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EXPERIMENTAL STUDY ON UTILIZATION OF FOOD BY YOUNG ANCHOVY,

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By

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The anchovy (*Engraulis japonicus*), one of the most important commercial fishes in Japan, is utilized as natural food for many fishes in high trophic level such as amber-fish, mackerel, saurel, squid, some of the flatfishes and others, hence it plays a rôle in maintaining the important fish resources.

Because of the continuous decline in catches of the sardine in recent years, the anchovy came to hold an important position in the sardines fisheries in Japan and biological investigations on it have been developed extensively. And many informations have been obtained on its development, growth, feeding habit, maturation, spawing and so on, but for the purpose to understand more deeply the state of its life it is necessary to know, on the one hand, the efficiency with which it is utilized by other fishes in high trophic level and, on the other hand, the efficiency with which it utilizes the organisms such as planktons.

Some studies (1, 2) on the amount of the anchovy consumed by other predatory fishes have been already carried out. In the present study, the anchovy was fed with large planktonic crustacea, *Euphausia pacifica*, in the aquaria and the relation between the amount of food consumed and the resulting growth was observed. Using this relation, the efficiency in utilizing zooplankton was estimated and discussed from the stand point of the anchovy as the predator. And, by combining the result of the present study with those of the previous ones, some considerations were made on the rôle of the anchovy as a bridge, so to speak, through which energy in a marine community flows from the lower to the higher trophic level.

Before proceeding further we thank the staffs members of the Onagawa Fisheries Experimental Station for their kind cooperation in carrying out the experiments and Mr. R. Endo, the owner of the trap-nets, for his cooperation in collecting the fish used in the experiments. The expense of this study was partly defrayed by a grant from the Fisheries Agency, Ministry of Agriculture and Forestry.

Materials and Method

The feeding experiments were undertaken during the periods from October to November in 1958 and from September to October in 1959 at the Onagawa Fisheries Experimental Station, attached to the Tohoku University.

The anchovy used in the experiments were caught in September and October by the trap-nets, settled along the shore in Onagawa Bay, Miyagi Prefecture. The trap-nets are operated by experienced fishermen in catching the anchovy without wounds for the live bait of the skip-jack angling. The size of the fish used in the experiments ranged between 60 and 90 mm long (to the end of the urostyle), weighing 1.4 to 7.2 g. From the body sizes at the time of collections, all the fish can be regarded as those hatched in the previous spring (3). All were premature.

About 30 to 50 individuals at a time were put, immediately after caught, into a barrel 50 cm in diameter and 50 cm deep containing 40 *l* of sea water and then brought to the laboratory, changing the sea water as frequently as possible. They were transfered quietly together with sea water into the concrete tank, which measured $1.8 \times 1.8 \times 0.6$ m. Thereafter the tank was refreshed with filtrated sea water continuously.

About a week after being held in the tank, the fish were induced to feed on a piece of *Euphausia* actively. The anchovy swim usually in a shoal but, when feeding, the shoal is entirely broken as soon as any one of them begins to react to the sinking food. They can perceive a piece of *Euphausia* slowly sinking to the bottom at the distance of 10 to 50 centimeters and show a pouncing action towards the food which they swallow. Such feeding behaviour can be observed always during the experiments and is similar to that of the herring in the aquarium observed by Blaxter and Holiday (4). The fish which displayed a good feeding activity were selected for the experiments. Each set of the experiment consisted of four to eight individuals. They were held separately in the tanks of the same size as mentioned above. The individuals in each group were distinguished from one another by their body size and the marks made on the caudal lobe by cutting off its lower, its upper or both portions and by no cutting.

Previous workers (3) showed that the anchovy, of nearly the same size with those used in the experiments, feed mainly on zooplanktons, especially copepoda, along the Eastern and Northeastern Pacific coasts of Japan. But in these experiments *Euphausia pacifica H. J. Hansen* was used for food, because it is easily obtainable and its size is large enough for the estimation of the amount taken by the individual fish. It was collected from the commercial catch during the period from February to April off Onagawa and stored in frozen condition. The size of *Euphausia* used for food ranged between 6 and 7 mm in the carapace length, each weighing 0.03 to 0.06 g. While feeding, they were given one by one and the number of them taken by each fish were recorded. By multiplying their average weight by the number, the weight of food taken is obtained. Fish were fed three to six times a day and after each feed the uneaten food and the faeces were siphoned off.

The anchovy were measured and weighed once per 10 or 15 days, respectively for the experiments made in 1958 or in 1959, after slightly narcotized by 0.5 per cent urethane solution. Since the fish is only tolerable for very slight narcotism and it keeps in motion during the measurement and weighing, the error of 2.0 mm in length and 0.2 g in weight will be included in the resuls of estimation. The narcosis by 0.5 per cent urethane solution seems to disappear completely at least after ten hours, namely the anchovy becomes to swim in three hours after narcotism at the water temperature of 20°C and in five hours at 14°C, and feeds actively again after ten hours.

Results and Consideration

The amount of food taken and the resulting growth for each individual fish during the experimental period are shown in Table 1. In 1958 the experiments were performed for 20 days from 20th October to 9th November under the water temperature ranging between 11 and 16°C and in 1959 for 45 days from 7th September to 22nd October in water temperature of 14 and 22°C.

The Growth in Length and in Weight.

The changes in length and in weight of fish varied widely, because some of them were fed as much as they would eat and the others were fed on restricted diet to find the efficiencies of food conversion at various rates of feeding. The changes in length of fish per each 10 or 15 days ranged between −2 and +5 mm and those in weight between −0.6 and +1.2 g, as shown in Table 1. Thus, the proportions of the error in measurement and weighing of these amounts of changes are rather large, especially in length. Taking the errors into consideration, the amounts of daily growth in length and in weight (the amount of growth per day) for 20 days or 15 days periods, respectively for the experiments in 1958 or in 1959, are shown in Table 2 only for the cases fed on *Euphausia* as much as over 11.5 per cent in daily rate of feeding. In this time the amounts of daily growth in length ranged between 0.20 and 0.33 mm per day and those in weight between 0.035 and 0.080 g per day.

Table 1. Growth and food consumption of the 32 anchovy fed with *Euphausia* in aquarium.

Fish No.	Date	1958 Oct. 20		Oct. 30		Nov. 9
	water temp. ℃		13 ~ 16		11 ~ 15	
1	Body length	82		83		85
	Body weight	4.4		5.1		5.4
	Food eaten		3.5		3.9	
2	l.	82		83		84
	w.	3.9		4.7		5.3
	f.		3.6		4.0	
3	l.	76		79		80
	w.	2.9		3.2		3.9
	f.		2.4		3.6	
4	l.	75		76		79
	w.	2.9		3.5		3.8
	f.		3.4		4.0	
5	l.	73		73		74
	w.	3.7		3.2		4.2
	f.		3.2		4.6	
6	l.	67		68		69
	w.	2.1		2.1		2.4
	f,		1.0		2.2	
7	l.	61		62		64
	w.	1.8		1.8		2.3
	f.		2.2		1.7	
8	l.	83		84		83
	w.	4.5		4.8		5.1
	f.		3.4		3.1	
9	l.	83		83		83
	w.	4.2		4.4		4.6
	f.		3.1		3.0	
10	l.	76		76		76
	w.	3.0		3.3		3.8
	f.		2.2		2.3	
11	l.	75		74		74
	w.	2.9		3.1		3.2
	f.		1.4		1.9	
12	l.	86		88		86
	w.	5.3		6.3		6.3
	f.		3.7		2.6	
13	l.	83		84		83
	w.	4.2		4.8		5.1
	f.		3.4		3.4	
14	l.	72		73		75
	w.	2.9		3.4		3.6
	f.		3.4		2.6	
15	l.	72		73		73
	w.	3.0		3.5		4.1
	f.		3.3		3.5	
16	l.	61		63		67
	w.	1.7		2.2		2.4
	f.		2.4		2.9	
17	l.	75		74		75
	w.	3.3		3.5		3.9
	f.		3.0		3.3	

Fish No.	Date	1958 Oct. 20		Oct. 30		Nov. 7
	water temp. ℃		13 ~ 16		11 ~ 15	
18	Body length	72		70		75
	Body weight	2.5		2.9		3.3
	Food eaten		2.6		3.9	
19	l.	60		60		60
	w.	1.4		1.4		1.7
	f.		1.5		1.7	
20	l.	62		64		68
	w.	1.5		1.8		2.2
	f.		2.2		3.0	

Fish No.	Date	1959 Sept. 7		Sept. 22		Oct. 7		Oct. 22
	water temp. ℃		20 ~ 22		18 ~ 20		14 ~ 19	
21	l.	81		85		85		87
	w.	4.4		5.6		5.7		6.4
	f.		12.3		6.9		6.4	
22	l.	75		80		80		83
	w.	3.6		4.6		5.2		5.9
	f.		11.3		4.0		9.4	
23	l.	73		74		74		78
	w.	2.7		3.5		3.6		4.4
	f.		6.4		4.8		6.8	
24	l.	68		72		74		died
	w.	2.1		2.8		3.3		
	f.		8.3		4.3			
25	l.	79		83		83		87
	w.	3.9		4.3		4.3		4.7
	f.		4.7		3.8		4.6	
26	l.	73		74		73		75
	w.	3.2		3.8		3.7		3.9
	f.		5.7		3.3		1.0	
27	l.			87		87		90
	w.			5.3		6.1		7.3
	f.				10.1		12.8	
28	l.			84		85		85
	w.			5.1		5.4		6.5
	f.				5.1		7.7	
29	l.			79		79		80
	w.			4.3		4.4		4.9
	f.				6.1		6.2	
30	l.			71		72		72
	w.			2.3		2.6		2.8
	f.				3.7		3.0	
31	l.			69		67		68
	w.			2.1		2.1		2.2
	f.				2.1		2.7	
32	l.			70		70		72
	w.			2.8		3.3		3.5
	f.				3.7		3.0	

(Body length in mm. Body weight in g. Food eaten in g.)

Table 2. Daily growth for the eight cases, extracted from Table 1, when the daily rate of feeding exceeds 11.5 per cent.

Fish No.	Daily rate of feeding	Ave. B.L.	Ave. B.W.	Daily growth in		Period
				B.L.	B.W.	
23	11.5	76.0	4.00	0.27	0.053	Oct. 7～Oct. 22 '59
27	11.8	87.0	5.70	0.33	0.056	Sept. 22～Oct. 7 '59
27	12.7	88.5	6.70	0.20	0.080	Oct. 7～Oct. 22 '59
16	13.2	64.0	2.05	0.30	0.035	Oct. 20～Nov. 9 '58
20	14.0	65.0	1.85	0.30	0.035	Oct. 20～Nov. 9 '58
21	16.4	83.0	5.00	0.27	0.080	Sept. 7～Sept. 22 '59
22	18.3	77.5	4.10	0.33	0.067	Sept. 7～Sept. 22 '59
22	22.4	70.0	2.45	0.27	0.047	Sept. 7～Sept. 22 '59

According to the trend of growth in length of the anchovy, reported by Yokota and Furukawa (5), they grow from 60.5 mm to 71.0 mm for the period from the third to the fifth month of life, corresponding to 0.18 mm per day, and from 71.0 mm to 97.4 mm for the period from the fifth to the eighth month of life, corresponding to 0.30 mm per day, in natural habitat in Hyuga-nada. The amounts of daily growth in weight of the anchovy will be calculated as 0.023 g and 0.061 g per day respectively for both periods, basing on a length-weight relation obtained by Maekawa and Yatsuyanagi. (6) on the anchovy caught along Seto Inland Sea coasts of Yamaguchi Prefecture.

Consequently it is possible to say that the experimentally obtained growth of the anchovy (60 to 90 mm long) sufficiently fed with *Euphausia* in the aquarium in water temperature ranging between 11 and 22°C, surpasses somewhat the natural growth of the anchovy of the same size during the warm seasons from summer to autumn.

The Conversion of Food to Body Substance.

The results of feeding and growth are dealt with collectively for 20 days- and 30 days-periods respectively for the experiments in 1958 and 1959. The average body length, the initial body weight, the final body weight, the average body weight, the amount of daily growth in weight, the daily ration (the amount of food consumed per day), the rate of daily growth (the rate in percentage of the amount of daily growth to the average body weight), and the daily rate of feeding (the rate in percentage of the daily ration to the average body weight) are shown in Table 3. And the relation between the daily rate of feeding and the rate of daily growth is shown in Fig. 1.

At the present time the regression of relation was calculated for all cases and the result can be expressed by the equation; $g = 0.124\,r - 0.23$ [1], where "r" represents the daily rate of feeding, "g" the rate of daily growth

Table 3. Daily rates of feeding and rates of daily growth of tne anchovy fed with *Euphausia* for each 20 or 30 days period.

Fish No.	Average body length mm	Initial body weight g	Final body weight g	Average body weight g	Daily ration g	Daily rate of feeding %	Daily groth g	Rate of daily growth %	Average water temp. °C	Period	
26	74.5	3.8	3.9	3.85	0.14	**3.6**	0.030	**0.08**	17.5	30 days from	Sept. 7 to Oct. 7 '59
12	86.0	5.3	6.3	5.80	0.32	**5.5**	0.050	**0.86**	13.6	20	Oct. 20 to Nov. 9 '58
11	74.5	2.9	3.2	3.05	0.17	**5.6**	0.015	**0.49**	13.9	20	Oct. 20 to Nov. 9 '58
25	85.0	4.3	4.7	4.50	0.28	**6.2**	0.013	**0.29**	17.5	30	Sept. 22 to Oct. 22 '59
25	81.0	3.9	4.3	4.10	0.28	**6.8**	0.013	**0.32**	20.0	30	Sept. 7 to Oct. 7 '59
10	76.0	3.0	3.8	3.40	0.23	**6.8**	0.025	**0.74**	13.9	20	Oct. 20 to Nov. 9 '58
8	84.0	4.5	5.1	4.80	0.33	**6.9**	0.030	**0.63**	13.9	20	Oct. 20 to Nov. 9 '58
9	83.0	4.2	4.6	4.40	0.31	**7.0**	0.020	**0.44**	13.9	20	Oct. 20 to Nov. 9 '58
32	71.0	2.8	3.5	3.15	0.22	**7.0**	0.023	**0.73**	17.5	30	Sept. 22 to Oct. 22 '59
6	68.0	2.1	2.4	2.25	0.16	**7.1**	0.015	**0.67**	14.4	20	Oct. 20 to Nov. 9 '58
21	86.0	5.6	6.4	6.00	0.44	**7.3**	0.027	**0.45**	17.2	30	Sept. 22 to Oct. 22 '59
13	83.0	4.2	5.1	4.65	0.34	**7.3**	0.045	**0.97**	13.6	20	Oct. 20 to Nov. 9 '58
28	84.5	5.1	6.5	5.80	0.43	**7.4**	0.047	**0.81**	17.2	30	Sept. 22 to Oct. 22 '59
31	68.5	2.1	2.2	2.15	0.16	**7.5**	0.033	**0.14**	17.5	30	Sept. 22 to Oct. 22 '59
2	83.0	3.9	5.3	4.60	0.38	**8.3**	0.070	**1.52**	14.4	20	Oct. 20 to Nov. 9 '58
30	71.4	2.3	2.8	2.55	0.22	**8.6**	0.017	**0.67**	17.5	30	Sept. 22 to Oct. 22 '59
22	82.0	4.6	5.9	5.25	0.45	**8.6**	0.045	**0.82**	17.2	30	Sept. 22 to Oct. 22 '59
26	73.0	3.2	3.7	3.45	0.33	**8.7**	0.017	**0.49**	20.0	30	Sept 22 to Oct. 22 '59
3	78.0	2.9	3.9	3.40	0.30	**8.8**	0.050	**1.47**	14.4	20	Oct. 20 to Nov. 9 '58
29	79.5	4.3	4.9	4.60	0.41	**8.9**	0.020	**0.44**	17.2	30	Sept. 22 to Oct. 22 '59
17	75.0	3.3	3.9	3.60	0.32	**8.9**	0.030	**0.83**	14.8	20	Oct. 20 to Nov. 9 '58
14	73.5	2.9	3.6	3.25	0.30	**9.2**	0.035	**1.08**	13.6	20	Oct. 20 to Nov. 9 '58
1	83.5	4.4	5.4	4.90	0.37	**9.6**	0.050	**1.02**	14.4	20	Oct. 20 to Nov. 9 '58
15	72.5	3.0	4.1	3.55	0.34	**9.6**	0.055	**1.55**	13.6	20	Oct. 20 to Nov. 9 '58
7	65.0	1.8	2.3	2.05	0.20	**9.8**	0.025	**1.22**	14.4	20	Oct. 20 to Nov. 9 '58
5	75.0	3.7	4.2	3.95	0.39	**9.9**	0.025	**0.63**	14.4	20	Oct. 20 to Nov. 9 '58
23	76.0	3.5	4.4	3.95	0.39	**9.9**	0.030	**0.76**	17.2	30	Sept. 22 to Oct. 22 '59
19	60.0	1.4	1.7	1.55	0.16	**10.3**	0.015	**0.97**	14.8	20	Oct. 20 to Nov. 9 '58
4	77.0	2.9	3.8	3.35	0.37	**11.0**	0.045	**1.34**	14.4	20	Oct. 20 to Nov. 9 '58
18	73.5	2.5	3.3	2.90	0.33	**11.4**	0.040	**1.38**	14.8	20	Oct. 20 to Nov. 9 '58
22	77.5	3.6	5.2	4.40	0.51	**11.6**	0.053	**1.20**	19.7	30	Sept. 7 to Oct. 7 '59
23	73.5	2.7	3.6	3.15	0.37	**11.8**	0.030	**0.95**	19.7	30	Sept. 9 to Oct. 7 '59
27	88.5	5.3	7.3	6.30	0.76	**12.1**	0.067	**1.06**	17.2	30	Sept. 22 to Oct. 22 '59
21	83.0	4.4	5.7	5.05	0.64	**12.7**	0.043	**0.85**	19.7	30	Sept. 7 to Oct. 7 '59
16	64.0	1.7	2.4	2.05	0.27	**13.2**	0.035	**1.71**	13.6	20	Oct. 20 to Nov. 9 '58
20	65.0	1.5	2.2	1.85	0.26	**14.0**	0.035	**1.89**	14.8	20	Oct. 20 to Nov. 9 '58
24	71.0	2.1	3.3	2.70	0.42	**15.5**	0.040	**1.48**	19.7	30	Sept. 7 to Oct. 7 '59

and the correlation coefficient was +0.714. From this equation it will be indicated that the anchovy assimilates *Euphausia* to its body substances at the rate of 12.4 per cent and expends 0.23 per cent of its body weight daily. The assimilability (7) and the metabolic rates (8) of fishes are believed to decrease as the fish grow larger or as the temperatures become lower. For

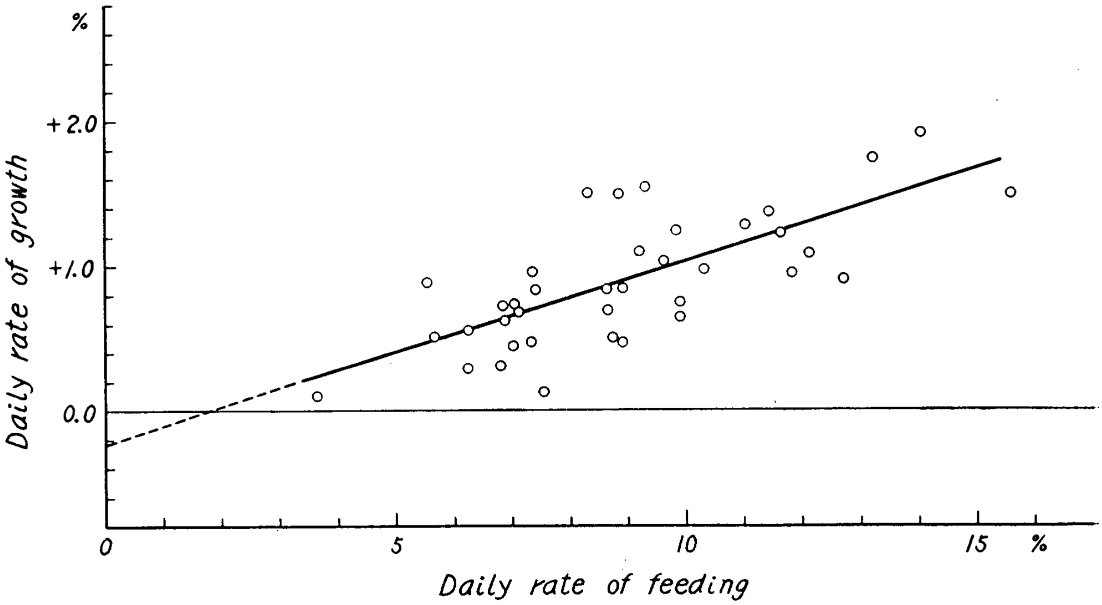

Fig. 1. Rates of daily growth plotted against daily rates of feeding of the anchovy (60-90 mm long) fed with *Euphausia pacifica* at the temperatures between 11 and 22°C.

example, Hatanaka and Takahashi (9) and Takahashi and Hatanaka (10) found that for the young mackerel fed with *Euphausia* under the water temperature between 16.3 and 21.4 °C the apparent anabolic rate* decreases from 22 to 18 per cent and the apparent catabolic rate** also decreases from 0.99 to 0.67 per cent daily as the fish grow larger from 16.7 g to 65.2 g in average weight, and also in the fish, weighing about 100 g and fed with anchovy, the apparent anabolic rate decreases from 25 to 11 per cent as the average water temperature becomes lower from 19.6 to 13.4 °C. Hence more detailed experiments will be

* "The apparent anabolic rate" is denoted here as the slope of the regression of the rate of growth upon the rate of feeding and is supposed to be constant for some limited range of the daily rate of feeding. Since the digestibility concerned with the assimilation will be higher at smaller rate of feeding, this supposition will not be used in the true meaning. But it is convenient, for an approximation, to use the rate for expressing an ability of assimilation in fish.

** The negative value of the rate of growth obtained by extrapolating the regression, when the rate of feeding equals to zero, is used here as an approximate estimate of catabolic rate of fish. This value will vary, to some extents, depending on the distribution of points on the regression. But it is also convenient for the estimation of the metabolic rate of fish without putting it in fast.

needed to know the variations in the anabolic rate or the daily catabolic rate, due to the sizes of fish or to the temperature conditions, on the anchovy. However, even by a mere comparison of the present results on the anchovy with the above mentioned variations on the mackerel, it is possible to say that the young mackerel assimilate *Euphausia* with better efficiency but expend more energies for daily life than the young anchovy do.

The unit of the wet weight was derived from the chemical analysis to be equivalent to 0.67 Kcal for the anchovy and to 0.56 Kcal for *Euphausia*. Therefore the equation [1] can be transformed on calorific base into $g = 0.141\,r - 0.23$ [2].

Food Consumption by Young Anchovy in Nature.

Providing the anchovy at sea could assimilate *Euphausia* and expend their body weight at the same rates found in the experiments, although the suppositions must be proved in the future, the amount of *Euphausia* consumed by the anchovy in nature can be estimated as follows;

As mentioned in the preceding paragraph, the amount of daily growth of the anchovy attains 0.023 g and 0.061 g respectively for the period from the third to the fifth month and the period from the fifth to the eighth month after hatched in nature and these values correspond to 0.75 and 0.95 per cent in the rate of daily growth for the anchovy, weighing respectively 3.05 g and 6.41 g. Applying these rates of growth (g = 0.75 and 0.95 per cent) to the equation [1], the daily rate of feeding (r) can be obtained as 7.8 and 9.5 per cent. This is identical with the results of Okul (11) who studied the digestibility and the stomach contents of the anchovy in the Azov Sea and assumed the daily rate of feeding on planktons in summer as 8 to 10 per cent.

The efficiency of conversion of *Euphausia* into the anchovy, expressed as the percentage growth in weight of the anchovy to the amount of *Euphausia* consumed, is estimated as 9.6 to 10.0 per cent.

Efficiency of Conversion of Euphausia passing through Anchovy into Mackerel.

Hatanaka and Takahashi (9) pointed out that the adult mackerel of nearly 350 g in weight, which corresponds to the average body weight of the commercially caught mackerel in Japanese waters, should consume the anchovy at the rate of 0.30 to 0.50 per cent to the body weight and the efficiency of conversion of the anchovy into the body substance of the mackerel is estimated as 6.1 to 8.5 per cent. As mentioned in the preceding paragraph, the efficiency of conversion of *Euphausia* into the anchovy is 9.6 to 10.0 per cent. Hence, the efficiency of conversion of *Euphausia* passing through the anchovy into the mackerel is calculated as 0.6 to 0.8 per cent by a simple multiplication.

On the contrary, if the mackerel grows directly by consuming *Euphausia*, it will be necessary for this mackerel to feed on *Euphausia* at the rate of 8.1 to 10.6 per cent to their body weight, basing on the experimentally obtained results (9). Hence the efficiency of conversion of *Euphausia* directly into the mackerel is 3.7 to 4.7 per cent. This is nearly six times more efficient than the indirect process of production of the mackerel by the two steppings. The calculation shows an example indicating how much energy is lost in the process of its transmission from the lower to the higher trophic level.

These experiments are only preliminary at present but it has been revealed that the anchovy fed with *Euphausia* in a small aquarium can grow somewhat more rapidly than in nature and there seems to be a possibility to observe directly the details of the schooling or feeding behaviour by some improved method of rearing. Studies for improving the method are now proceeding.

Summary

1. For the two periods, the one from October to November in 1958 and the other from September to October in 1959, 32 anchovy 60 to 90 mm long were fed with *Euphausia* under the water temperature 11 to 22°C in the concrete tanks measured 1.8×1.8×0.6 m at the Onagawa Fisheries Experimental Station, Tohoku University.

2. The fish grew daily 0.20 to 0.33 mm in length and 0.035 to 0.080 g in weight during the experiments. These amounts of growth exceed those of the fish in nature, calculated from the trend of growth obtained by the previous workers.

3. The relation between the rate of daily growth "g" and the daily rate of feeding "r" may be expressed in the equation $g = 0.124\,r - 0.23$ (correlation coefficient $= +0.714$). This equation can be transformed into $g = 0.141\,r - 0.23$ on the calorific base.

4. Some considerations were made on the amount of *Euphausia* consumed by the anchovy in nature and on the conversion efficiencies of *Euphausia* passing through the anchovy into the mackerel.

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