Some Considerations Regarding the Amount of Foods Daily Taken by an Early Postlarva of Sardine

By

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Abstract

Using the most probable value for the first coefficient of growth energy in a sardine postlarva which is assumed to feed principally upon tiny larval forms of copepods and other zooplankters, the amount of its daily ration in the natural environment has been estimated. The critical density in food animal distribution fulfilling the requirement by the postlarva has also been discussed.

Introduction

Much discussion has been made concerning the food problem of marine fish larvae since HJORT (1914, 1926) suggested hunger as one of the most critical causes for the tremendous reduction in number in the early life history of those marine teleosts which are very fecund. Some authors obtained results favorable to HJORT's opinion, whilst others gave different conclusions and showed scepticism.

Through the intensive cooperative sardine resources investigation in Japan carried out since 1949, it has been cleared up that the Japanese sardine (*Sardinops melanosticta*) also undergoes a marked reduction in number during the rather short period of early life history. According to NAKAI *et al.* (1955), no less than 99.9 % of the amount of spawn is lost during the period (about 60 days) up to the time when the larva reaches 20 mm. in total length. As to the possible cause for this high mortality rate, there have been presented by researchers many factors to be responsible, among which starvation by lack or deficiency of propor foods for early postlarva is also included.

It is a distinguished fact that, while engaged in the gut content observation of sardine postlarva, one is frequently confronted with a vast proportion of specimens with empty gut. The younger the larva, the larger the fraction of empty gut specimens to the total examined. YAMASHITA (1955) observed that only in eight individuals out of 100 sardine postlarvae examined which were less than 14 mm. in length traces of foods were hardly recognized, while 117 contained foods out of 180 larvae ranging 21 - 40 mm. in length and almost all individuals were fed in specimens with the size larger than 41 mm. inclusive.

The chances that the observer recognizes foods in the larval gut are determined by the magnitude and time distribution of incidence of feeding, the amount of foods taken and the speed and the rate of digestion in the larva. The low and timely restricted incidence of feeding accompanied with the small amount of ration as well as the rapid and complete digestion will give rise to an empty gut most of the time. MORRIS (1955) has recognized through laboratory observation that digestion proceeds by no means at a very rapid rate nor appears it to be very complete for such diets as nauplii and veligers. This and other similar observations may eliminate the high digestion speed and rate as the cause for so often encountered empty guts. There comes next the question how large is the amount of foods a sardine postlarva must take per unit time in order to carry out the maintenance as well as the growth metabolism sufficiently, or at the minimum level at least.

The present paper concerns this problem. Another problem regarding the incidence of feeding will be discussed in a different paper.

Estimating Formula

Suppose that, by taking foods amounting to $r = Rdt$ during the time span dt, a sardine postlarva has increased its body weight by dw in the same period, then

$$K_1 = \frac{dw}{r} = \frac{dw}{dt} \Big/ \frac{r}{dt} = \frac{dw}{dt} \Big/ R,$$

where K_1 is the first coefficient of growth energy (RICKER, 1946) or the efficiency of conversion and R is the daily ration when the day is taken as unity of time. The above equation is transformed into

$$R = \frac{1}{K_1} \cdot \frac{dw}{dt} .$$

Let L be the total length and W the body weight of the larva. During the early postlarval phase when L lies between 0.45 and about 1.0 cm, W can be expressed as equal to aL^3, where a is a constant. Thus we have

$$R = \frac{3aL^2}{K_1} \cdot \frac{dL}{dt} .$$

According to NISHIMURA (1957), $W = 0.23 \times 10^{-3}$ (gr.), when $L = 0.50$ (cm.). Hence $a = 1.84 \times 10^{-3}$.

Discussion on K_1

When a larva is taking foods of high nutritive value, K_1 may no doubt be high. Contrarily when it is taking foods of low nutritive value, K_1 may be low. A few laboratory experiments have hitherto been made in order to estimate the magnitude of K_1 in young fishes of several kinds, among which a sardine larva is regretfully not included. SCHOLZ (1932) showed that K_1 for a one-year-old pike which had been reared with fish meat as foods under the optimum condition was 29 - 36 % and that some large individuals of 0-age also had given similar value for K_1. According to KARZINKIN (1939), the yearling pike which had been fed with various items of natural diets showed K_1 to be 24 - 27 % under the optimum experimental condition. Whenever food particles too small in size for the fish were given, however, the value of K_1 dropped rapidly. He conducted this rearing experiment on the larval and young pikes of 9 to 80 days old and found that K_1 was lower during the first 10 to 20 days than during the following days. PENTELOW (1939) obtained the value up to 29 % as K_1 in the young brown trout which had been fed with Gammarus. HATANAKA & TAKAHASHI (1956) observed that K_1 for the young mackerel (4 - 9 gr. in initial body weight) was 27 - 39 % when reared with anchovy under the water temperature 22.0 - 24.5°C.

There are considerably many observations regarding the natural diets of sardine larvae and it is generally believed that the principal foods are nauplii and eggs of copepods, and at times Lamellibranchia and gastropod larvae. Considering the fairly large proportion of water and indigestible integuments in copepod larvae, and further taking into account the supposed differences in amino and fatty acid compositions of proteins and fats of copepods from those of fish larvae, K_1 may not perhaps reach so high a value as cited above. But it is yet undetermined how high the value for K_1 is to be taken in a postlarval sardine. Therefore, with foregoing lines in mind, we must be contented with tentatively assuming that 0.2 or thereabout may be most valid, when the larva is feeding in the main upon the nauplii and eggs of copepods.*

Discussion on dL/dt

As for the larval growth rate of the sardine, we have only a few estimations. According to NAKAI *et al.* (1955), nearly 20 days appear to be needed for the sardine larva to grow from 5.3 to 8.3 mm. in length. Assuming a constant growth during this interval, $dL/dt = 0.015$ (cm. per day). But, as these authors have indicated, the growth rate may be somewhat smaller than this value in the early half period and larger than that later, because the early development is considered to be exponential as regards time. AHLSTROM (1954) has estimated on the larva of California sardine (*Sardinops caerulea*) that it may need 3.9, 3.3 and 2.9 days respectively for growing successive 1 mm. from the initial length of 5.26 mm. Hence, dL/dt will be in the average 0.026, 0.030 and 0.034 (cm. per day)

* When, however, the larva is feeding mostly upon such diets of low nutritive value as decaying remains of phytoplankton and humic substances suspended or dissolved in sea water, the value of K_1 may be doubtlessly very low. In this situation, the larva may have to take in a vast amount of such matter in order to maintain itself and to grow.

respectively for the larval size ranges 5.26 - 6.25, 6.26 - 7.25 and 7.26 - 8.25 mm. Thus the value of growth rate in this case is about twice as large as that by NAKAI *et al.* (*op. cit.*).

We shall make computation of the amount of daily ration R using AHLSTROM's estimate.

Computaion of Daily Ration

Under are given the results of computation in the amount of daily ration in mgr. taken by a sardine postlarva belonging to different size ranges in respective cases $K_1 = 0.25$, 0.20 and 0.15. The midvalue of each size range was taken as L.

Size range in mm.	5.26 - 6.25	6.26 - 7.25	7.26 - 8.25
Duratron in days	3.9	3.3	2.9
Mean body weight in mgr.+	0.35	0.57	0.86
$K_1 = 0.25$	0.19	0.30	0.45
0.20	0.24	0.38	0.56
0.15	0.32	0.50	0.75

+ Mean body weight was calculated from the equation: $W = 1.84L^3$

From the table, we see that when $K_1 = 0.20$, for example, a sardine postlarva is daily taking foods 0.70 - 0.65 time as much as the body weight (if computed using the estimate of growth rate by NAKAI *et al.*, however, the value is reduced to about half), and that the amount of food animals consumed during the period when the larva grows from 5.26 to 8.25 mm. in length (10 days, according to AHLSTROM; and nealy 20 days, according to NAKAI *et al.*) comes up to about 3.8 mgr.

Consideration

As mentioned in the preceding section, a sardine postlarva of 5.75 mm. in length takes daily foods amounting to some 0.24 mgr. in the natural environment. Assume that the foods be composed exclusively of larval forms of copepods and other planktonic crustaceans. According to my measurement, the widest mouth aperture in a postlarva of this size is about 0.60 mm. × 0.38 mm. And doubtless the diameter of the pharyngeal pass is considerably smaller than 0.38 mm., although it may be expansible to some extent. Regarding fhe larval crustacean as a sphere or an ellipsoid in shape, it can be stated that those forms which are smaller than 0.35 mm. and its neighbourhood in diameter or in length of the longer axis will be more frequently taken by the fish larva than larger food animals, because of the distinguished predominancy in number and the greater feasibility to be ingested of the former over the latter.*

Among the crustacean animals occurring in great quantities in the nursery grounds of sardines along the Japan Sea coasts, copepod species such as *Calanus finmarchicus* (*helgolandicus* type), *C. tenuicornis, Paracalanus parvus, Corycaeus anglicus, Oncaea venusta* and *Oithona spp.* are most important. We now take *Calanus finmarchicus*, the most large-sized of those plankton copepods commonly occurring on the nursery grounds, for particular consideration. GIBBONS (1933) observed the nauplial growth in this copepod and described the body length at respective stages as follows:

Stage I	240 μ
Stage II	270 μ
Stage III	320 μ
Stage IV	360 μ
Stage V	480 μ
Stage VI	810 μ

We can now imagine nauplius stages I and II to constitute by far the greater proportion of this copepod speies taken by the postlarvae. Stage III may be also taken, but in smaller proportion; because the strongly setose and well developed appendages may be obstacle to ingestion. According to LEBOUR (1916), on the other hand, the body length of nauplii of the same species is:-

Stage I	210 μ
Stage II	270 μ
Stage III	420 μ

It is thus considered that a sardine postlarva 5.75 mm. in length may take in mostly nauplius larvae younger than stage III and of course copepod eggs as well.

Based on the data afforded by GIBBONS (*op. cit.*) and by MARSHALL & ORR (1955), the wet weights of these nauplii are roughly estimated as follows: 0.004 mgr. at stage II and 0.003 mgr. at stage I. In this connection, it may be added that an ovum of this copepod weighs about 0.002 mgr.

We can now mention with some generality that the sardine postlarva of the considered size takes principally food animals the individual weight of which is 0.004 mgr. and less, if assumed nearly equal body density in various living food animals including other copepod species and molluscan larvae. This leads us to the following conclusion: the sardine larva has to take daily 60 individuals and more of such food animals as available to it. How high density of distribution of food animals is then sufficient to meet this requirement?

* Food organisms actually found in the postlarval gut are usually smaller and in many cases by far smaller than this size.

Consider the probability of encountering of a sardine postlarva with its food animals. Let V be the water mass in which one postlarva is contained in the average, n the number of available food animals in the same water mass, v the relative speed of the postlarval movement to any food animal and r the range of perception of the postlarva. Then encountering frequency per unit time f is approximately given by the following equation:

$$f = \pi r^2 v \frac{n}{V}.$$

According to my own estimation (NISHIMURA, MS), $V \fallingdotseq 1 \sim 2$ m³ in the intermediate layers where sardine early-stage larvae are abundant in the nursery ground off Noto Peninsula, Japan Sea. Uniform distribution of food animals may be assumed in the water volume of this degree of dimensions. Put $n/V = N$, where N is the density in food animal distribution in this water volume. Further put $f \geqq 60/(24 \times 3600)$ sec^{-1} and $v \fallingdotseq 1.0$ cm. per sec. As to the value for r, 0.1 cm. and its neighbourhood will be appropriate when the postlarva is to scout foods by smell, and 0.5 cm. will be tentatively assumed when it is to find foods by sound or vibration of medium given rise to by movements of any food animal. In this connection, it may well be mentioned that by this developmental stage the sardine postlarva is not yet equipped with effective visual function. Thus we have

$N \geqq 0.022$ per ml. or 2.2×10^4 per m^3. ($r = 0.1$ cm.) or
0.00088 per ml. or 8.8×10^2 per m^3. ($r = 0.5$ cm.).

That is to say, the postlarva can maintain itself and grow in the water mass in which the density in distribution of its food animals is higher than 2.2×10^4 per m.^{3} or 8.8×10^2 per m.^{3}, respectively, according to the type of feeding, *i.e.*, "olfactory" or "auditory".

It should be, however, remembered that the sardine postlarva by no means continues to swim at the constant speed above given throughout the time, and moreover that it does not always succeed in capturing the food animal when the latter enters the range of perception of the former, as SOLEIM (1942) depicted regarding herring larvae. So the above-given value for N may perhaps be much under-estimated.

Further we see, from the foregoing equation, that, as the postlarva grows on, its encountering frequency with food animals will be rapidly increased through the distinguished expansion in the range of perception after the establishment of visual function, the greater speed in movement and the accomplished skill in capturing on one hand, and through the reduction in size limitation upon food animals resulting from the enlargement in mouth aperture on the other. Thus we may safely mention that there may be or may not be for the sardine postlarva the possibility to starve to death, and that if there actually be, the rather short period just after the exhaustion of yolk reserves may be most critical.

Future Lines of Research

In the present paper, the first coefficient of growth energy K_1 has been rather arbitrarily assumed, because we have no data proper concerning the study on this coefficient in very early larvae. So the determination of this right value is much desired. The same can be said with much more accentuation on the critical density in food animal distribution. It may be very important to clearify whether the early postlarvae are olfactory or auditory scouters and by which time they become equipped with effective visual function and begin to search foods optically. The speed and the duration in larval movements are also desired to determine.

When all these items have been cleared up, we can obtain the more precise figure of the daily ration in a sardine postlarva and criticize finally the validity of the opinion emphasizing starvation as the main cause for the tremendously high mortality rate in the early life history.

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