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On the Early Larval Growth, Survival and Variation of Body Form in the  
Walleye Pollock, *Theragra chalcogramma* (Pallas), in Rearing  
Experiment Feeding the Different Diets

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Abstract

The eggs and larvae derived from the B-type adult fish of the walleye pollock were incubated and reared at the water temperature of 5°C. The larvae were separated into 5 experimental sections and were fed on the rotifers or the nauplii of brine shrimp in their respective sections successively. The rate of fertilization of the eggs, the hatching rate of the larvae and the occurrence rate of the deformed larvae were 93.0, 72.1 and 18.0 % respectively. This was determined in view of the function that the stage of yolk absorption occurred at the beginning of the second decreasing period of the yolk-sac volume, viz. on the 21st day after hatching. Among the experimental sections fed on the nauplii of brine shrimp, the larvae with an empty gut were fewer in Section V with the highest larval density compared to those in the other sections during the early period of feeding. No effect caused by different physical and chemical conditions of water was recognized on the larval growth, survival and body form between the experimental sections. The larvae in Section V showed faster growth of body length and had relatively smaller eyes than the larvae in all other experimental sections. The relative growths of body parts were significantly different between the hatching and the larval period. The survivals of larvae were more numerous in Section IV fed on rotifers than in the sections fed on nauplii of the brine shrimp.

Introduction

The authors reported previously<sup>1)</sup> the effect of temperature on the body form and mortality in the developmental and early larval stages of the walleye pollock,<sup>2)</sup> *Theragra chalcogramma* (Pallas). In that experiment the nauplii of brine shrimp, *Artemia salina*, were served to the larvae in all vessels placed in respective experimental sections except the non-fed vessels and a vessel set at 6°C where *Nitzschia closterium* was given as food to the larvae. And it was pointed out that no contribution from *N. closterium* as food for the larval survival and growth was recognized.

In the rearing experiment of fish larvae various diets have been used separately or in combination or have been changed according to the growth of the larvae by many workers. In the present experiment the rotifers, *Brachionus plicatilis*, and the nauplii of brine shrimp were provided. Both species are common for diet of fish larvae in rearing experiments. To simplify the experimental condition, these

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two species were served separately to the larvae in respective experimental sections. And the effects of diets on the growth, survival and body form of the larvae were examined.

### Material and Methods

#### *Material, incubation of eggs and rearing of larvae*

The eggs and the milt in running-ripe condition were stripped from a female and a male fish caught by a demersal gill net in Funka Bay, Hokkaido, on March 1, 1966. Artificial fertilization was carried out by the ordinary dry method on board when the surface water temperature was 5.8°C. The parent adults were identified as B-type fish<sup>3)4)</sup> from the measurements of the eye diameter and otolith weight (Table 1). The fertilized eggs kept in a thermos jar were transported to the laboratory. The incubation of the eggs began 7 hours after fertilization, when the eggs were developing in a 4-cell stage and the water temperature was 6.5°C in the jar.

Table 1. *Measurements on mature fish used for artificial fertilization.*

Sex	BL (mm)	BW (g)	ED (mm)	Mean otolith weight (mg)
Female	409	680	21	305
Male	415	605	21	284

The eggs were incubated in a 14-liter glass vessel (23×30×27 cm) containing still sea water at 5°C, which was placed in a fresh-water bath (89×129×34 cm). The water temperature in the bath was regulated by a thermostat.

The rearing experiment of the larvae was performed in 5 experimental sections. Eight-liter glass vessels (18×24×22 cm) were used by twos in each experimental section, I, II, III and IV, and about 500 newly hatched larvae were held in each vessel on March 19. In the experimental Section V a 5-liter beaker containing 5 liters of rearing sea water was used, in which 3,100 newly hatched larvae, viz. 1,600 on March 19 and 1,500 on March 20, were reared. These rearing vessels and beaker were set in the same fresh-water bath used for the egg incubation, and the temperature of the rearing water was controlled at 5°C. Among 5 experimental sections, Sections I, II and IV were placed in a closed circulation system of rearing water and Sections III and V were conditioned in still water. For diet to the larvae the nauplii of the brine shrimp were furnished in Sections II, III and V and rotifers in Section IV. Section I was the non-fed experimental section (Table 2 and Fig. 1). Feeding was done at noon every day from the 8th day after hatching. Although the quantities of diet furnished daily were not always constant, part of the food animals remained till the next day. These

Table 2. Number of eggs and larvae reared, and water conditions in rearing vessels.

Items	Exp. sect.	Egg	Larvae				
			I	II	III	IV	V
Number of individuals		19,460	365,499	433,468	522,489	503,439	3,100
Temperature (°C)							
mean		5.08(18)	4.61(29)	4.62(31)	4.64(31)	4.63(41)	4.55(36)
range		4.5~6.6	4.0~6.5	4.0~6.4	4.0~6.5	4.0~6.4	4.0~6.0
Chlorinity (‰)							
mean		18.36(4)	18.55(6)	18.55(6)	18.46(5)	18.53(9)	18.33(6)
range		18.18~18.60	18.46~18.63	18.45~18.63	18.37~18.62	18.36~18.61	18.28~18.39
pH							
mean		7.81(4)	7.80(6)	7.73(6)	7.67(5)	7.77(9)	7.39(6)
range		7.58~7.95	7.70~7.91	7.59~7.87	7.50~7.81	7.67~7.89	7.26~7.56
Ammonia-N*							
mean		1.77(3)	7.67(6)	4.90(6)	6.46(5)	8.72(9)	33.47(6)
range		1.0~2.7	2.6~16.4	1.6~7.6	3.3~10.5	1.9~14.7	10.2~64.0
Nitrite-N*							
mean		0.14(3)	0.25(6)	0.25(6)	0.38(5)	0.49(9)	0.73(6)
range		0.00~0.33	0.09~0.49	0.08~0.49	0.12~0.57	0.09~1.32	0.41~1.12
Food			Non-fed	Brine	Brine	Rotifers	Brine
Condition of water		Still	Circulating	Circulating	Still	Circulating	Still

Figures in brackets represent the number of observations.

\* The values are shown in  $\mu\text{g-atoms/L}$ .

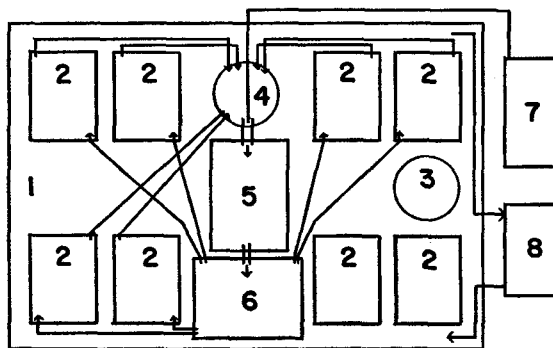


Fig. 1. Diagrammatic surface view of rearing apparatus. 1: fresh-water bath, 2: glass rearing vessel, 3: 5-liter beaker for rearing, 4: 5-liter beaker for reservoir, 5: filter vessel with sand, 6: glass reservoir, 7: air compressor, 8: cooler.

residual animals, faeces and other dirts were removed by siphoning before feeding.

Dead eggs and larvae were also removed, counted daily and preserved in a 3% formalin solution of sea water.

*Observation of embryonic development and measurement of larvae*

In the embryonic period, developmental stages were determined and the time

in hours elapsed from the time of fertilization to the observed stages were recorded.

In the larval period the body length, the pre-anal length, the eye diameter, the diameter of the auditory vesicle, the largest horizontal length of the yolk-sac and the largest height of the yolk-sac were measured every 5 days when 10 individuals were sampled randomly from each experimental section. The tail length was determined by subtracting the pre-anal length from the body length. The numbers of nauplii of the brine shrimp in the guts of the larvae drawn out from Sections II, III and V were counted under the microscope during the experiment, but reliable count of rotifers ingested by the larval fish in Section IV could not be obtained.

#### *Measurement of environmental factors*

The water temperatures for incubation and rearing were measured at noon every day. Chlorinity, pH, ammonia-N and nitrite-N were determined at the time interval of 4~6 days (Table 2).

The mean temperatures of water in the respective experimental sections were about 5°C. The temperatures varied little from day to day except for the rising up to 6.6°C about the time of hatching caused by some accidents in the cooler, and the daily differences between the rearing vessels were less than 0.7°C. The differences in chlorinity, pH, ammonia-N and nitrite-N were also little, and the changes of their values with the lapse of time tended to be similar among Sections I, II, III and IV. The contamination of water was more highly recognized in Section V showing a lower chlorinity and pH and higher ammonia-N and nitrite-N than those in the other larval experimental sections. Owing to the renewal of water for incubation several times, the amount of ammonia-N and nitrite-N during the incubation of eggs were smaller than that in the larval experimental sections.

## **Results**

#### *Embryonic development and hatching*

The times required from fertilization to 7 stages in embryonic development are as follows; morula stage: 23 hours, germ ring stage reached equator: 96 hours, closure of blastopore: 139 hours, formation of lens: 148 hours, pulsation of heart: 247 hours, fully circled embryo: 330 hours and mean hatching time: 411 hours.

Although hatching occurred firstly on the 13th day after fertilization when the embryos were not yet fully circled, all the larvae, 112 individuals, hatched for 2 days from the 13th to the 14th day were abnormal in one part of the tail, so that they were identified as deformed fish. The normal larvae began to hatch from the 15th day after fertilization and their hatchings continued for 6 days together with some deformed fish. The rate of fertilization of the eggs, the hatch-

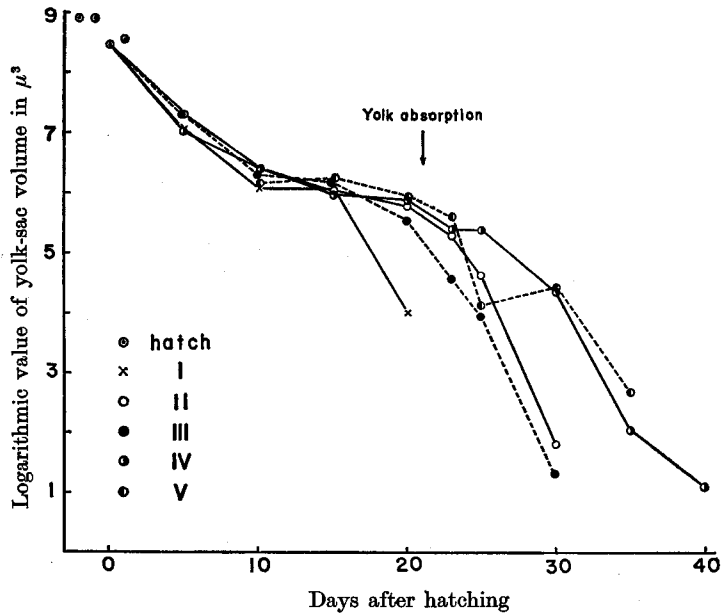


Fig. 2. Changes in mean yolk-sac volume of larvae with the lapse of time after hatching.

ing rate of the larvae and the occurrence rate of the deformed fish in all hatched larvae are respectively 93.0, 72.1 and 18.0 %.

#### *Yolk absorption*

As the yolk-sac of the larva is elliptical in shape during the yolk-sac stage, the volume can be calculated from the measurements of its length and height. The mean volumes of the yolk-sac in the age groups of the larvae were reckoned separately in each experimental section (Fig. 2).

Regarding the changes of the yolk-sac volumes with the lapse of time, three periods are distinguished; that is, the first decreasing period for 10 days, next the sluggish period for 5 days in the non-fed section or for 10 days in the fed sections and the second decreasing period. These changing tendencies are similar to those of the length of the yolk-sac in the rearing experiment at 6°C according to the author's previous results.<sup>1)</sup>

The individuals having a disappeared yolk-sac were found at first on the 20th day after hatching in the non-fed Section I, on the 23rd day in Sections III and V, on the 25th day in Section II and on the 30th day in Section IV of the fed experimental section. As described later, the daily mortality of the larvae increased remarkably on the 21st day after hatching in each experimental section (Fig. 4). Taking these facts into account, it was reckoned that the time of yolk

Table 3. Frequency distribution of the number of brine shrimp observed in the gut of larvae.

Days after hatching	Exp. sect.	Number of brine shrimp										Number of larvae observed	
		0	1	2	3	4	5	6	7	Total	Mean		
10	II	8	1	1							3	0.3	10
	III	8	1	1							3	0.3	10
	V	4	1	3	2						13	1.3	10
15	II	9		1							2	0.2	10
	III	8	1	1							3	0.3	10
	V	5	3	2							7	0.7	10
20	II	4		3	2	1					16	1.6	10
	III	4	1	1	1	2		1			20	2.0	10
	V	3	3	3			1				14	1.4	10
23	II	2	4	2	1	1					15	1.5	10
	III		4		3	1	1	1			23	2.3	10
	V		5	1	2		1	1			24	2.4	10
25	II		3	2	2	2		1			27	2.7	10
	III		4	1	2	1		1	1		29	2.9	10
	V		1	5	1	2	1				27	2.7	10

absorption in the larval developmental stage was on the 21st day after hatching, though the larvae in the fed section had their remaining yolk-sac.

#### *Food amount in gut*

Although it was observed on the 5th day in the course of rearing that the mouth of the larva became functional, when its vent has opened, feeding began on the 8th day after hatching. Some individuals in all experimental sections took food the next day. Counts of nauplii of the brine shrimp ingested by the larvae were performed at each measurement time of body parts (Table 3). Section IV fed on rotifers was ignored from this observation because reliable counts could not be obtained.

In the early period of feeding, about a half or more larvae had empty gut or a few food animals were contained in guts. From the 20th day after hatching, it appeared that as the more days went on, the fewer larvae had empty guts and the more abundant food animals were observed in the guts of larvae. The larvae with empty guts were fewer in Section V than in Sections II and III in the early period of feeding. This means that more abundant larvae began to eat food earlier in Section V than in the other sections.

#### *Growth (Fig. 3)*

There exists a tendency that newly hatched larvae begin to have larger mean body lengths when the hatching day is delayed. These differences of the sizes at

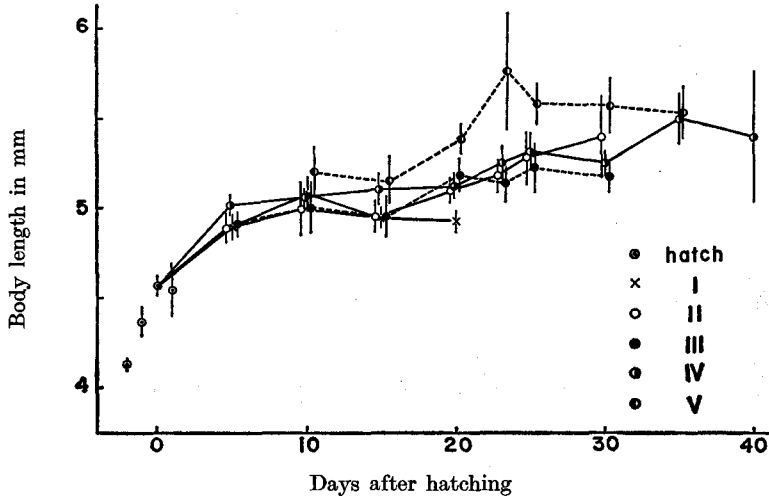


Fig. 3. Growth of body length. Vertical lines represent 95% confidence interval of mean body length.

the time of hatching are probably due to the growth of the embryo in the last period of the development.

The average increases in body length of the larvae during the experiment are about 0.5 mm in the non-fed section and about 0.6~1.0 mm in the fed sections. The growth over 0.5 mm in the fed sections are, therefore, due to the effect of food taken by the larvae. The mean body lengths increase similarly for 10 days after hatching in all experimental sections, but those in the non-fed section do not increase thereafter. The mean lengths of the larvae in the fed sections change little for the next 5 days and thereafter increase again. Showing similar growths of length in Sections II and III, both fed on nauplii of the brine shrimp, no effect on growth due to the experimental conditions of water, circulated or still water, is noticeable. Although the feature of the larval growth in Section IV, fed on rotifers, is similar to that in Sections II and III, the larvae in the former survive longer and achieve a greater length than those in the latter. The growth in Section V where the larvae were reared in a beaker containing 5 liters of still water and fed with nauplii of the brine shrimp, in spite of higher larval density, is the best among the experimental sections.

*Daily mortality and survival curve in early larval period*

Two rearing vessels were used in each experimental section, I~IV. Because the daily changes of mortality were similar between these two vessels, the data were pooled in each section. These pooled data and the data in Section V were used for the analysis of daily mortality and survival curves in the larval period.

Mortality per day calculated every 3 days is low till the 18th day from hatching,

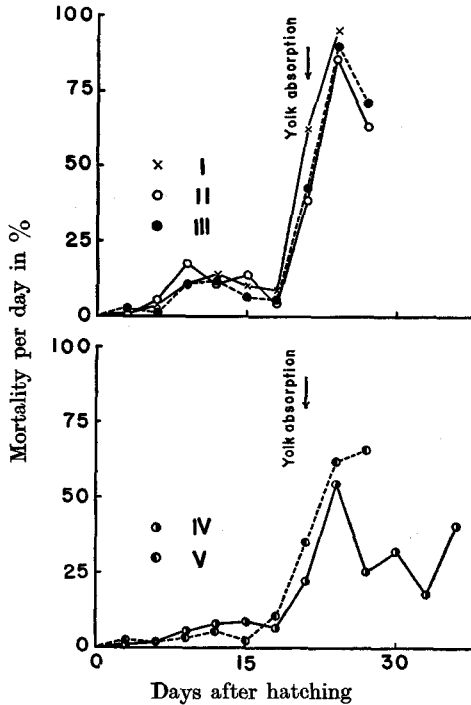


Fig. 4. Percentage mortality to total survivors per 3-day interval.

steeply increasing nearly the stage of yolk absorption, and thereafter somewhat decreasing with the exclusion of Section V. The changes in mortality in Sections II and III were very similar to those in non-fed Section I. The mortalities in Sections IV and V were lower than those in Sections I, II and III in general (Fig. 4).

Survival curves can be divided into two periods in all experimental sections; that is, the periods before and after the stage of yolk absorption (Fig. 5). Before the stage of yolk absorption, survival curves decline gradually in all experimental sections and their reduction coefficients ( $d$ ) are within the range of  $-0.008 \sim -0.016$ . Comparing each other between the experimental sections, the differences of the reduction coefficients were significant except only in the cases between Sections I and II and between Sections IV and V (Table 4). This result may indicate that the reductions of larval numbers in this period were the smallest in

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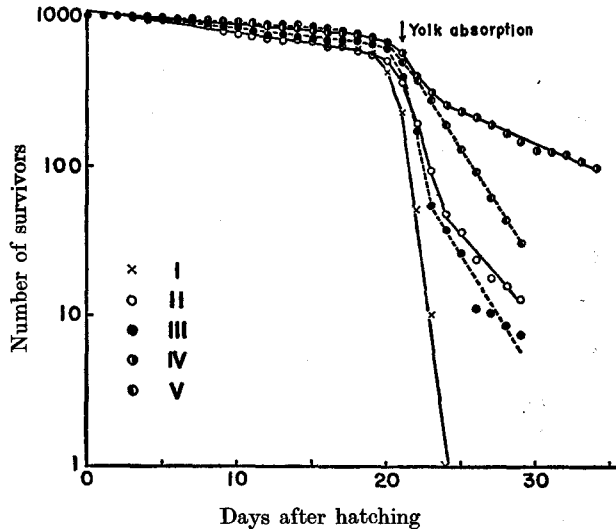


Fig. 5. Survival curves for each experimental section, the initial number of larvae being 1,000.

Table 4. Comparison of reduction coefficients (*d*) in survival curves between experimental sections.

Exp. sect.		I	II	III	IV	V
	<i>d</i>	-0.774	-0.114	-0.145	-0.043	-0.154
I	-0.014		df=1, 6 F <sub>0</sub> =187.78 P<0.005	df=1, 7 F <sub>0</sub> =95.52 P<0.005	df=1, 11 F <sub>0</sub> =591.21 P<0.005	df=1, 9 F <sub>0</sub> =339.42 P<0.005
II	-0.016	df=1, 37 F <sub>0</sub> =1.74 0.25>P>0.10		df=1, 9 F <sub>0</sub> =0.91 0.50>P>0.25	df=1, 13 F <sub>0</sub> =87.16 P<0.005	df=1, 11 F <sub>0</sub> =21.42 P<0.005
III	-0.012	df=1, 37 F <sub>0</sub> =7.60 0.01>P>0.005	df=1, 38 F <sub>0</sub> =20.72 P<0.005		df=1, 14 F <sub>0</sub> =39.79 P<0.005	df=1, 12 F <sub>0</sub> =0.11 P>0.50
IV	-0.009	df=1, 37 F <sub>0</sub> =37.03 P<0.005	df=1, 38 F <sub>0</sub> =67.52 P<0.005	df=1, 38 F <sub>0</sub> =15.94 P<0.005		d = 1, 16 F <sub>0</sub> =1731.81 P<0.005
V	-0.008	df=1, 37 F <sub>0</sub> =31.77 P<0.005	df=1, 37 F <sub>0</sub> =51.49 P<0.005	df=1, 38 F <sub>0</sub> =15.57 P<0.005	df=1, 38 F <sub>0</sub> =1.04 0.50>P>0.25	

After yolk absorption

From hatching to yolk absorption

Sections IV and V, intermediate in Section III and the largest in Sections I and II. After the stage of yolk absorption, survival curves decline more steeply than the curves in the preceding period and their reduction coefficients range between -0.043 ~ -0.774. The reduction coefficients in Section I and also in Section IV are significantly different from the others. There is not a significant difference between the coefficients in Sections II and III and also between the coefficients in Sections III and V, while the coefficients show a significant difference between Sections II and V (Table 4). Judging from these results, the survival curves in this period may be divided into three groups such as Section I, Section IV, and Sections II, III and V. They correspond to the non-fed experimental section, the section fed on rotifers and the sections fed on nauplii of the brine shrimp. That is to say, the effect of the diets on the survival of the larvae is reflected in this result and may be concluded that the rotifer is better than the nauplius of brine shrimp for the diet of larva in the early period of growth.

*Relative growth*

The changes in body form during the larval period were analyzed by means of the allometric equation,  $\log y = \log b + k \log x$ , where *y* is the length of the body part, *x* the body length (*L*) as a standard, *k* the equilibrium constant of allometry and *b* the initial index. The body parts treated here are the pre-anal length (*L*<sub>1</sub>), the tail length (*L*<sub>2</sub>), the diameter of the eye (*ED*) and the diameter of the auditory

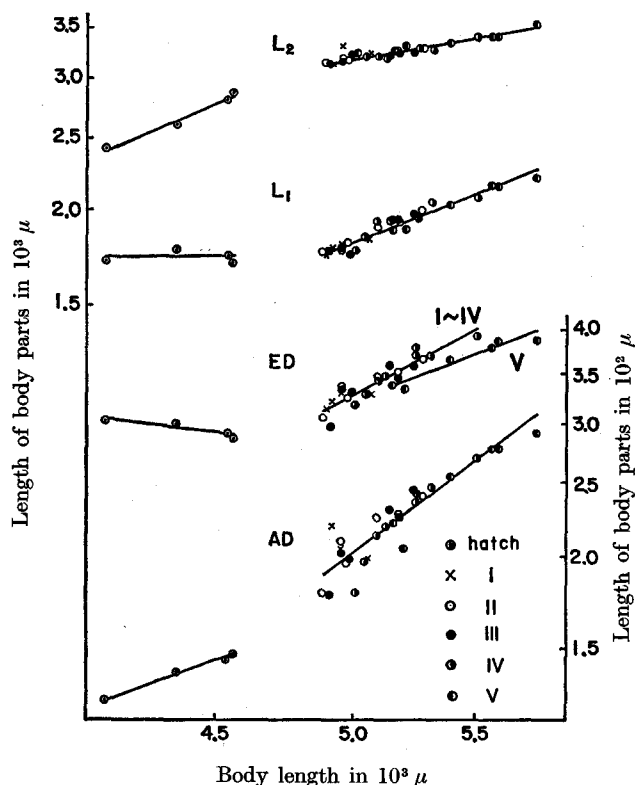


Fig. 6. Relative growth of body parts in relation to body length.

vesicle (*AD*). The values of body length and body parts used for calculation were the averages of age groups for a day. As mentioned above, there were increases of body length in later newly-hatched larvae and those were regarded as a growth during the last period of the embryonic stage. The relation of body part to body length in this period cannot be recognized to be similar to the relation in the larval period, because a critical breaking point exists at a certain period until the 5th day after hatching (Fig. 6). Therefore, the allometric equations in the hatching period and in the larval period were calculated separately in each relation of body part to body length.

#### 1. Allometric analysis

Comparing the allometric equations in the larval period among all experimental sections, the values of *k* and the adjusted means have no significant difference in all relations of body part to body length except the adjusted mean in the relation of *ED* to *L* where exists a significant difference at the 5% level (Table 5). Being analysed between each two experimental sections, only the difference of

Table 5. Comparison of equilibrium constant ( $k$ ) and adjusted mean in the allometric equation as the regression between experimental sections.

	$L_1$	$L_2$	$ED$	$AD$
Equilibrium constant	df=4, 20 $F_0=0.84$ $P>0.50$	df=4, 20 $F_0=0.79$ $P>0.50$	df=4, 20 $F_0=1.23$ $0.50>P>0.25$	df=4, 20 $F_0=0.84$ $P>0.50$
Adjusted mean	df=4, 24 $F_0=1.16$ $0.50>P>0.25$	df=4, 24 $F_0=1.31$ $0.50>P>0.25$	df=4, 24 $F_0=3.20$ $0.05>P>0.025$	df=4, 24 $F_0=1.36$ $0.50>P>0.25$

the adjusted mean in the relation of  $ED$  to  $L$  between IV and V is significant (df=1 and 11;  $F_0=9.64$ ;  $0.025>P>0.01$ ), as a matter of course the values of  $k$  do not differ significantly in all occasions. However, the relative growth of  $ED$  in Section V is distinct from those in Sections I~IV as shown apparently in Fig. 6. Comparing the allometric equation calculated from the pooled data in Sections I~IV with that of Section V, the equilibrium constant,  $k$ , has a significant difference (df=1 and 26;  $F_0=4.73$ ;  $0.05>P>0.025$ ). Consequently, it may be concluded that the relative growth of  $ED$  in Section V is different from those in other experimental sections and the larvae in Section V have relatively a smaller eye than the larvae in the others. According to these facts, allometric equations of the respective parts were determined by using the pooled data in all experimental sections except the relation of  $ED$  to  $L$  in Section V (Table 6).

When these allometric equations are compared with those of hatching period

Table 6. Equilibrium constant ( $k$ ) and initial index ( $\log b$ ) in the allometric equation.

		$L_1$	$L_2$	$ED$		$AD$
Newly hatched larvae	n	4	4	4		4
	$k$	-0.0317	1.6732	-0.4808		1.3909
	$\log b$	3.352	-2.670	4.221		-2.923
Larvae after hatching	n	30	30	Section I~IV 24	Section V 6	30
	$k$	1.5812	0.6624	2.1433	1.4861	3.0285
	$\log b$	-2.589	1.053	-5.413	-2.989	-8.899

Table 7. Comparison of equilibrium constant in the allometric equation between newly hatched larvae and larvae after hatching.

$L_1$	$L_2$	$ED$		$AD$
		Section I~IV	Section V	
df=1, 30 $F_0=69.67$ $P<0.005$	df=1, 30 $F_0=76.00$ $P<0.005$	df=1, 24 $F_0=55.23$ $P<0.005$	df=1, 6 $F_0=60.49$ $P<0.005$	df=1, 30 $F_0=5.36$ $0.05>P>0.025$

shown in Table 6, the equilibrium constants show significant differences in the respective body parts (Table 7). The results indicate that the relative growths of these body parts in the larval stage are not the same as those in the last period of the embryonic stage and in each body part the critical breaking point exists at a certain period until the 5th day after hatching.

2. *Body length at the inflection point of relative growth*

Given the system of linear equation,  $\log_e y = \log_e b_i + k_i \log_e x$ ;  $i=1, 2, 3, \dots$ , the necessary and sufficient condition that these equations have a common solution ( $x=x_0, y=y_0$ ) is that  $b = B e^{-r^k}$ , where  $r = \log_e x_0$  and  $B = y_0$ .<sup>5)</sup> This means that these lines intersect at the point ( $x_0, y_0$ ) only, if the condition is satisfied.

The regression lines, expressed by  $\log b = \beta - \kappa k$ , where  $\beta = \log B$  and  $\kappa = r \log e$ ,<sup>6)</sup> fitted with the relations of  $\log b$  to  $k$  in the allometric equations of respective body parts calculated in the respective experimental sections and in the group of newly hatched larvae (Table 8 and Fig. 7). Therefore, the relative growth lines in each body part should have a sole intersecting point which represents the inflection of the relative growth. When the regression equations are compared between body parts, it is found that there is no significant difference in the regression coefficient and significant differences exist in adjusted means in all cases (Table 8); that is to say, the regression lines are parallel to each other. Since the intersecting point ( $x_0, y_0$ ) has been indicated as  $r = \log_e x_0, B = y_0$ , it is concluded that the mean body lengths of the larvae at the intersecting point, viz. the inflection point, of relative growth lines may be equal regarding respective body parts though

Table 8. *Comparison of regression lines in the k-log b relation between body parts.*

	$L_1$	$L_2$	ED	AD	Adjusted mean
$\kappa$	3.6599	3.6858	3.6743	3.6904	
$\beta$	3.200	3.496	2.465	2.258	
$L_1$		df=1, 9 $F_0=6.37$ $0.05 > P > 0.025$	df=1, 9 $F_0=56.73$ $P < 0.005$	df=1, 9 $F_0=61.85$ $P < 0.005$	
$L_2$	df=1, 8 $F_0=0.01$ $P > 0.50$		df=1, 9 $F_0=30800.29$ $P < 0.005$	df=1, 9 $F_0=4336.49$ $P < 0.005$	
ED	df=1, 8 $F_0=0.01$ $P > 0.50$	df=1, 8 $F_0=1.13$ $0.50 > P > 0.25$		df=1, 9 $F_0=163.39$ $P < 0.005$	
AD	df=1, 8 $F_0=0.06$ $P > 0.50$	df=1, 8 $F_0=0.00$ $P > 0.50$	df=1, 8 $F_0=1.52$ $0.50 > P > 0.25$		

$\kappa$

the mean lengths of body parts at that point are different from each other. The values of  $\kappa$  are 3.6599 in  $L_1$ , 3.6858 in  $L_2$ , 3.6743 in  $ED$  and 3.6904 in  $AD$ . Converting these values into lengths of larvae at the inflection point, they come to 4.57, 4.85, 4.72 and 4.90 mm respectively. Excluding Section V of which the lengths of larvae are not measured on the 5th day after hatching, the mean body length on hatching day is 4.557 mm and the mean lengths on 5th day after hatching come to 4.894, 4.885, 4.905 and 5.010 mm in respective experimental Sections I, II, III and IV. Out of the body lengths at the inflection point, the smallest 4.57 mm in  $L_1$  is similar to the length on the hatching day and the largest

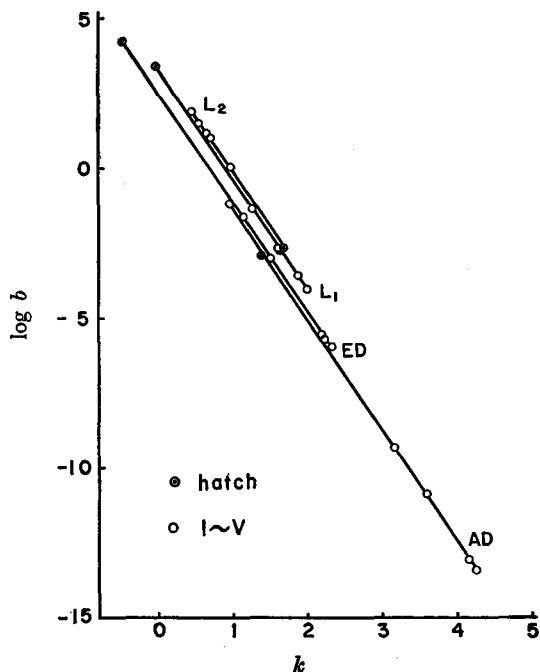


Fig. 7. Relationship between equilibrium constant and initial index in the allometric equation.

4.90 mm in  $AD$  bears a resemblance to the values on the 5th day in the respective experimental sections. Therefore, it may be true that the changes of form in the respective body parts treated here occur at a certain period during 5 days following hatching. The variation ranging from 4.57 to 4.90 mm should be attributed to a considerable large dispersion of measured values in the whole and in all the parts.

### 3. The test of equilibrium constant in allometric equation

Equilibrium constants of allometric equations as regression coefficients were tested as to whether the null hypotheses that the population regression coefficient ( $\hat{k}$ ) was equal to zero or equal to unity could be rejected or not (Table 9), the following results were obtained.

$L_2$  shows a tachyauexesis in the hatching stage and thereafter changes for a bradyauexesis in relation to  $L$ . The relation of  $AD$  to  $L$  shifts from an isaexesis to a marked tachyauexesis.  $L_1$  and  $ED$  show no growth in the hatching stage in relation to  $L$ , then  $L_1$  changes for a tachyauexesis and  $ED$  shows a tachyauexesis in pooled Sections I~IV and an isaexesis in Section V in relation to  $L$ .

Table 9. Test of the null hypotheses that the population regression coefficient ( $k$ ) is equal to zero or unity with regard to equilibrium constant in the allometric equation.

	Hypotheses	$L_1$	$L_2$	$ED$		$AD$
Newly hatched larvae	$k=0$	df=2 $t_0=0.137$ P>0.50	df=2 $t_0=13.483$ 0.01>P>0.001	df=2 $t_0=4.047$ 0.10>P>0.05		df=2 $t_0=11.888$ 0.01>P>0.001
	$k=1$		df=2 $t_0=5.425$ 0.05>P>0.02			df=2 $t_0=3.341$ 0.10>P>0.05
Larvae after hatching	$k=0$	df=28 $t_0=25.098$ P<0.001	df=28 $t_0=17.432$ P<0.001	Section I~IV df=22 $t_0=12.339$ P<0.001	Section V df=4 $t_0=8.077$ 0.01>P>0.001	df=28 $t_0=12.598$ P<0.001
	$k=1$	df=28 $t_0=9.225$ P<0.001	df=28 $t_0=8.884$ P<0.001	df=22 $t_0=6.582$ P<0.001	df=4 $t_0=2.642$ 0.10>P>0.05	df=28 $t_0=8.438$ P<0.001

### Discussion

Some larvae were reared in water conditions either in a closed circulation system or in still water. To our regret, the volume of running water was not measured. However, these water conditions may be negligible in the present experiment for the reason that no different results were obtained between Sections II and III of which the experimental conditions differed in water condition only. Moreover, it is a pity that the measurements of lengths on the 5th day after hatching had been lacking in Section V, because this section was not designed for measurement at the beginning of the experiment.

The mouth and the vent of larval fish had opened already at the measurement time of the 5th day after hatching. It had been observed in the larval rearing of this species at 6~7°C that the mouth was functional and the vent had opened on the 3rd day after hatching.<sup>7)</sup> Taking this observation into account, the day that the mouth and the vent had opened in the present experiment might possibly be somewhat earlier than the 5th day.

Feeding began on the 8th day after hatching and some larvae which had taken food were observed the next day. But it is inferable that the beginning of feeding was several days later, considering the fact that the body length of the larvae increased little for 5 days from the 10th day after hatching.

Taking into account the decreasing tendency of the yolk-sac volume with the lapse of time from hatching and the changes of larval daily mortality, the stage of yolk absorption was decided to be on the 21st day after hatching in the present experiment. Some larvae of which their yolk-sac had disappeared occurred on the 20th day in the non-fed section, though the remaining yolk-sac was observed in

all larvae in the fed sections. The decision that the stage of yolk absorption was on the 21st day may be reasonable as far as function is concerned.

From the data where the energy expenditure was computed for the larvae of the Pacific sardine, *Sardinops caerulea*,<sup>8)</sup> the larvae of the largemouth bass, *Micropterus salmoides*,<sup>9)</sup> and the larvae of other fishes during yolk absorption, the fact that the energy of the remaining yolk became insufficient to supply the energy requirements in larval catabolic processes before the complete yolk absorption has been demonstrated. Especially, in the larvae of *S. caerulea* the energy deficit occurred before the larvae were capable of feeding. To know the period of these energy deficits is very important to study the larval population dynamics. The energy expenditure of the larvae of walleye pollock has not been studied at all. From the results obtained in the present experiment, it may be presumed that the energy deficit for larval catabolism occurred several days previously to the 21st day after hatching.

No effect on the growth of larval length due to the difference of food species in question was recognized. As one of the reasons for better larval growth seen in Section V with a higher larval density, it is pointed out that many larvae began to feed on the diet earlier in this section than in the other sections. According to the facts that the main spawning season of the walleye pollock is from January to March, and young fish of 4~7 cm long are sampled on June intermingling with the catch by a set net and others in Funka Bay, it has been concluded that the body length of the fish attained to 4~6 cm some 4 months after hatching.<sup>10)</sup> The growth of larvae in the present experiment is much slower than that in nature.

The result that the larvae in Section V showed a faster growth have a relatively smaller eye than those in the other sections was obtained. This is a very interesting and suggestive result in connection with the following characteristics regarding some biological distinctions between the A- and B-type fish of walleye pollock caught in Funka Bay and its adjacent areas; that is, the B-type fish grow faster<sup>11)</sup> and have a relatively smaller eye<sup>3)4)</sup> than the A-type fish.

Only the result on the survival of the larvae was different between the section fed with rotifers and the sections fed on nauplii of the brine shrimp; that is, the rotifers, the smaller species, were better as a diet for the larvae of the walleye pollock during the early period. However, the mortality rates per day of the larvae in Section IV fed on rotifers tended to increase again at the last period of the experiment, and no larva survived beyond the 40th day after hatching. Therefore, real success may not be expected by feeding the rotifers only in the rearing of the larvae of walleye pollock. It is necessary to use the method that feed such smaller food animals as rotifers during the early period of the larval stage and gradually vary the diet to larger species such as nauplii of the brine

shrimp and so on according to the size of larvae.

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