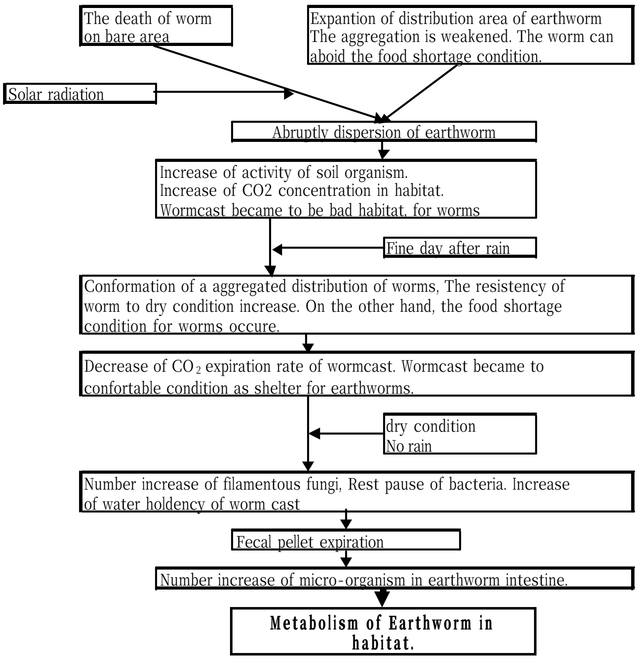

Fig7-9 Population meaning of the simultanously death of earthworm; Pheretima sp. (H-1) on fine days after rain

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(Slide22) Fig7-9 Population meaning of the simultanously death of earthworm; Pheretima sp. (H-1) on fine days after rain

Bacteria increased to 3-5 fold during the passage of materials through the intestine of *Pheretima* sp. (H-1). It was inferred that the wormcast had more plentiful flora of microbial population than the control soil.

Worm cast showed higher soil respiration rate and larger water holding capacity than those of control materials. The higher respiration rate of wormcast might be due to the high microbial activity besides the high water holding capacity of the materials. The warm and wet condition on fine days after rain stimulated the activity of microbial populations contained in wormcast and then the soil respiration rate increased.

CO_2 expiration rate was higher in wormcast (earthworm's habitat) than in other areas. By the reason that earthworm piled up the pellets on soil surface most abundantly in early summer, soil respiration in earthworm's habitat might be highest in this season through a year. This might be the reason why mass emergence of earthworm occurred only in this season.

Earthworm adjusted their density to the adaptive density by the dispersion of individuals on fine days after rain. As the biological conditioning of the earthworm’s habitat caused the mass emergence of earthworm, the mass emergence of earthworm on fine days after rain was regarded as the self regulation.

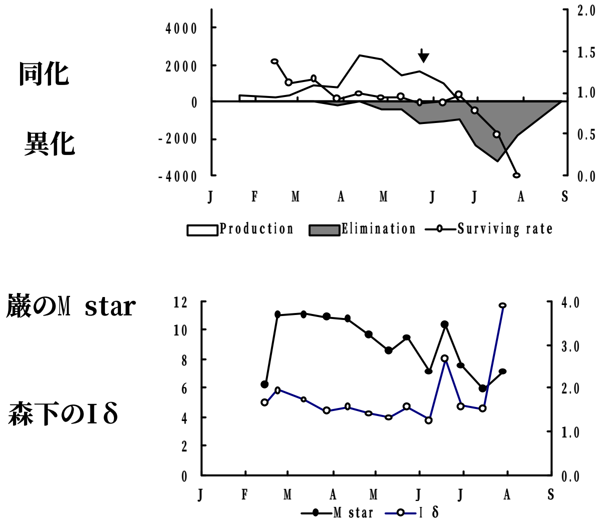

Figure8-2 Distribution pattern of individuals

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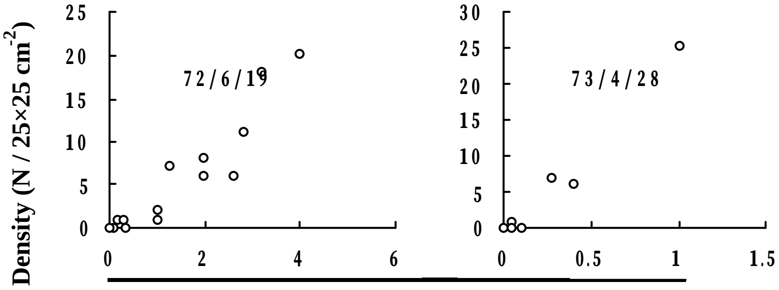
(Slide23) Figure8-2 Distribution pattern of individuals

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.



	A	1/A	B	r
1973/4/20	24.18	0.414	0.0157	0.889
1973/5/10	14.89	0.07	0.143	0.834
	(21.38)	(0.037)	(0.221)	(0.739)
1972/6/8	4.86	0.2058	0.499	0.849
1973/6/15	6.1	0.1639	0.665	0.812
1972/6/19	6.01	0.1664	0.7658	0.911
1972/6/30	5.08	0.1967	1.1167	0.767
1972/7/15	9.92	0.1008	0.8306	0.257

The regression coefficient between number of earthworm and thickness of wormcast 24

(Slide24) . The regression coefficient between number of earthworm and thickness of wormcast

Ecological meaning of wormcast relating to the life history of earthworm

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.

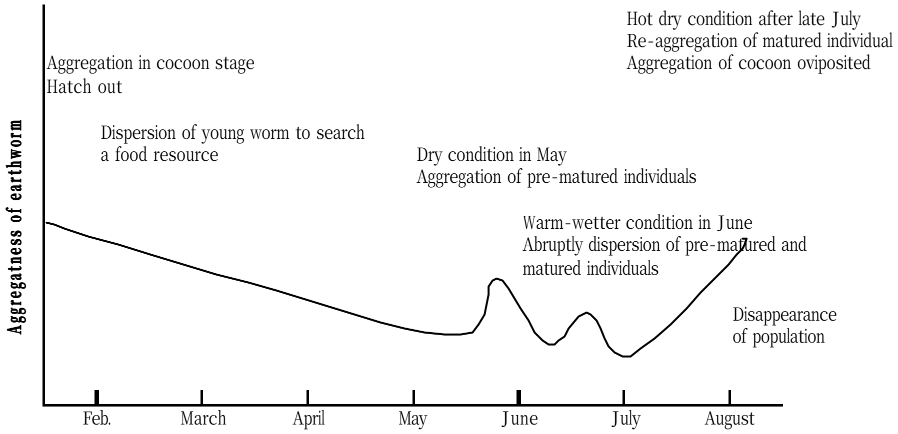


Fig. 8-7. The seasonal change in the degree of aggregation of *Pheretima* sp. (H-1) in relation to own's life history.

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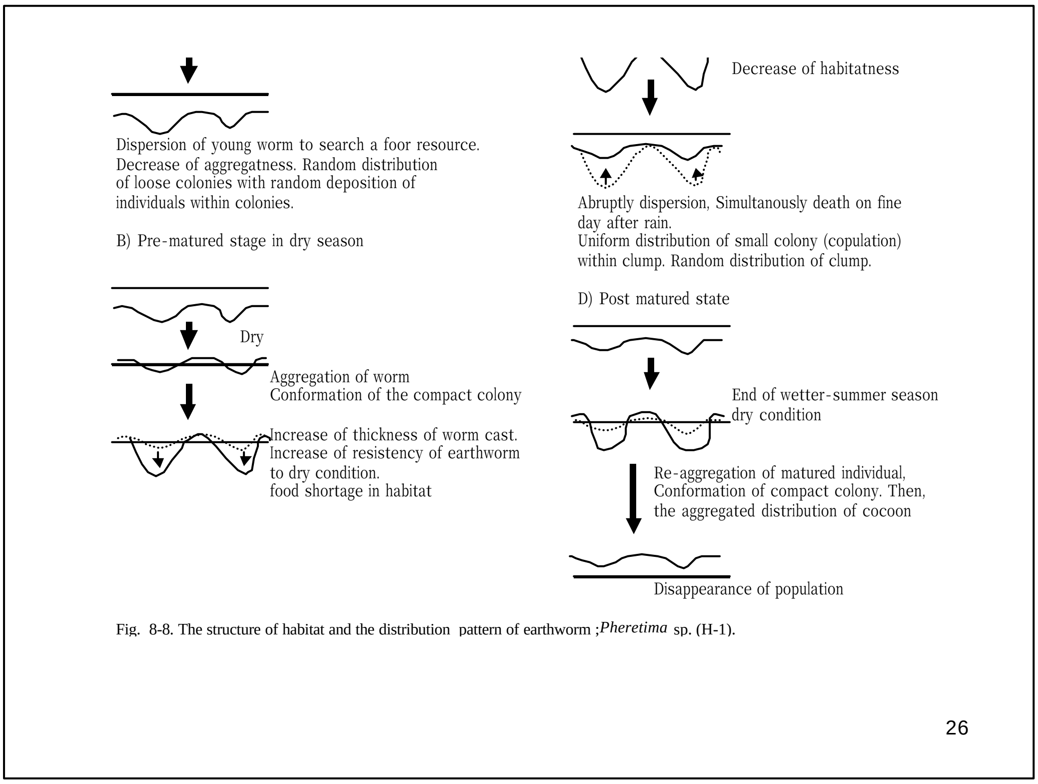
(Slide 25) Figure8-7 The seasonal change in the degree of aggregation of Pheretima sp. (H-1) in relation to own's life history.

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.



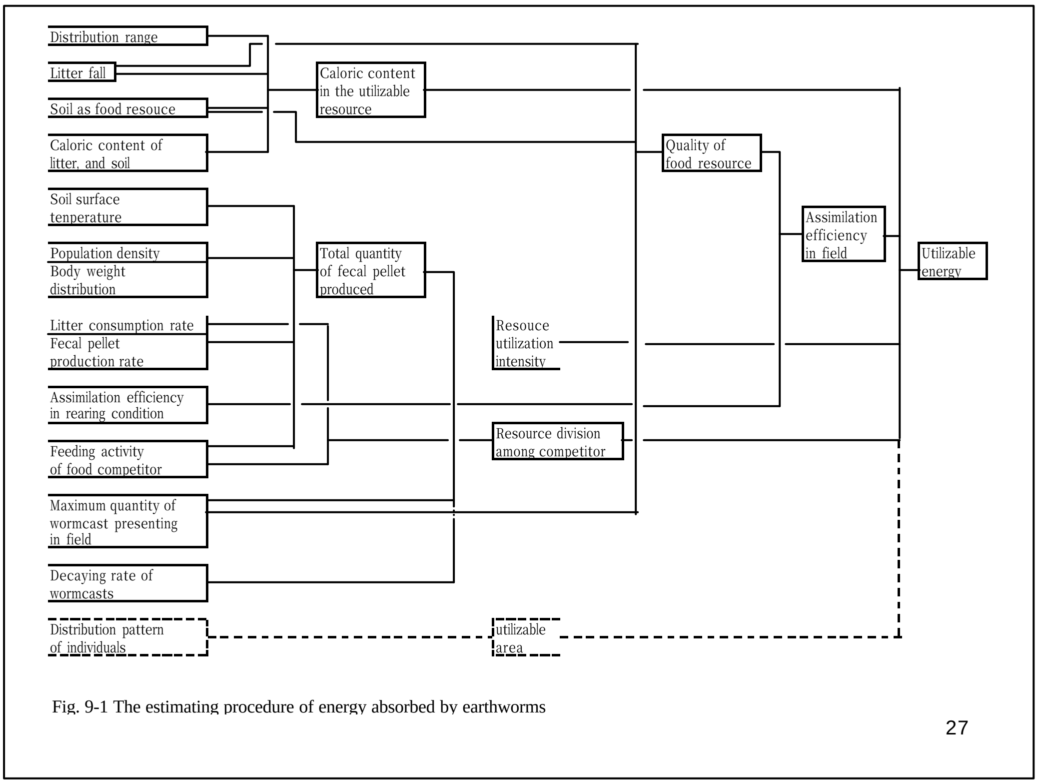
(Slide26) Fig. 8-8. The structure of habitat and the distribution pattern of earthworm ; *Pheretima* sp. (H-1).

Young 1 stage: When a new individual of Pheretima sp. (H-1) gives birth at the early spring, these individuals forms the contagious distribution. This distribution pattern may be caused by the aggregately distribution of the cocoons. In early spring, young individuals dispersed with the slow pace for earching newly food, remaining the posterior part of their bodies in the wormcast site.

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. Earthworm might move from thin wormcast to thick wormcast to avoid drying in dry days. Newcomer 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 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. Copulation was frequently observed on rainy days of June and early July 1972.

Post matured stage; The population density decreased with the end of wetter summer. Earthworm begun to form aggregated phase to avoid drying again. 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.



(Slide27) Figure9-1 Secondary estimation of the resource utilization

The secondary estimation process is an amount of the energy supply from the environment. It is synonymous with the amount of energy which animal can use. Some preparations are necessary for this estimation. Figure 9-1 shows the procedure of secondary estimation. The content of each items in the figure are represented as follow

(a) The different vegetation area (area G) adjoined study area (area D). *Pheretima* sp. (H-1) distributed mainly in area D but rarely in area G (chapter 2). The estimation of the available energy was made on the population distributed within area D.

b)Annual net production of the above ground vegetation in area D 1972 has been presumed to be 1176.45 g dry wt m^{-2} (Chapter 1).

(c) The maximum thickness 1.834 cm of the wormcast was equivalent to 7441 g dry wt m^{-2} (Chapter 8).

(d)This means that earthworm blend 1176 g dry wt of litter fall with 6264 g dry wt of soil. Then, wormcast contained litter at a ratio of 15.81 %. The value of 15.81 % of the litter to total weight was equivalent to 25.088 % of the food used for cultivation to total weight consumed.

(e) total quantity of fecal pellet produced by two litter dwellers: *Pheretima* sp. (H-1) and *Ph. vittata* (Goto et hatai) were amount to 13247.09 g dry wt m^{-2} and 1766.5 g dry wt m^{-2}, respectively (Chapter 4).

(f) The maximum thickness 1.834 cm of the wormcast was equivalent to 7441 g dry wt m^{-2} (Chapter 8). Its turn over rate was given by the ratio of the pellet production of earthworms to the maximum quantity of wormcast. The rate was estimated at 2.0177. This value mean that soils and litter passed twice per a year through the earthworm intestine.

(g) The amount of the fecal pellet production of two primary litter feeders in area D 1972, is presumed like 13247.09 g dry wt m^{-2} as for *Pheretima* sp. (H-1) and 1766.5g dry wt m^{-2} as for *Pheretima vittata* (chapter 4). These figures mean, 11.766 % among all food resource was divided for *Ph. vittata* and 88.234 % was divided for *Pheretima* sp. (H-1). After these preparations, the amount of energy which the earthworm can absorb from these materials is presumed as follows.

Then, the available energy of *Pheretima* sp. (H-1) could be estimated as 490.365 (26713.459 × 0.88234 × 0.02080) in first pass and 479.905 {(26713.459 × 0.88234 - 490.365) × 0.02080} in second pass, and 8.326 {(26713.459 × 0.88234 - 490.365 - 479.905) × 0.02080 × 0.0177} in third pass. This calculation means that *Pheretima* sp. (H-1) could absorb 978.638 KJ m^{-2} in total.

Three process of resource utilization

food requirement (cultivated earthwom)	62416.494 KJ m^{-2} (=10283.43×0.887+2963.66×17.983)
the absorbed energy	892.531 KJ m^{-2}
the absorbable energy	The procedure for estimation are shown in side22 978.638 KJ m^{-2}

(P+R=832.198 KJ)

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(Slide 28) Three process of resource utilization

1. First estimation of the resource utilization

The food requirement of *Pheretima* sp. (H-1) in area D 1972 was presumed 2963.66 g dry wt m^{-2} of litter (Chapter 4). Otherwise, the amount of fecal pellet produced by this population was presumed to be 13247.09 g dry wt m^{-2} (Chapter 4). Then, the total energy quantity of the resource consumed was estimated as 62416.494 KJ m^{-2} (2963.66 × 17.983 + 10283.43 × 0.887). The average assimilation efficiency of cultivated earthworms was 8.124 % (Chapter 5). These values mean that the population of *Pheretima* sp. (H-1) in area D 1972 would absorb 5070.715 KJ m^{-2}. This estimated value is amount to 609.32 % of the energy consumption of A=P+R (832.198 KJ m^{-2}) (Chapter 3).

3. Third estimation of the resource utilization

Third feeding process was estimated basing on the nutrient contents of the gut materials of earthworms. The nutrient analysis showed that earthworms ingested litter at 15.61 % (Chapter 4). The field population of *Pheretima* sp. (H-1) in area D 1972 eject 13247.09 g dry wt of fecal pellet (Chapter 4). This means that the field population consumed 2067.71 g dry wt litter and 11179.38 g dry wt of soil. The energy equivalent of litter was 17.983 (Golley 1963) and that of soils 0.887 KJ g^{-1} (chapter 4). The assimilation efficiency of the earthworms in field was 1.895 % (Chapter 5). Then, the absorbed energy was calculated as 892.531 KJ {(2067.71 × 17.983 + 11179.38 × 0.887) × 0.01895}. This value exceeds only 7.25 % than the energy consumption for respiration and production.

2 Second **estimation of the resource utilization**

The second guess process was shown in Slide 27. Second calculation means that *Pheretima* sp. (H-1) could absorb 978.638 KJ m^{-2} in total.

If population requires resource as the cultivated earthworm (First estimation), the required energy would attain to 6.08 times of the energy consumption (A=P+R). The weight of field earthworms was smaller than that of the cultivated earthworms. The weight of the field earthworms decreased after maturation. Otherwise, the cultivated earthworms gained the more weight growth after maturation. The difference in the growth pattern between field and cultivation mean that first estimation did not reflect the true process of the resource utilization of the population in field.

The absorbable energy (second estimation) exceeds 17.6 % than the energy consumption (A=P+R). The absorbed energy (third estimation) exceeds only 7.25 % of the energy consumption of field population (A=P+R). Then, the second and third process on feeding activity of earthworm population may reflect the true process of the resource utilization in field. This mean that the assumption in the second estimation and the third estimation were reasonable. Namely, animals share the available resource from litter and other thing with members and the available resource pass through the earthworm intestine more than twice per a year.

Table 11-1 Bio-economic life table of *Pheretima* sp. (H-1) in area D 1972

Date	N	B	B.W	P	E	F.R A.H	F.R A.V	F.C A.H	F.C A.V	L-C	R.W	* _ m/m	* m	A
Jan.	0.0	0.0	0.0			0.0	0.0	0.0	0.0	1176.5				
				15.8										
Feb.14	60.8	379.6	6.2			0.2	0.0	0.1	0.0	1175.3		1.7	6.2	
				26.6										
Feb.23	83.2	619.2	7.4			0.4	0.0	0.3	0.0	1170.2		1.9	11.0	
				18.5										
Mar.12	92.8	933.7	10.1			0.6	0.1	0.4	0.1	1162.2		1.7	11.1	
				57.3										
Mar.28	108.8	1850.9	17.0			3.8	0.3	2.6	0.3	1118.7		1.5	11.0	
				51.9	11.5									
Apr.12	100.5	2457.3	24.5			5.9	0.5	4.1	0.5	1049.7		1.6	10.8	
				166.2	1.7									
Apr.27	99.8	4924.5	49.3			19.3	1.5	13.4	1.4	827.7		1.4	9.7	24.2
				152.5	26.1									
May 10	93.4	6821.0	73.0			30.7	3.1	21.4	2.8	531.3		1.3	8.6	14.9
				114.2	31.9									
May 23	88.3	7892.4	89.4			33.0	6.4	23.0	5.9	68.4		1.5	9.5	
				101.7	71.3									
Jun. 8	76.8	8378.2	109.1			32.8	5.1	22.9	4.7	0.0	15.2	1.3	7.1	4.9
				87.9	92.6									
Jun.19	68.0	8326.0	122.4			27.0	4.9	18.9	4.5		15.2	2.7	10.4	6.01(6.10)
					87.2									
Jun.30	66.6	7368.0	110.6			25.6	5.6	17.9	5.1		15.2	1.6	7.5	5.1
					156.0									
Jul.15	51.8	5028.5	97.1			19.3	8.6	13.4	7.9		15.2	1.5	5.9	9.9
					232.5									
Jul.29	26.2	1803.5	68.8			9.1	4.9	6.3	4.5		15.2	3.9	7.1	
					60.1									
Aug.28	0.0	0.0	0.0			0.0	0.0	0.0	0.0		15.2			

N:density (N m^{-2}), B:Biomass (dry wt m^{-2}), B.W:Body dry weight of individual, P:Production (dry wt w^{-2}), E:Elimination (dry wt w^{-2})
F.R A.H:Litter requirement of *Amynthas* sp.(H-1), F.R A.V:Litter requirement of *Amynthas vittatus* ,
F.C A.H: Litter consumption of *Amynthas* sp. (H-1), F.C.A.V: Litter consumption of *Amynthas vittatus*
L-C:Litter supply - Litter consumption, R.W: Resource supply from wormcast, (m/m, m, A: The degree of Aggregation of individuals, see Chapter 8)

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(Slide 29) Fig. 11-1 Bio-economic life table

How is population density or biomass decided? The fundamental factors deciding population density or biomass may be the quantity and the quality of food resource. In Chapter 9, the resource utilization process and the energy balance of ***Pheretima*** sp. (H-1) (Oligochaeta: Megascolecidae) population in area D 1972 were studied. The population density and the presence of food competitor besides the quantity and quality of food resource influenced on the resource utilization process and the energy balance of earthworm. Also, the resource utilization process might relate to the space deposition of individuals and the mortality of the population. Namely, the earthworm divides the resource with the companion of the same species or another species, in field condition. These results show that the population study and the bio-economics must be thought from mutual viewpoints.

Morisita (1973) proposed a bio-economic life table basing on new concept. A bio-economic life table contained production, elimination, food consumption and respiration besides survivor ship rate and mortality rate. Morisita said, the table had a possibility that population study and bio-economic study could be thought from mutual viewpoints.The purpose in this chapter is the following. Using the bio-economic life table, which Morishita (1973) advocated, a population ecology side and a bio-economics side of ***Pheretima*** sp. (H-1) was discussed from mutual viewpoints.

The bio-economic life table of *Pheretima* sp. (H-1)

Some new bio-economic items were added to the bio-economic life table for earthworm. New bio-economic items were food requirement, food consumption, food requirement of competitor, food consumption of competitor and resource supply. The bio-economic life table of earthworm may be available for the study on the resource utilization process of population. Table 11-1 shows the bio-economic life table for the population of *Pheretima* sp. (H-1) in area D 1972. The main food competitor of *Pheretima* sp. (H-1) in area D was *Pheretima vittata* (Goto et Hatai). The content of the added new item in this table is as follows.

a) The intrinsic food requirement of population, b) The intrinsic food requirement of food competitor, c) The litter consumption of the field population, d) The litter consumption of field population of food competitor, e) Litter supply, f) Alternatively food resource from the decaying wormcast,

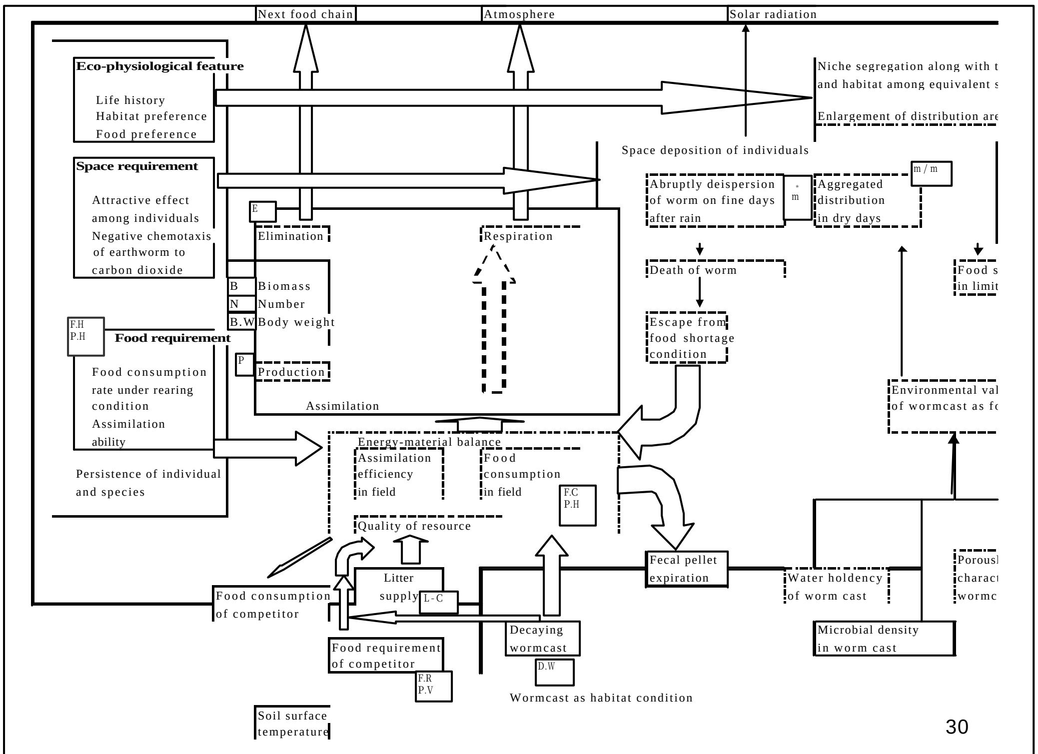


Fig. 11-1. Inter relation ship between environment and earthworm

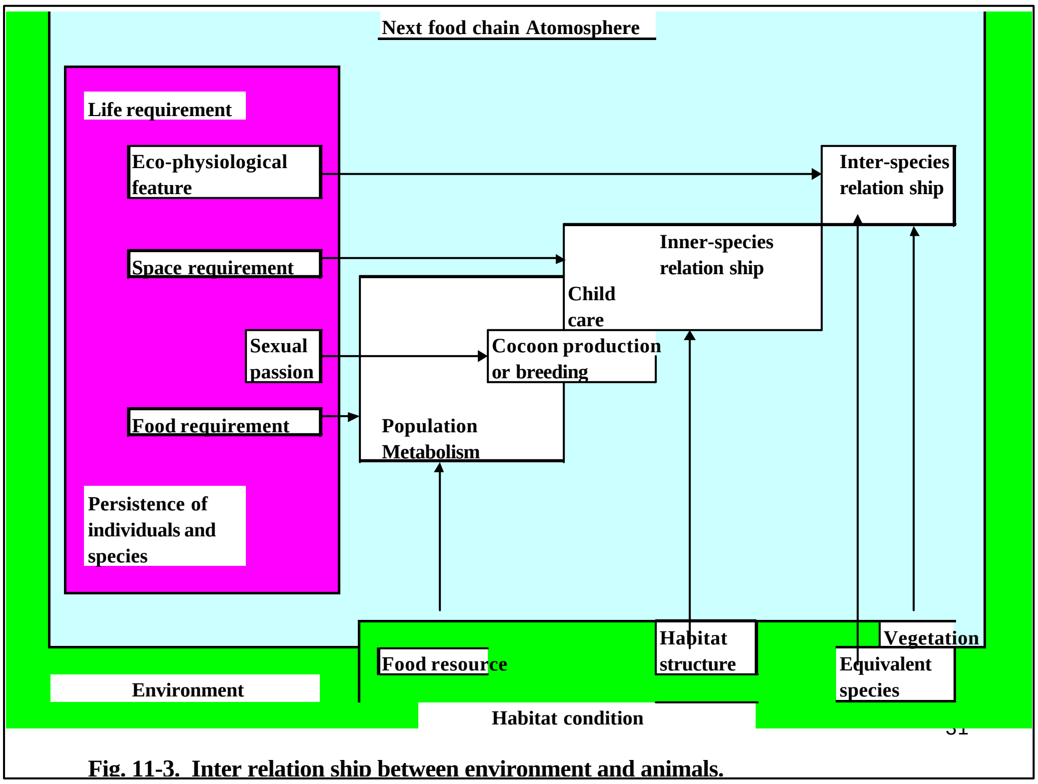
(Slide30) Figure 11-1 The relation among each items

In hitherto sections the relation among each item composing the bio-economic life table was interpreted. The bio-economical faces and the population faces, of *Pheretima* sp. (H-1) can be summarized in a figure with the viewpoint of the reciprocal relation ship between animal and environment. Figure 11-1 shows these relations. The thick letters in the figure show each item composing the bio-economic life table. The fundamental component in the figure consists of three groups of items. The left part in the figure shows the items related to the intrinsic life requirement of animals. The items related to the intrinsic life requirements are consisting of three sub groups: food requirement, habitat requirement and physiological tolerance. Biomass may mean the size of requirement. Also, development stage may mean the quality of requirement because the change of content of requirement with aging.

The lower part in the figure shows the environment surrounding animals. The projecting items from the environment show the habitat condition, which have the relation to the intrinsic life requirement of animal.

The center part in the figure shows the consequence of the reciprocal relation between animal and environment. Namely, the consequence of reciprocal relation is the real life of a population developed in field. The lines in the figure show the basically relation ship between items.

In the relation ship between animal and environment, animal is the subject, and environment is the background for life of animal. Animal recognizes the resource relating to their life requirement from environment by his sensory organs and act on its resource. As for expressing the animal production, animal detect food from environment with his sensory organ, take this material in their intestine and produce animal tissue. Where, production is the outcome of the reciprocal relation between animal and environment. As animal tissue is animal themselves, production connected with the items of life requirement. It is shown in a thick line in the figure. The animal tissue produced appears as the change of life requirement.



(Slide31) Fig. 11-3. Inter relation ship between environment and animals.

The schema shown in figure 11-3 may be useful as a guide for the understanding of life of individuals-species in environment, where various faces of life of individuals-species (such as bio-economics, population change and inner species relation ship) were concerned in the mutual relations of each faces.