Chapter 11
The bio-economic life table of earthworm *Pheretima* sp.
-The interaction between animal and environment-

Introduction

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 consider side of *Pheretima* sp. (H-1) from mutual viewpoints.

1. 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

The intrinsic food requirement is the litter consumption under cultivation. The intrinsic food requirement of population was estimated by integrating the litter consumption rate of the earthworms in cultivation and the weight frequency of population assuming Q_{10} law (Chapter 1).

b) The intrinsic food requirement of food competitor

The most important food competitor of *Pheretima* sp. (H-1) in area D was *Pheretima* *vittata*. Then, the intrinsic food requirement of food competitor population was estimated by using the litter consumption of *Ph. vittata*.

c) The litter consumption of the field population

The litter consumption rate of the earthworms in field was 69.78 % of the rate of the cultivated earthworms of *Pheretima* sp. (H-1) (chapter 4). Then, the litter consumption of the population of *Pheretima* sp. (H-1) is 69.78 % of the intrinsic food requirement of *Pheretima* sp. (H-1) population.

d) The litter consumption of field population of food competitor

The litter consumption rate of *Pheretima vittata* in the D area was 91.7 % of the litter consumption rate of the cultivated earthworms of *Ph. vittata* (Chapter 4). Then, the litter consumption of food competitor population is 91.7 % of the intrinsic requirement of that population.

e) Litter supply

Net production of above ground vegetation was 1176.5 g dry wt m^{-2} in area D 1972 (Chapter 1). It is assumed that the litter of 1176.5 g dry wt m^{-2} exists in February, and the litter supply is an amount by which the amount taken by the first consumer is subtracted from total litter fall.

f) Alternatively food resource from the decaying wormcast

The maximum weight of wormcast was 7441 g dry wt m^{-2}. The wormcast contained 1176.5 g dry wt of litter. The wormcast decayed at 38.72 % per a month (Chapter 8). The decayed wormcast may become the alternatively food resource for earthworm. Then, the alternatively food resource rate is 15.185 g dry wt m^{-2} d^{-1} (1176.5 × 0.382 /30) (Chapter 8).

g) Some additional items

The quantity of wormcast, the degree of the aggregation ($\overset{*}{m}$, $\overset{*}{m}/\bar{m}$, and 1/A) were studied in earlier chapters. These composed a portion of the bio-economic life table. The population abundance or biomass may relate to the aggregation pattern of individuals and the nature of habitat as shelter for animals (chapter 8). Then, the bio-economic life table gets a further possibility for the mutual consideration between population study and bio-economic study.

1-1. The relation among resource supply, resource requirement, aggregation pattern, population change and production.

From table 11-1, some aspect on the relation among food resource, aggregations pattern and population change can be explained as bellow.

a) The population reduced the degree of aggregation ($\overset{*}{m}$ / $\bar{m}$, $\overset{*}{m}$ and 1/A) in the period between March and early May. Table 11-1 shows that the litters supply decreased in that period and disappeared by late May. In these periods, individuals gained the weight increase but the population density did not decreased. These mean the enlargement of the resource requirement of population. Then, the decrease of the degree of aggregation would be due to the dispersion of earthworms

searching for newly food resource.
b) In dry days, the value of 1/A increased. This means that earthworm concentrate in thicker wormcast. The aggregation in these days is due to the migration of earthworm from thin to thicker wormcast to avoid dry condition (Chapter 8). The earthworms in thicker wormcast, where many earthworms concentrated, could not expect large quantity of litter after middle May. Table 11-1 shows the absence of litter fall after late May and the alternatively resource could sustain only 45.0 % of the litter requirement on June 8 1972. The difference between food requirement and food supply shows that two litter feeder populations were in severe food shortage condition after late May in field. The food shortage condition might be most severe especially for the earthworms in thicker wormcast. However, the population density did not decreased in these periods (Table 11-1).
c) On fine days after rainy day, the mass emergence of earthworm occurred frequently (Chapter 7). At same time, the degree of the aggregation ($\overset{*}{m} / \bar{m}$, $\overset{*}{m}$ and 1/A) decreased in that period (Chapter 8). Namely, earthworm might migrate from thicker wormcast to thinner wormcast. However, the dispersion in these days was not due to the migration of animal for searching resource. The dispersion with the mass emergence of animal in fine days after rain was due to the increase of CO_2 tension in soil air. The dispersion on fine day after rain was due to the decrease of the environmental value of wormcast as shelter of animal. However, it doesn't always mean that the dispersion in these periods had no relation with the quantity and quality of the food resource. Earthworms were under the ordinary food shortage condition after May. Particularly, the food shortage condition would be most severe for the earthworms in thicker wormcast. Then, the food shortage condition is a premise of the dispersion on fine days after rainy days.

The above mentioned results could be summarized in relating to production or elimination as bellow.

Ⅰ) In the period between early April and early May, there was still a considerable quantity of litter fall on the soil surface (Table 11-1). The production was largest and the elimination was very small in these periods.

Ⅱ) After middle May, the density decreased, caused by the mass emergence on fine days after rainy days. The surviving individuals gained weight growth in the period from middle May to early June. Because the weight of the surviving individual increases, the assimilation and the elimination between the middle of May and the beginning of June do the balance. The density decrease in this period would bring on survivors the increase of food supply per individuals.

3) After middle June, there was few quantity of litter and then survivors must gain food resource only from the decaying wormcast. While population density decreased, each individual loses the weight after Middle June. Then, the elimination was largest in this period (Table 11-1). Soil temperature after middle June was about 25 ºC in field. However, the cultivated earthworms gained the more weight growth even under this temperature condition (Chapter 4). Then, the weight loses of

the earthworms in field after middle June might be caused by severe food shortage condition.

The productivity can be replaced with the problem on the dividing process of the resource among members. The pattern of spatial distribution of individuals may show the inner- relation ship as background for resource utilization of individuals. The author wants to emphasis that the mass emergence of earthworm on fine day after rain was caused by the decrease of the value of wormcast as shelter. Uchida (1975) said that density-effect follows a different process with a different of resource between space and food. Namely, when the resource is food, the density-effect follows to the type of scramble. When the resource is space, the density-effect follows to the type of contest. In earlier case, the populations disappear. Otherwise in later case, the populations decrease to an adaptive density. The mass emergence of earthworms was pull the trigger by the decrease of the environmental value of wormcast as shelter. The survivor gained the more weight increase at the sacrifice of density decrease. Then, the process of the mass emergence of earthworm on fine days after rain seems to be belonging to the contest type, according to Uchida (1975).

When many earthworms were cultivated in a large container, all earthworms dead on the surface of wormcast in the container after eating up all of food resource (Sugi unpublished). Then, the mass emergence of earthworm on fine days after rain can be regarded as the self-regulation, which prevent the extinction of population.

The bio-economic life table contains three items relating to the bio-economy: resource requirement, resource consumption and resource supply. Three estimates of feeding process studied in chapter 9 related to other items composing the bio-economic life table. In chapter 9, each estimation process was compared with mutual. The bio-economic life table reveals the daily change of energy balance of population through a life history.

1-2 The factors determining the abundance of earthworms

The population of *Pheretima* sp. (H-1) in area D 1972 between abundance and bio-economy was studied in detail, by using the bio-economic life table. However, there were not enough data for constructing the bio-economic life table of other populations. Nevertheless, it is possible to discuss the factors and the relations determining the population size of other population of *Pheretima* sp. (H-1), in comparison with the result on the population in area D 1972.

a) *Pheretima* sp. (H-1) in area H 1968

The maximum density and the maximum biomass were 23.8 m^{-2} on March 20 and 2.982 g dry wt m^{-2} on July 6, respectively. The average weight at maximum level was 183.51 mg dry wt (1828 - 3578 mg fresh wt) on July 6 (Chapter 1 and Chapter 2). These values were equivalent to 21.9 %, 35.6 % and 150 % , respectively, of those of the population in area D 1972. The half of food resource in area D was the deciduous tree leaf. Also, the food competitor: *Pheretima vittata* was abundant in the area (Chapter 1 and Chapter 2). Then, the smaller biomass in area H than in area D 1972 might be due to the unsuitableness of the food resource and the presence of competitor in former area. The larger maximum weight of matured individual in area H than in area D 1972 might be due to the smaller density in former area. This means the more quantity supply of resource per individuals. The mass emergence of earthworms did not occurred in area H through the period. The $\overset{*}{m} / \bar{m}$ value in area H was calculated by using the number frequency per quadrats. The size of quadrats was 50 × 50 cm^2 and the number of sample was 16. The $\overset{*}{m} / \bar{m}$ values show the more dispersed distribution ($\overset{*}{m} / \bar{m}$ = 1.09 - 2.20), compared with that in the D area. The more dispersed distribution of individuals and the misfire of the mass emergence of earthworms in the H area were due to the low density and to the cover of large tree vegetation. (The cover by large tree may protect the soil surface from the penetration of solar radiation and moderate the microclimate condition near soil surface.) Many amebas were founded on the body surface of the earthworms collected after July in area H (Chapter 1). Amebas concentrated particularly surround the gonad of the earthworms. This parasitization might induce the low rate of cocoon production and then the low density of next year's generations.

b) *Pheretima* sp. (H-1) in area D 1971

The maximum density and the maximum biomass were 95.3 m^{-2} on May 8 and 3.324 g dry wt m^{-2} on June 10, respectively. The maximum weight was 126.48 mg dry wt (1155-2532 mg fresh wt) on July 7 (Chapter 1 and Chapter 3). The smaller maximum biomass in 1971 than in 1972 was due to the low density of matured generation. The mass emergence of earthworms occurred 30 days later in 1971 than 1972. Also, its size was smaller in earlier year. These results show that the size of biomass highly related to the size of mass emergence (Chapter 7, 8). Still, the mass emergence did not occurred in area H 1968, but occurred in area D 1971, instead of same maximum biomass. This difference was due to the difference in the cover degree of tree vegetation between both areas.

c) *Pheretima* sp. (H-1) in area G 1972

The maximum density and the maximum biomass were 22.4 m^{-2} on March 25 and 0.76 g dry wt m^{-2} on June 1, respectively. The maximum weight of individuals was 73.1 g dry wt (465-1667 mg fresh wt) on June 15 (Chapter 1 and Chapter 2). These values were small compared with those in area D 1972. This result was due to the unsuitable habitat of the high soil density for *Pheretima* sp. (H-1) (Chapter 1 and 2).

d) *Pheretima* sp. (H-1) in clay sand area 1972

The bio-economic life table of this population can be constructed, lacking some items. Table 11-2 shows the bio-economic life table of the population in the clay sand area. The maximum density and the maximum biomass were 105.6 m^{-2} on February 15 and 4.352 g dry wt m^{-2} on March 26, respectively. The maximum weight of individuals was 84.56 mg dry wt (1235 mg fresh wt) on June 15 (Chapter 11). The maximum biomass was equivalent to 52 % of that in area D 1972, though the highest density was almost the same. The litter supply from the decaying leaf and stems of *Oryza sativa* L, almost disappeared by late April (Table 11-2). The migration of young earthworms occurred after April and the death after the mass emergence occurred after May in the clay sand area. The beginning day of this phenomenon was several days earlier in the clay sand area than in area D 1972. All of these might be due to the small quantity of resource supply in clay sand area. The weight of individuals in clay sand area was equivalent to 69.1 % of that in area D 1972. The smaller weight in clay sand might be due to 'partly' the small quantity of resource supply in this area, but not all. The values of $\overset{*}{m} / \bar{m}$, and $\overset{*}{m}$ show the more dispersed distribution of individuals compared with those in area D 1972. In the clay sand area, the soil surface was smooth and was covered by the uniformity cover (KAMASU). Also, the thickness of wormcast was uniform over the area (Chapter 10). The more dispersed distribution of individuals in the clay sand area was due to the uniformity of environmental condition in the area. The wormcast act an important role as the shelter for earthworms and as a regulator of population density (chapter 8). The uniform thickness of wormcast over the area may induce the not enough function of cast material as the density regulator. The population in the clay sand area might not adjust to adaptive density under this circumference. Thus, individuals accepted the small quantity of resource per individuals and could not gain the more weight growth.

2. 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.

Animal live in environment, doubtless as like a part of ecosystem. But they have a boundary between itself and environment. The inside of the body have owns structure being different from that of environment. Animal is not subordinate to environment, but act upon environment by his requirement. The animal is not an automatic machine though the animal acts according to his rule. They alter it, and provide environment with a steady structure (assimilation of animal). The subjectivity of animal in the energy and material balance was interpreted in earlier. The subjectivity of animal in interaction can be seen also in the improvement of habitat condition. The wormcast produced by earthworm became to good habitat for them under a certain weather condition (chapter 7 and 8). Namely, earthworms alter resource into the wormcast providing the shelter for earthworm.

Clark et al (1967) said

"The effective environment consists of inimical agencies, which oppose the survival and reproduction of individuals of the subject species, besides the resource (supplies of all kinds) required for population maintenance such as living space, food and favorable physio-chemical conditions."

However, animal tolerates the inimical agencies such as high temperature with their migrating behavior. For example, in dry days of May, earthworms move to thicker wormcast to avoid drying. Also, on fine days after rain, some individuals escape from thicker wormcast with the decrease in the value of the environmental values of habitat as shelter (chapter 7-8).

Sibuya (1960) said,

“A fundamental content of the life of the animal changes by the level's of the subject shifting from individual to species.”

According to Sibuya, the principal of life at the level of the individual is self-maintenance. Its fundamental event is energy-material metabolism. Also, the principal of life at the population level is population maintenance. The fundamental event at the population level is an inner relation ship, under which earthworm divide resource between individuals. Still, some indices such as biomass, R/A, and P/B are statistical characters, which result from the collective metabolism of every individual. The principal of life at species level is species maintenance and species differentiation. Its fundamental event may be the resource division among species.

To understand various sides of life of *Pheretima* sp. (H-1) unitedly, Shema shown in Figure 11-1 was made. The various sides have been shown in a current chapter. However, the copulation and oviposition had not occupied the important part in my hitherto study, although these form a large parts of the life of individuals-species in all animals. Therefore, to complete the comprehensive understanding of the life of individuals-species, it may be necessary to add the items of copulation and oviposition to the schema. Copulation must be important for the life of the individual after eating, because the copulation and the oviposition appear after the satisfaction of the food requirement at the level of individual.

The copulation action is approved by recognizing others individual of same species. Moreover, the parent recognizes the child, and nurture is approved. Copulation and nurture are the relations in the species. Therefore, it is appropriate to arrange the item of copulation-oviposition-nurture between food requirement and shelter requirement in my shema (Fig. 11-3).

Solomon (1949) said

'The population functions in relation to a whole which includes itself. It is therefore better to think of the populations as an integral part of the ecosystem.' (Cited by Clark et al, 1967).

In the view of Solomon that animals is an integral part of the ecosystem, the relations shown in Fig. 11-1 seem to be merely a variety of the life system proposed by Clark et al (1967). Clark et al (1967) said,

“The approach advocated by Solomon can be used in the study of the dynamics of specific populations simply by regarding that part of an ecosystem which determines the existence, abundance, and evolution of a particular population as the 'Life system' of that population. Thus a life system is composed by a subject population and its effective environment which includes the totality of external agencies influencing the population.”

If the schema shown in figure 11-1 is renewed along the conception of life system, the relations in figure 11-1 may be rewritten as figure 11-2. The explanation of this figure may be as bellow.

Phase I: The inherited properties of subject species, in the form of an array of genotypes, mold matter and energy supplied by environmental resource into phenotypes - the individual of the species.

Phase II: The inherited ability of individuals to survive and multiply and the condition for existence provided by the effective environment, supplies of all kinds and limited repressive action by inimical agencies, enable them to form a population with group (Statistical) characteristics which result from their collective existence.

Phase III: The persistence and abundance of a population are the outcome of interactions between inherited properties of individuals and the intrinsic attributes of the subject species.

Both figures consisted of three components: animal, environment and outcome. However, there is a difference in an individual content of the composition factor and the mode of the relations between the composition factors in these two figures. In the life system conception, animal is the genotypes and the outcome is the phenotypes. Then, environment and animal are the co-determinants, which determines the presence, number and other characters of a population. In the life system conception, the initiative of animal in interaction was not expressed. In my opinion, Animal is life requirement (subject), and environment is the field (object) by which the animal acts. And, the outcome is the animal life developed in field. Namely, animal is the subject and environment is the object in the interaction between animal and environment.

Thus, the contents of the items and the relations in Figure 11-1 were very different to those of Life system advocated by Clark et al (1967). My purpose to make the figure 11-1 is to obtain the comprehensive description about the life of individuals-species. Where, the number of individuals or the biomasses are merely one face of the life of individuals-species. Naturally, animal live in environment and, rightly, the number of any population are determined within an ecosystem. However, the inner site of animal bodies is distinguished with his body wall from the environment. Various sides of the life of the animal: Bio-economics and inner-species relation ship, etc. are expressions with a different life of a certain animal's individual-species. Animal (individuals - species) live according to owns life requirement, being relatively independent of the principle of its environment. Then, it was necessary to suppose the independence of animal in the mutual interaction between animal and environment.

The approach of Life system i) express a full appreciation of the fact that a population and its environment are complementary elements in a system, and interact in the ecological events and process which are involved in the determination of population number: and ii) links the study of specific populations with the study of communities and hence ecology with evolution (Clark et al 1967).

Otherwise, 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.

Summary

1) The bio-economic life table of earthworm: *Pheretima* sp. (H-1) was constructed. The bio-economic faces and the population faces were concerned with mutual viewpoint by using the bio-economic life table.

2) The relation among the items composing the bio-economic life table were arranged in one schema, under the assumption that, in the mutual interaction between animal and environment, the subject was animal themselves.

3) The purpose for the construction of the schema on the mutual interaction between animal and environment, the content of the items composing the schema, and the way of the mutual interaction were characterized by comparing with the concept of “Life system” advocated by Clark et al (1967).

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