STUDIES ON THE AMOUNTS OF THE ANCHOVY CONSUMED BY THE MACKEREL

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By

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The investigations on the stomach contents of fishes in the warm waters of Japan show that the anchovy (*Engraulis japonicus*) plays an important rôle in supplying foods for many species such as amberjack, mackerel, saurel, tunas, squid and bottom fishes. Hence, the anchovy is com pelled to undergo a high mortality due to predations by other fishes as well as the human consumptions. The feeding experiments on the mackerel, the amberjack and the saurel (3, 4, 5) had hitherto been made to determine the amounts of food necessary for supporting their lives in the coastal warm waters. At the same time, these experiments are important for understanding the so-called natural mortality of such fishes of prey as the anchovy, the sardine and/or Euphausids.

Lately, some feeding experiments on the medium sized mackerel (*Pneumatophorus japonicus*) were undertaken succeeding to the experiments on the young previously reported. And the amounts of the anchovy and/or *Euphausia* consumed yearly by the mackerel were estimated bared on the results of the experiments. It was revealed that this amount was exceedingly greater than that by human catch as reported in this paper. Supposing how intricate the relationship between prey and predator in a community may be, it is obvious that the predations by other fishes cause a great diminution of prey in nature.

The feeding experiments on the mackerel were performed during 1958 and 1959 at the Onagawa Fisheries Research Laboratory, Tohoku University. The authors express their thanks to the members of the Laboratory for the facilities during the experiments. The expenses of this study was partly defrayed by a grant from the Fisheries Agency, the Ministry of Agriculture and Forestry.

Feeding experiments of the mackerel

The mackerel used in the experiments were caught by a trap-net set near Enoshima Island, Miyagi Prefecture, and kept there for a few days in a live well to let them be accustomed to live in a restricted space. The habituated mackerel were removed to the Laboratory aquaria, taking nearly one hour for the transportation. Approximately 30 per cent of the mackerel died within three days probably due to some injuries received during the transportation. Thereafter there was almost no mortality among the established mackerel. The feeding usually commenced within seven days after capture. The concrete aquaria measured 4×3 m and 1 m in depth, was provided with running sea water and occupied with five to eight mackerels at a time. The size of the mackerel is approximately 300 mm long, weighing 350 g, which practically coresponds to the average size found in the commercial catch as stated later.

Twenty-four hours before the experiments, the food supply was stopped thus giving them time to empty their intestinal contents and be ready for the experiments. From the beginning to the end of the experiments, the fish were measured and weighed once per ten days after slightly narcotized by one per cent ethyl-urethan solution. The effects of the drug lasted for 15 to 30 minutes, before the fish begun their feeding actively again. The amount of food taken and the growth attained were recorded by individual fish, identification being made by the size of the fish and the dermal spots of the head portion.

The foods were usually fed sufficiently five to six times daily, but in some cases the number of feeding times were restricted to once or twice per day to determine the growth by the smaller ration. The anchovy used as food were collected in Onagawa Bay during the experiments and served in fresh conditions. They measured between 60 and 80 mm and weighed between 1.0 and 3.5 g. *Euphausia* (*Euphausia pacifica*) given as food were provided during the winter season in Onagawa Bay and frozen for preservation. Before use, the frozen *Euphausia* were melted and made into a small lump and weighed accurately in the order of 0.1 g. The mackerels were investigated at each time when a weighed amount of food was offered, and the unused food were removed immediately. The water temperature of the aquaria recorded daily at noon ranged between 16° and 22°C and coresponded to the temperatures of the natural summer habitat of the mackerel.

The Results

Provided the initial body weight of the individual mackerel is "w_0", the total amount of food taken "f", and the final weight "w" during the feeding period "t", then the following may be expressed:

$$\text{The mean body weight}: W=\frac{w_0+w}{2}$$

$$\text{The mean daily rate of feeding}: r=\frac{f}{t\cdot W}$$

$$\text{The mean daily rate of growth}: g=\frac{w-w_0}{t\cdot W}$$

$$\text{The efficiency of food conversion}: e=\frac{w-w_0}{f}$$

Using a set of the results from an appropriate number of fish reared under the same conditions a formula expressing the relationship between "r" and "g" may be obtained.

Among the mackerel collected in July, 1958, 15 fishes ranging from 267 to 297mm in body length, weighing between 208 and 329 g, were fed on the anchovy for 50 days, and also among the mackerel caught in September, 1959, the ten fishes ranging between 260 and 338 mm, weighing between 209 and 543g, were fed on *Euphausia* for 20 days.

With a purpose to describe the general process of the feeding experiments, the increase in body weight and the amount of food consumed for each ten mackerel fed on the anchovy during the 50 days period in 1958 is shown in Table 1.

During the experiments, half of the cases were fed sufficiently and the rest insufficiently for each ten days period repeating at random as shown in the Table. Among the cases of restricted feeding, some fishes decrease in body weight and others show a high efficiency of food conversion according to the amounts of food consumed. The weight of the mackerel gained by consuming 1,158.6 g of the anchovy during the 50 days period amounts to 116.6g in an average for the ten fishes, showing an efficiency of conversion as 10.06 per cent. A fairly good efficiency in this case will depend on feeding manners as repeated sufficient and the restricted diets.

The experiments on the fish fed on anchovy were performed in 62 cases in 1958. The body weight of the mackerel used in these cases ranged between 229.5 and 438.0 g, averaging 330.4 g and the water temperatures were between 21.0° and 22.0°C. The results are shown in Table 2. The daily rate of feeding ranged between 0.0 and 15.4 per cent, averaging 6.8 per cent and the daily rate of growth was between -1.91 and 2.59 per cent, averaging 0.68 per cent, although these values have no important significance because the

Table 1. The increase in body weight and the amounts of food consumed for each ten mackerel fed on sufficient and restricted diet of the anchovy for the 50 days at temperatures between 21.0° and 22.0°C in aquaria. * Denote restricted diet. 1958

Fish No.	Date	July 30	—	Aug. 9	—	Aug. 19	—	Aug. 29	—	Sept. 8	—	Sept. 18	Increase in weight g	Total amount of food g
No. 10	Body weight g	234		280		302		342		338		343	109	
	Food taken g		225.7		206.3*		417.1		131.0*		122.8*			1,102.9
No. 3	Body weight	236		292		312		326		351		360	124	
	Food taken		373.8		194.2*		245.6*		235.0		190.6*			1,239.2
No. 1	Body weight	261		318		346		404		390		398	137	
	Food taken		354.0		182.2*		523.4		73.2*		134.3*			1,267.1
No. 14	Body weight	261		289		263		254		296		340	79	
	Food taken		341.4		0.0*		0.0*		222.5		331.5			895.4
No. 2	Body weight	269		329		363		353		351		402	133	
	Food taken		367.4		291.3		99.9*		86.7*		348.8			1,194.1
No. 7	Body weight	278		325		333		350		376		374	96	
	Food taken		243.9		146.3*		175.6*		131.4*		150.7*			847.9
No. 4	Body weight	284		343		356		354		364		397	113	
	Food taken		322.1		206.4*		137.0*		128.8*		338.8			1,133.1
No. 15	Body weight	284		326		338		347		361		402	118	
	Food taken		258.1		178.9*		154.5*		199.0		342.6			1,133.1
No. 6	Body weight	308		351		376		426		410		466	158	
	Food taken		267.3		131.4*		502.0		123.4*		448.2			1,589.3
No. 11	Body weight	329		355		405		425		439		428	99	
	Food taken		121.4		405.8		317.8		239.3		99.5*			1,183.8
Average		274.4		320.8		339.4		358.1		365.8		391.0	116.6	1,158.6

rations were regulated artificially. But the wide range of variation of these values are necessary for obtaining the relationship between the feeding rates and the growth rates. The growth rates increased in an approximately linear

Table 2. The feeding rates and the growth rates per day of the mackerel fed on the anchovy for each ten days- period at temperatures between 21.0° and 22.0°C 1958, Onagawa.

Mean body weight	Feeding rate per day	Growth rate per day	Mean body weight	Feeding rate per day	Growth rate per day
g	%	%	g	%	%
229.5	9.6	1.87	338.5	6.9	0.74
235.0	8.7	1.19	340.0	3.9	−0.12
250.5	15.4	2.59	340.5	3.6	0.15
257.0	8.9	1.52	341.5	5.1	0.50
258.5	0.0	−0.35	342.5	4.5	0.26
259.0	0.3	−1.39	346.0	8.4	0.98
264.0	6.1	0.98	349.0	5.7	0.16
264.0	14.2	2.12	349.5	5.9	0.37
268.0	8.1	1.27	352.0	2.5	−0.06
268.5	0.0	−1.15	355.0	3.8	−0.06
275.0	12.4	1.02	355.5	5.4	0.25
275.0	8.1	1.49	358.0	2.8	−0.28
276.0	0.0	−0.94	359.0	3.6	0.28
282.5	12.4	2.23	363.0	3.6	0.72
283.5	5.2	0.04	363.5	6.6	0.66
284.0	0.0	−1.91	375.0	4.0	−0.05
289.5	11.3	1.97	375.0	14.0	1.55
297.0	4.9	0.07	376.5	9.3	1.36
299.0	12.3	1.97	378.5	11.8	0.98
300.0	3.2	0.13	380.0	6.8	1.32
301.5	8.1	1.56	380.5	8.9	0.87
302.0	6.4	0.66	381.5	9.0	1.07
305.0	8.5	1.38	394.0	3.4	0.20
313.5	10.3	1.88	397.0	1.8	−0.35
318.0	10.4	1.38	401.0	12.5	1.25
319.0	7.7	0.44	415.0	7.7	0.48
322.0	13.0	1.24	418.0	2.9	−0.38
329.0	4.5	0.24	432.0	5.5	0.32
329.5	8.1	1.31	433.5	2.3	−0.25
332.0	5.5	0.84	438.0	10.2	1.27
332.0	5.4	0.36			
337.0	8.0	1.34	Average	6.77	0.682

manner with increased rations as shown in Fig. 1. By fitting a rectilinear line to this relation (20) the following formula was obtained.

$$g = 0.2005r - 0.6743 \quad \cdots\cdots [3]$$

For the mackerel of these sizes at the above mentioned temperatures, the efficiency of utilization of the anchovy appears to be less complete when the ration exceeds 10 per cent to the body weight and thereafter there was an increased variation.

The following two formulae were obtained from the results previously reported (4) on the young mackerel fed on the anchovy at the temperatures between 20° and 22°C :

For the 17 cases, on an average body weight of 15.2 g,

$$g=0.416r-1.96 \quad \cdots\cdots [1]$$

For the 33 cases, on an average body weight of 51.6 g,

$$g=0.267r-1.10 \quad \cdots\cdots [2]$$

Comparing the above three formulae, the following facts are noticed; the inclinations of the lines, namley the efficiencies of food utilization, decrease

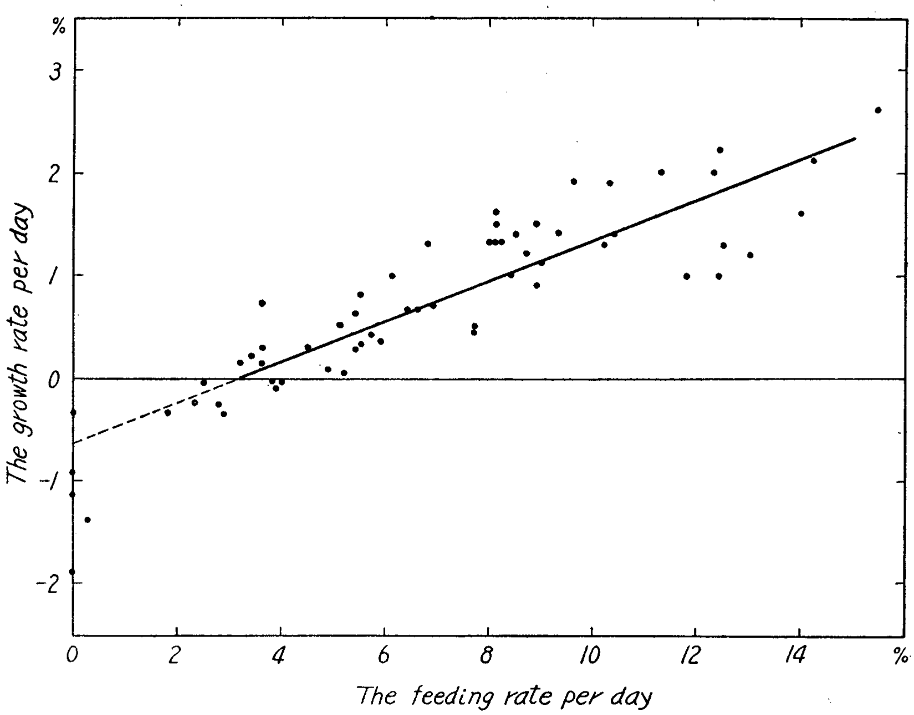

Fig. 1. Relation between feeding rates and growth rates of the middle sized mackerel fed on the anchovy at temperatures between 21.0° and 22.0°C. 1958, Onagawa.

and the growth rates during fasting ($r=0$), roughly the catabolic rates, decrease also according with the increase in fish size in the manner of an exponential-type curve.

According to the experiments on fasting for the mackerel weighing nearly 50 g in the aquaria at the water temperatures of 21° and 22°C, the decreasing rate of body weight during fasting varies as follows:— 2.68 per cent at the first day of the experiment, 2.50 per cent at the second day, 2.24 per cent at the fourth day and 1.26 per cent daily in the mean for the eight days period. Thus, the decrease in body weight per day during fasting gradually slows down during a long period of fasting. But at the beginning of fasting the energy expenditure of the mackerel in the aquaria can be calculated approximately as 30 Cal/kg/day. The constants of the formula [2], namely the decreasing rate in weight when "r" equals 0, is obviously lower than the value at the beginning of the fasting of this case, because it is obtained from an extraporation of linear line.

The daily rate of feeding at the time when "*g*" equals 0, namely the maintenance ration to the body weight, can be calculated as 4.7 per cent by the formula [1], 4.1 per cent by [2] and 3.4 per cent by [3]. Thus the decreasing tendency of the maintenance ration according to the size of the fish seems to be reasonable as compared with the result of the amberjack previously reported (5). On the caloriferic basis, these coeficients can be expressed respectively for 31.3 Cal, 27.5 Cal and 22.8 Cal/kg/day, since the anchovy used for food coresponds to 0.68 Cal/gram.

The results obtained by the experiments in 1959 using *Euphausia* as food are shown in Table 3. The size range of the mackerel is between 209.0 and

Table 3. The feeding rates and growth rates per day of the mackerel fed on Euphausia for each ten days-period at temperatures between 16.9° and 19.4°C. 1959, Onagawa.

Mean body weight	Feeding rate per day	Growth rate per day
g	%	%
209.0	15.9	1.24
209.5	13.5	1.00
226.0	11.1	0.31
226.5	13.5	0.57
252.5	12.0	0.59
258.0	5.0	−.016
263.0	11.9	0.61
276.0	7.9	0.36
307.5	0.1	−0.24
321.5	0.0	−0.59
399.5	2.3	0.03
415.5	8.9	0.75
440.0	1.0	−0.41
451.5	1.0	−0.11
486.0	18.8	1.03
505.5	17.5	0.97
520.0	10.4	0.35
543.0	9.6	0.29
544.0	11.9	0.52
558.5	6.4	0.27

558.5 g in body weight, averaging 370.7 g and the water temperatures were between 16.9° and 19.4°C. In the 20 cases the total weight gained by consuming 6557 g of *Euphausia* during the 20 days of the experimental period, amounts to 262g, and showed the efficiency of food conversion to be 4.0 per cent. The range of the daily rate of feeding was between 0.0 and 18.8 per cent, averaging 8.9 per cent and the daily rate of growth was between −0.59 and 1.24 per cent, averaging 0.37 per cent. The relationship between the feeding rate and the growth rate is shown in Fig. 2, and by fitting a rectilinear line to this relation, the following formula can be obtained:

$$g=0.0800r-0.3461 \quad \cdots\cdots [6]$$

The maintenance ration can be calculated from this formula at 4.3 per cent to the body weight.

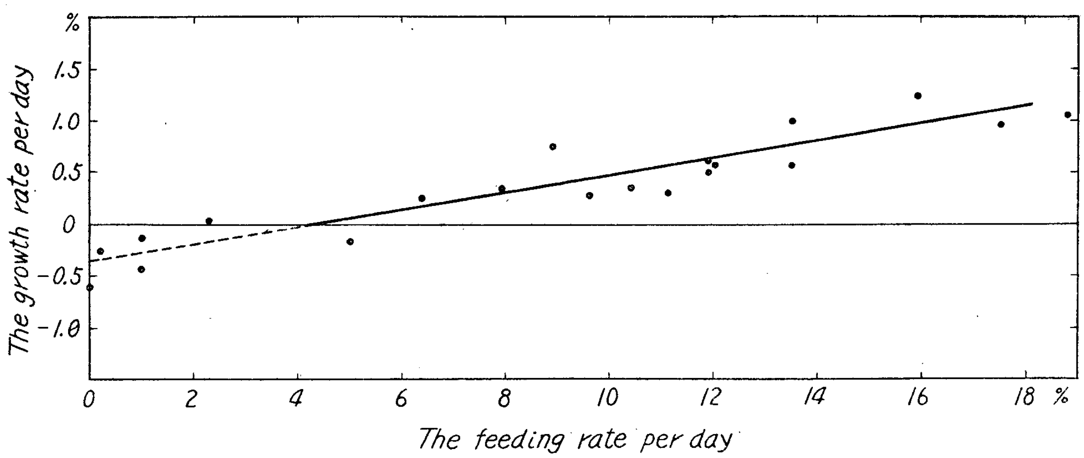

Fig. 2. Relation between feeding rates and growth rates of the middle sized mackerel fed on Euphausia at temperatures between 16.9° and 19.4°C. 1959, Onagawa.

According to the results of the young mackerel previously reported in the case of using *Euphausia* as food at the temperatures between 16.3° and 21.4°C, the relation between "r" and "g" becomes:

For the 27 cases on an average body weight of 16.7 g,

$$g=0.221r-0.993 \quad \cdots\cdots [4]$$

For the 30 cases on an average body weight of 65.2 g,

$$g=0.177r-0.665 \quad \cdots\cdots [5]$$

Within thes e three formulae, either the efficiencies of food conversion or the apparent catabolic rates decrease as the fish grow larger and their decreasing tendencies seem to be reasonable considering from the results fed with the anchovy.

Notwithstanding whether the mackerel are large or small, it utilizes the anchovy more efficiently than *Euphausia*, probably because of the different digestibility between the two kinds of food. The mackerel grow more rapidly when fed on the anchovy than on *Euphausia*, even though the mackerel consumes a much larger diet of the latter. The anchovy seems to be more a favourable food than *Euphausia* for the growth of the mackerel.

Investigations on the stomach contents

The relationship between the amounts of the food consumed and the growth made by the mackerel was realized by the feeding experiments in the aquaria as already mentioned. For obtaining the basis to analyze the food cosumption of the mackerel in nature more knowledges are needed concerning how much the mackerel will grow in nature feeding and on what kind of foods it will consume in each seasons of the year.

Concerning the feeding habits of the mackerel, Kasahara and Ito (1953) refered to nearly 30 reports available for the mackerel of the Sea of Japan and summarized as follows: For the food of the adult mackerel, planktonic crustaceans, especially Euphausids, Copepods and Amphipods, are most important followed by small fishes such as sardine, anchovy, sand lance and small squids. This coincides generally with the results on the Atlantic mackerel (*Scomber scombrus*) made by Steven (1949) and Sette (1950). The Altantic mackerel is said to feed mainly on small fishes (especially on *Clupea spp.*, *Ammodytes spp.* and *Onos spp.*) while the mackerel approaches to the coasts in summer and this fact is also noticed in the case of the Japanese mackerel.

Recently more detailed studies were made on the stomach contents of the mackerel from Japanese waters. Concerning the Pacific Coasts of Japan, Takano (1954) stated basing on the investigations on 68 fishes, ranging between 330 and 420 mm in body length, caught by bottom gill nets during May and July, 1953, near Ohshima Island, that the most important food is of pelagic crustaceans so far as the season is concerned. Takano and Hanado (1955) found that seven fishes among the ten (301 to 372 mm in body length) caught by hooks and lines in July, 1955, on the coasts of the northern part of Iwate Prefecture, depend on the anchovy as food, whose sizes ranged between 80 and 107 mm, weighing 7.1 g in an average. And they stated that the anchovy is the most important food in quantity, followed by *Euphausia pacifica* and *Calanus plumchrus*. Hatanaka *et al* (1957) reported basing on the 1,489 young mackerel (60 to 260 mm in body length) caught mainly by the set nets along the coast of Miyagi Prefecture, that during the period from July to October, when the fish grow most rapidly, they take mainly the anchovy followed by *Euphausia.*

Concerning the mackerel in the Sea of Japan, Maeda *et al* (1955) found basing on the 655 mackerel (90 to 860 g in body weight) caught by purse seine and pole fishing during the seasons of 1953 and 1954 that the most important foods are fishes especially the anchovy and sardine, which consisted of 67 to 100 per cent in weight of the stomach contents during the period from May to October. Nishimura and Okachi (1957) reported basing on the 98 mackerels (198 to 430 mm) caught by ring net in February and March, 1957, along the middle part of the coasts of the Sea of Japan, that the stomach contents are quite small or frequently empty during the season of the lowest temperature and when containing materials they consisted exclusively of *Euphausia pacifica* and rarely of the anchovy or small squids. Matsui and

Maeda (1958) summarized the studies on the feeding habits on the occasion of the Explorations on the Tsushima Currents Waters and stated that the main foods of the mackerel are generally the anchovy, followed by *Euphausia* without concern with the young or the adult, although the additional foods varies according to seasons in such manner as the phytoplankton in midwinter, pelagic crustaceans in spring, fishes in summer and zooplankton in autumn.

In short, it seems to be true that the mackerel found in the waters around Japan feed mainly on the anchovy for the three months from midsummer to autumn, and to a certain extent on the sardine, saurel, small squids and *Euphausia*. During the rest seasons, they eat mainly the larger sized crustaceans, such as *Euphausia* and Amphipods.

It was already known that the anchovy is certainly predated by the mackerel, but its sizes are not yet fully understood except for a short report by Takano and Hanado above cited. Hence, the stomach contents were again examined in 1957 succeeding to those made in 1954. In general, the foods composition is quite similar in both the years. Among the collections made in 1957, three samples were selected to represent the sizes of the anchovy contained in the stomach (Table 4).

Table 4. The stomach contents of the mackerel samples selected from the collections made in 1957.

Date	Numb.	Range of body length in mm	Range of body weight in g	Percentages of occurence of each food items					
				Anchovy	Small fish	Squid	Crus-taceans	Others	Empty
July 23, 1957	34	210—276	98—236	38.2	5.9	2.9	5.9	35.3	11.8
Aug. 17, 〃	23	206—252	102—228	73.9	0	0	4.4	21.7	0
Sept. 14, 〃	39	232—274	167—218	92.3	0	2.6	0	2.61	2.6

In July, the 13 mackerels among the 34 feed on the anchovy ranged between 74 and 125 mm in body length, chiefly being 85 mm long and weighing 5 g. The ratio in size of the anchovy against the mackerel is 37 per cent in an average and 47.5 per cent at a maximum. In August, the 17 mackerels among the 23 feed on the anchovy ranging between 56 and 113 mm, most frequently were 100 mm long, weighing 7 g. The size preference by the mackerel on the anchovy is 43 per cent in an average and 45 per cent at a maximum. In September, the 36 mackerels among the 39 feed on the anchovy ranging from 69 and 109 mm in length and among them the anchovy of 80 mm long, weighing 3 g occupied nearly 90 per cent. The size of the anchovy prefered by the mackerel is 34 per cent of the body length in an average and 44 per cent at a maximum. The relation in body length between the mackerel and the anchovy is shown in Fig. 3.

From the above investigations, the mackerel seems to be able to feed at least on the anchovy in size coresponding to 30 to 45 per cent of its body length. According to the Progres Report of the Cooperative Sardine Research Investigations (1954), the commercial catch of the anchovy in Japan are

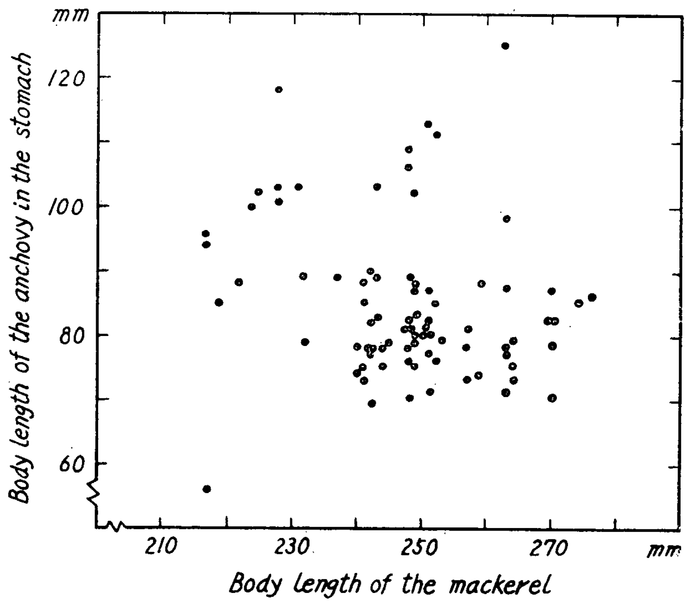

Fig. 3. The body length frequency of the anchovy found in the stomach against the body length of the mackerel examined. 1957.

mainly of the fish under 120 mm long. Thus, the size of the anchovy consumed by the mackerel is identical with that of the commercial catch. The anchovy in summer receive the most severe predations by the mackerel and the proliferous fishing by man.

Amount of the catch

The amounts of the catches of the commercially important species in the warm waters of Japan are shown in Table 5, according to the Japan Fisheries

Table 5. The annual catches of the commercially important fishes in the warm waters of Japan during the period from 1952 and 1958. Unit: Thousand tons. Source: Japan Fisheries Statistics.

Years / Fish name	1952	1953	1954	1955	1956	1957	1958	Average
Sardine	302	344	245	211	206	212	136	236.6
Anchovy	290	243	304	391	346	430	417	345.9
Saurel	206	240	251	238	246	312	324	259.5
Mackerel	287	235	297	244	266	275	268	267.4
Amberjack	59	49	46	46	42	42	43	46.7
Skipjack	86	73	99	99	97	97	147	99.7
Blue fin tuna	14	18	19	23	36	34	21	23.6
Squid	601	420	398	383	299	364	354	402.7

Statistics during the period between 1952 and 1958. It is noticeable that the catch of the anchovy is gradually increasing recently showing a marked contrast with the gradual decrease of the sardine. All the six species described under the "Anchovy" in the Table depend on the anchovy as their main foods. Among them the mackerel is one of the most significant predators in its number and in its dependency on the anchovy. The catch of the mackerel is rather stable in recent years, showing approximately 270 thousands tons annually. The mackerel is caught almost throughout the coastal waters around Japan as shown in the Regional Catch Statitics (Table 6).

Table 6. Regional catch statistics of mackerel in Japan during the period between 1954 and 1957. Unit: Thousand tons. Source: Japan Fisheries Statistics.

Region \ Year	1954	1955	1956	1957	1958
Hokkaido	10.2	13.3	11.8	4.0	2.5
Pacific Coasts	88.9	78.9	155.7	142.4	132.0
Japan Sea Coasts	90.8	73.2	50.1	63.1	48.3
South China Sea	101.9	77.3	41.0	63.9	83.6
Seto Inland Sea	5.5	1.6	7.5	1.8	1.9
Total	297.3	244.3	266.1	275.2	268.3

Along the Japan Sea coasts, the most proliferous fishing season occurs twice a year in April and in November and thereabout. The number of the mackerel separately for the size range caught along the Japan Sea coasts during the period from 1954 to 1956 is shown in Table 7, as reported by

Table 7. The size composition in number of the mackerel caught in Japan Sea Coasts during the period from 1954 to 1956. Unit: Thousand. From Okachi (1958).

Body length in cm / Year	15—21	22—28	29—35	36—39	40—	Total
1954	19,828	62,873	105,181	38,028	9,065	234,975
1955	37,394	70,896	58,588	39,882	7,486	214,246
1956	20,985	72,315	35,972	21,910	2,411	153,593

Okachi (1958). The average body weight of the mackerel caught there can be estimated from the above two tables as follows: 386 g in 1954, 342 g in 1955, 326 g in 1956 and 351 g in an average for the three years.

Along the Pacific coasts, the main catches (74 per cent) for the period between 1954 and 1957 were in the following four Prefectures: Aomori (13.0 per cent), Iwate (6.6 per cent), Chiba (36.9 per cent) and Shizuoka (17.3 per cent). In Chiba ond Shizuoka Prefectures, the most proliferous fishing season occurs in spring and according to the figures of Takano and Hanado (1958), the average body weight of the mackerel landed at Katsuura, Chiba Prefecture, is 367 g during the period from 1954 to 1957. In Aomori and Iwate Prefectures, the mackerel is caught mainly during the season from August to November and its size was between 250 and 850 g, being most abundantly at 350 g.

In the East China Sea Region, the greater portion of mackerel consisted of *Pneumatophorus tapeinochephalus*, however this species has quite similar feeding habits with *P. japonicus* as stated by Yokota and Mita (1958). The two species can be considered together as far as feeding habits are concerned. According to Tanouye (1958), the main portion of the catch consisted of the fish ranging between 320 and 340 mm in fork length, coresponding nearly to 430 g in weight.

The smaller mackerel is abundant among the catches in the Seto Inland Sea and also among the catches by the set-nets along the Pacific coasts.

Considering from the above investigations made in recent years, although they do not always include strictly acurate size-composition, it seems to be reasonable to assume the average body weight of the mackerel caught in Japanese waters to be between 300 and 400 g. Hence, the annual catch of the mackerel becomes 7 to 9×10^8 in number.

Investigations on the growth

Many investigations have been made on the growth of the mackerel, however, at present their results are not always in a good uniformity. This is because the mackerel spawns for a fairly long period in broad area, hence the fish contributing to the fishery consist of various groups from different localities. Moreover the age-marks of the mackerel are said by some investigators to be formed twice a year on the otolith or on the vertebral centrum.

Kasahara and Ito (1953) stated basing on the results of many investigations concerning the growth and age published before 1953 that the average body length of the mackerel in the Japan Sea in summer will fall in the size range between 25 and 30 cm for the second-, between 30 and 34 cm for the third-, and between 34 and 38 cm for the fourth-age group. Yoshihara (1955) found from the year marks of the otolith that the mackerel of the Pacific coasts grow in fork length at the end of the year as follows: for the 0-age group under 20 cm, for the first-, between 20 and 26 cm, for the second- between 26 and 31 cm, for the third- between 31 and 35 cm, for the fourth- between 35 and 38 cm and for the fifth-age group beyond 38 cm.

According to the Report for the Explorations on the Tsushima Currents Waters (1958), the age marks are formed once a year on the scales and twice on the otolith or the vertebral centrum and the mackerel grows in fork length or in body weight as follows: for the O-age group under 160 mm or 57 g, for the first- between 160 and 280 mm or between 57 and 318 g, for the second- between 280 and 350 mm or between 318 and 615 g, for the third- between 350 and 388 mm or between 605 and 803 g and for the fourth-age group beyond 388 mm or 803 g.

Basing on the above mentioned investigations the growth of the mackerel seems to vary considerably and the adult fish will probably gain in a year between 210 and 270 g in body weight.*

Since the mackerel is considered to grow for the period of the three months in summer by half of its annual growth (Fitch 1951, Hatanaka *et al* 1957), the daily growth during this season attains 1.2 to 1.5 g in weight, coresponding to 0.30 to 0.50 per cent in daily rate of growth for the mackerel of 300 to 400 g in body weight. During the rest seasons except for summer, the amount of the daily growth attains 0.38 to 0.49 g, coresponding to 0.10 to 0.16 per cent in daily rate of growth.

These growth rates in nature are considerably inferior to the cases sufficiently fed in the aquaria as stated in the preceding paragraph.

Food consumption of the mackerel in nature

The results already stated are briefly summarized as follows: The average body weight of the mackerel caught in Japanese waters ranges between 300 and 400 g. The average amount of the catch in recent years attains to 270 thousands tons annually. These mackerel feed on small fishes (especially the anchovy) and small squids for the period of the three months between mid-summer and autumn. The daily rate of growth during this period ranges between 0.30 and 0.50 per cent. During the rest seasons of the year the mackerel eat larger-sized pelagic crustaceans, especially *Euphausia*, and grow at the rate of 0.10 to 0.16 per cent to the body weight daily.

If the experimentally obtained results on the relation between the food consumed and the growth made are applied for the calculation on the food consumption of the mackerel in nature, the calculated amount of food will be under-estimated to some extents. And also it is difficult to estimate precisely the frequency of the anchovy occuring in the stomach contents of the mackerel in nature throught the year. However, it will not be over-estimated to consider basing on the above investigations that the mackerel will depend on the anchovy for 50 days in a year.

* According to Enami (1959), the group maturity of the mackerel in the spawning season is estimated as 72 per cent for the second- and 95 per cent for the third-age group and the gonads weight attains more than 20 g for the second- and 30 g for the third age-group. Considering with the discharge of the gonads, the mackerel will grow at least, even in gram weight base, more than the above mentioned weight in a year.

Basing nearly on the minimal estimations, the amounts of the anchovy consumed by the mackerel in nature can be calculated as follows: Applying the daily rate of growth (g=0.30 to 0.50 per cent) of the mackerel in summer to the formula [3], the daily rate of feeding will be calculated as 4.9 to 5.9 per cent. Namely the individual mackerel of 300 to 400 g in weight should at least consume 16.2 to 21.2 g of the anchovy daily in nature to grow at the rate of 0.30 to 0.50 per cent of the body weight. Provided the mackerel depends on the anchovy for 50 days in a year, the commercially caught mackerel of 7 to 9×10^8 in number will consume approximately 700 to 800 thousands tons of the anchovy annually.

Moreover, these mackerel will consume nearly the same amounts of other small fishes except the anchovy. The annual landing of the anchovy is only 350 thousands tons, that is to say, less than half of the amount of the anchovy consumed by the commercially caught mackerel.

During the remaining nine months, the mackerel feed primarily on pelagic crustaceans, such as *Euphausia* and grow at rates between 0.10 to 0.16 per cent to the body weight daily. Applying these rates of growth to the formula [6], the daily rate of feeding can be estimated as 5.6 to 6.3 per cent. Hence, the mackerel of 300 to 400 g in body weight should consume 18.0 to 23.2 g of *Euphausia* daily in nature. The commercially caught mackerel of 7 to 9×10^8 in number will consume 4,300 to 4,700 thousands tons of pelagic crustaceans coresponding to *Euphausia* for the remaining 275 days of the year.

The above amounts of food consumption by the commercially caught mackerel are all based on a minimal or under estimations. The total amounts of the anchovy consumed by the natural populations of the mackerel, amberjack, saurel, tunas, squids and bottom fishes will attain a tremendously large number. On the contrary, the fishing mortality becomes quite small as compared with the natural mortality, hence the regulation of the fishing on young anchovy becomes almost meaningless. The recruitment amounts of the anchovy varies greatly with the variation in the amounts of predation by other fishes situated in the higher trophic level.

Discussions

The amounts of food consumed by the mackerel in nature have been estimated utilizing the results of the feeding experiments schemed to make the conditions similar with nature as regards temperatures, kinds of foods, daily ration, size of fish etc. The first problem involved is concerned with the method which applies the experimental results directly to nature. The activities of the mackerel and also the constitution of the body substances accumulated will differ between nature and experiment in enclosure.

It seems to be difficult to estimate directly the energy expenditures of fish in nature except for the case of salmon during the spawning migration in fasting. Idler and Clemens (1959) estimated the energy expenditures of the Fraser River sockeye salmon by analysing the differences in fat, protein and water contents during the spawning migration to the lakes to be 44.2 Cal/kg/day for the male and 51.6 Cal/kg/day for the female. The salmon in this case are in the most unusual states of life, actively swimming against the stream currents for days and nights and maturing the gonads. In the case of the young mackerel in the aquaria, the energy expenditures at the first day of fasting are estimated as 30 Cal/kg/day as stated before. It is not adequate to compare the results of the salmon during the spawning migration with those of the mackerel in aquaria but the amounts of food consumption obtained from the feeding experiments might obviously result in estimations lower than real values in nature.

The second problem is concerned with the effects of the pattern of feeding, namely the amounts of food taken, the frequency of feeding times and the combinations of different kinds of food. A few experiments performed hitherto showed that their effects are not so important for obtaining the relation between the foods consumed and the growth made because of the individual variations.

The amounts of food consumption by the mackerel should be estimated on the basis of the population size. Tauchi (1940) estimated, utilizing the results of the marking experiments, the fishing rate of the mackerel to be at 0.55 per cent along the Pacific coasts and 0.64 per cent along the Japan Sea coasts. However, the catch amounts of the mackerel in those days were 25 thousands tons in 1926 and 77 thousands tons in 1936 for the Pacific coasts and 27 thousands tons in 1926 and 28 thousands tons in 1936 for the Japan Sea coasts. It seems to be inadequate to apply Tauchi's results for the estimation of the present population.

The amounts of growth and food consumption in this study have been expressed only on the basis of gram weights, however the analysis on the general constituents of body substances of both fish and foods are necessary to be expressed in terms of calorific equivalents and the study is now proceeding.

Enomoto (1956) found that *Noctiluka* will predate on the anchovy eggs spawned in spring in the Kyushu area at the rate of 7 to 67 per cent in number. Ito (1957) stated that the amounts of predation by squids on the sardine-like fishes are nearly proportional to the human catch in the Hokkaido area. It seems to be quite important to promote the investigations concerning the mortality of the anchovy due to predations by other fishes.

Summary

(1) The relation between the food consumed and the growth made have been obtained by the feeding experiments on the middle-sized mackerel fed on the anchovy and / or *Euphausia*. The results combined with those on the young mackerel previously reported show that the efficiencies of food conversion and the apparent catabolic rates decrease in the manner of an exponential-type curve as the fish grow larger. The anchovy is a more favourite food than *Euphausia* for the growth of the mackerel.

(2) In summarizing the many investigations already made on the stomach contents, on the seasonal growth and on the catch amounts of the mackerel in Japanese waters, it was found that the average body weight of the fish among the catch ranges between 300 and 400 g, that the annual landing in recent years attains in an average 270 thousands tons, which is approximately converted in 7 to 9×10^8 in number, that the mackerel depends primarily on the anchovy and other small fishes as food during the three months from the mid-summer to autumn, during this period it grows 0.30 to 0.50 per cent to the body weight daily, that during the remaining nine months the mackerel feeds mainly on larger sized pelagic crustaceans, especially Euphausids, and grows 0.10 to 0.16 per cent daily and that the size and the season of the anchovy predated by the mackerel are over-lapped with those caught by the fisheries.

(3) Basing on the above results, the amount of food consumed by the mackerel caught by the fisheries have been estimated and obtained as a result that they consume yearly 700 to 800 thousands tons of the anchovy and approximately the same amounts of other small fishes and also 4,300 to 4,700 thousands tons of pelagic crustaceans coresponding to *Euphausia*. The annual amounts of consumption of the anchovy by the natural populations of the mackerel, amberjack, saurel, tunas, squids and the bottom fishes attain a tremendously large number as compared with the mortality (350 thousands tons annually) due to fishing, hence the effects of the regulation on the anchovy fisheries become almost meaningless.

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