Thermotaxis of Eel Fry in Stage of Ascending River Mouth

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INTRODUCTION

How fish can notice the way of migration in open sea, or the presence of river mouth to ascend is the interesting problem which has been discussed so long. On the other hand, actual survey of fishing grounds tells some relation between migration and distribution of water temperature or movement of water mass is sea in so many cases though not precisely cleared in any case. However, as far as the author knows, there were few experiments on the thermotaxis of fish. Thus these experiments were undertaken to know thermotaxis of eel fry in stage of ascending river mouth from sea, so as to see that water temperature can be a guide for eel fry to ascend river mouth from sea or not, let aside other conditions of water such as salinity, which seems to be more apparent factor of taxis, and the author may have chance to write it later days. And the results of these experiments were compared with actual water temperature distribution at river mouth in central Pacific coast of Japan of corresponding season of year.

These experiments were carried on by sincere help of Mr. Tadashi YAMAMOTO during nights of Spring of 1942 at laboratory in Tokyo University.

MATERIAL USED

Japanese common eel, *Anguilla japonica*, of the size from 75mm to 90mm in total length, slightly or non-pigmented on body, the stage which we call "shirasu-unagi" (means Eel White Bait), caught at river mouth of Ikawazu, Aichi Prefecture, during night of 1st of March, 1942, is used for these experiments.

The temperature of water they were caught was 12°C, and during eight hours transportation by train to the laboratory, it was cooled down to almost 8°C. They were kept in glass tank in the laboratory during three weeks before the experiment, where water temperature varied from 6 to 12°C before the experiments, and up to 20 during the cource of those.

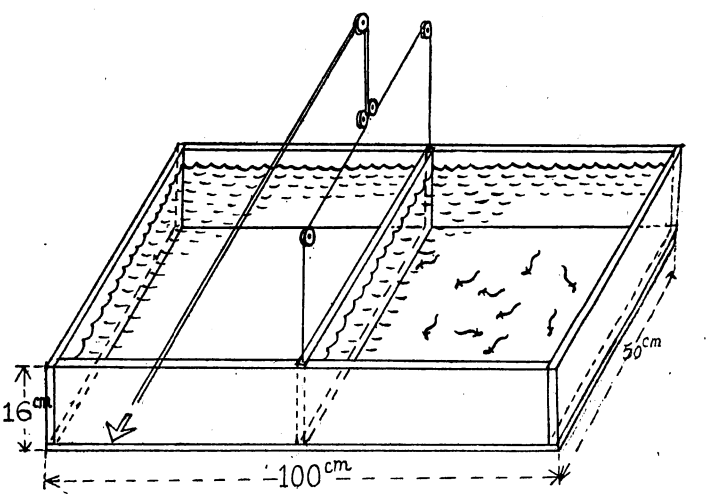

Fig. 1 Apparatus and tank used in these experiments.

At the begining of the transportation, the fish were kept in the natural brackish water where they had been caught, but adding fresh water since then, it turned to pure fresh during transportation and reservation. The water in experiment tank was purely fresh, got from water supply, either heated by burner or cooled by ice to desired temperature.

METHOD OF EXPERIMENT

The tank prepared for these experiments is wooden, painted white inside, and size of which is 100cm×50cm×16cm. (Fig. 1) At the exact center of the tank, a small groove is made, so as to fit a septum board in, which devides the tank into two independent tanks to contain the different temperature water entirely separate from each other.

In each experiment, ten individuals of healthy eel fry were taken from hundreds of them reared in the reserve tank in the laboratory, and put into one of the rooms of the experimental tank where water temperature was kept not so far from that of reserve tank, which was nearly same as air temperature of the room. In another room, neighbouring to the room the fish are in, the water of different temperature was prepared in same depth. After several minutes, the septum board at center, which divides the tank into two rooms, was taken off quietly by aid of string and pulleys, so as to the fish can emigrate into another room freely and naturally without any excitement or disturbance.

Since this time, the number of the fish emigrated in to another room was counted at every 20 seconds during 8 minutes. These numbers were recorded on the graph, regarding the duration of time in each experiment. (Fig. 2) The graph thus made is one of the method to record the tendency of locomotion of fish, which would be more precise to express the movement of fish school than to decide the tendency of behavior by observation only. This sort of method of record is named as "Transferring graph" and first applied for this experiment by the auther, and succeedingly used to determine the effect of fishing net to screen the fish school and others by the author (1948) and by OKA (1948).

To get the "Transferring graph" available to determine the taxis of fish, any condition of the water in both rooms, except water temperature, should be quite equal and same. So, we payed special attention on this matter. However, in some experiments, slightly different results were obtained by changing the room at first the fish kept in, even in the case of the same water was used both rooms. So, we made couple of experiments for comparison, having the same water in both rooms alternatively changing the room at first the fish kept in, either before or after the experiments at each night.

During the course of experiment, the original water temperature of the experiment tank was gradually changed by the influence of air temperature and by the contact with another water mass in neibouring room. So, prior to the experiments for determine the thermotaxis, the author made experiments to see how the two water masses of different temperature would mixd together after the central septum has

taken off, on account of direct contact of two water masses and of fish movement, by using colored water in the same sort of experiment. By this, the author assured that though at the extreme surface and bottom the contact line of both water masses is a little distant from the central line, where the septum had fitted in, but in the region pretty remote from it the condition is quite unchanged. Therefore, if the difference of temperature of the water is limited whthin 4°C, there may be no objection to think the central line is the boundary of two water masses so as to see the tendency of thermotaxis. And also found the difficulty to continue one experiment over eight

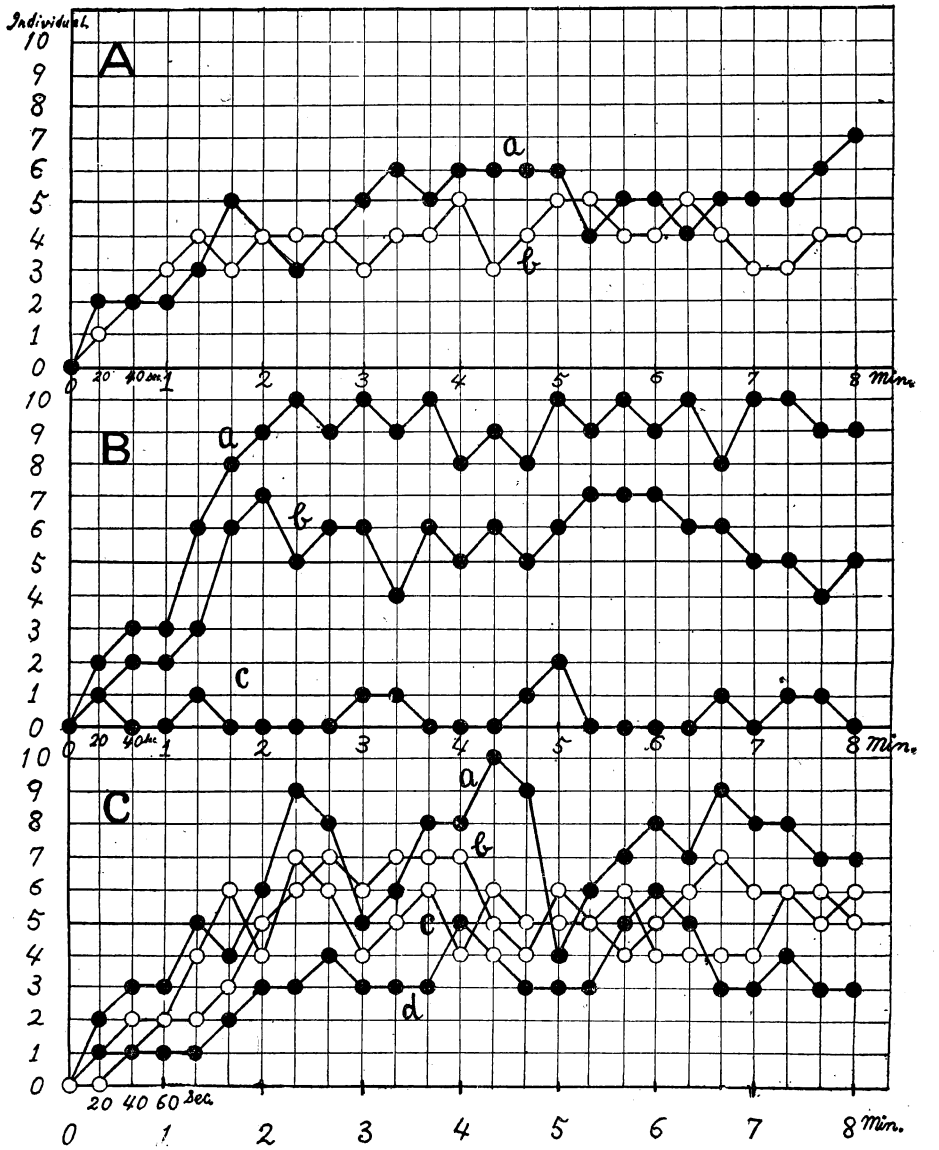

Fig. 2 Examples of "transferring graph".
A. Control experiments, i. e. the same quality of the water in both rooms.
a. From left to right. b. From right to left.
B. a. Type 1. b. Type 3. c. Type 5.
C. b and c. Control Corresponding experiments. a. Type 2. d. Type 4.

minutes as change of water temperature was too fast. Thus, these experiments were done getting various sorts of combination of temperature, from 9.2 to 20.5°C, having the differences of temperature as ± (0.4~4.3° C).

As the movement of eel fry was more active in night than day time, all the experiments were carried on in night under gloomy lump light enough to be able to calculate the number of fish.

These series of experiments were done within 37 days, because the author was anxious about the change of physiological condition of eel fry by growth.

DETERMINATION OF THERMOTAXIS

"Transfferring graph" obtained by the method mentioned above is the material to determine the thermotaxis. In general, if the inclination of the curve at the begining is steep and the whole run of the curve remains above the middle line, like that of B-a in Fig. 2, it would be able to say that in this case this fish have clear tendency of taxis toward another room. On the contrary, if the curve of the graph remains beneath the middle line, it tells that the fish school does not want to go outside of the water being put in at first, as shown in B-c in Fig. 2.

However, in the actural results obtained, so many cases were of intermediate type, so the author classified the tendency of the taxis into five groups, deciding it as follows.

As mentioned in the foregoing chapter, to eliminate the effect of inequality of conditions in both right and left rooms, couple of experiments were done for comparison, having the same water in both tanks, either before or after the series of experiment at each night. The "Transferring graph" of this is used as the standard to compare with each experiment done in same night. As the behavior of the fish school was quite at random, the author had to do the same experiment more than twice for each direction of emigration. The group of standard curve thus gained, as shown in A in Fig. 2, was used as the standard for comparison instead of middle line in the graph, to decide five degrees or types as follows.

Type 1) If the whole run of the curve remains clearly above the band of 2, standard cureve like B-a in Fig. 2, the author thought it has clear possitive thermotaxis, and expressed it as "P" in table and ● in Fig. 3.

Type 2) If it runs partly in or beneath and mainly above the standard curves, like C-a in Fig. 2, it was expressed as "*p*" in the table and ■ in Fig. 3, having less tendency of taxis than above.

Type 3) As in case of B-b in Fig. 2, If the almost whole run of the curve is in the region where standard curves (A-a and b in Fig. 2) run, it can be said that fish has no tendency to prefer either to emigrate or stay, and it was expressed as "*O*" in the table and X in Fig. 3.

Type 4) If it runs partly in or above and mainly beneath the standard curves like C-d in Fig. 2, it was expressed as "n" in the table and □ in Fig. 3. It means in this case the fish has slight tendency to remain in the original water, less obvious than the next degree.

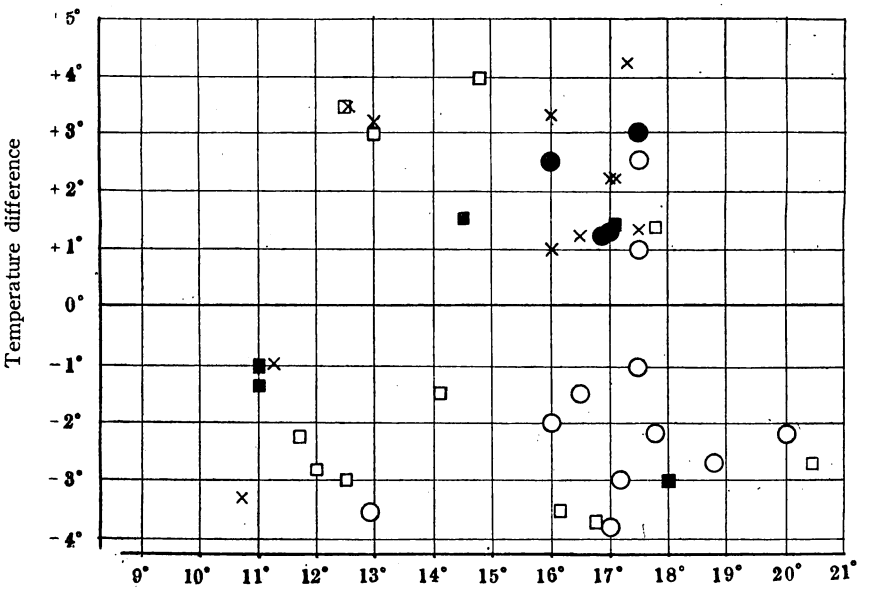

Fig. 3 Results obtained arranged according to the temperature of the start room and the temperature difference to the another room from it.
● Type 1. ■ Type 2. × Type 3. □ Type 4. ○ Type 5.

Type 5) If the nearly entire curve is beneath the band of standard curves, it means the fish school prefers to stay in original water, without any trace of tendency of taxis toward another room. This was expressed as "N" in the table and ○ in Fig. 3.

This is merely a conventional classification of the degree of taxis, and far from the precise expression. Actually the auther had difficulty in some cases to decide by the definition above mentioned. However, speaking roughly, it would not be so far from the fact to know about the general tendency of thermotaxis by this method.

THE RESULTS OBTAINED

The results obtained by the way thus mentioned are shown in the table and Fig. 3. It would be able to consider this as follows.

1) In cases the water temperature of reserve tank and that of start room (means the room the fish kept at first) is low (about 11° C), the fish prefers to emigrate to cooler water.

2) On the other hand, (upper and left hand of the graph of Fig. 3. the temperature of the water is high, (about 14 to 19° C) the fish has tendency to go toward warmer water.

3) When the fish kept in the water of 12 to 14° C, as shown at the middle part of the graph of Fig. 3, the fish prefers to stay in original room, without any tendency to go toward either cooler or warmer water.

How slight difference of temperature of water fish can notice is not the problem to be cleared by these experiments. Because in the contact part of two water masses temperature gradually and continuously changes from one to other, so the fish would pass through this part during the course of emigration. At least, it is under 1° C by these experiments, as the least difference of temperature themotaxis was seen is 1° C.

Date of Experiment	Temp. of rearing tank °C	From which room fish started	Temp. of start room at beginning. °C	Temp. of start room at end. °C	Temp. of the another room, at beginning. °C	Temp. of the another room, at end. °C	Difference of temp. between two rooms. °C	Types of taxis, decided by Transferring graph.
22th Mar.	14.5	L	13.0	13.3	16.2	15.5	+ 3.2	O
〃	〃	R	13.0	13.2	16.0	15.3	+ 3.0	n
〃	〃	R	12.5	13.0	16.0	15.2	+ 3.5	n
〃	〃	L	12.5	12.8	16.0	15.6	+ 3.5	O
25th Mar.	17.0	R	16.5	16.8	17.7	17.2	+ 1.2	O
〃	〃	R	17.0	17.2	18.2	18.1	+ 1.2	P
〃	〃	L	17.5	17.5	18.8	18.2	+ 1.3	O
〃	〃	L	17.8	17.8	19.1	18.2	+ 1.3	n
〃	〃	L	17.5	18.0	20.0	19.2	+ 2.5	N
〃	〃	L	18.0	16.8	15.0	16.2	− 3.0	p
31st Mar.	12.5	L	12.9	12.2	9.3	9.8	− 3.6	N
〃	〃	L	12.5	12.0	9.5	9.8	− 3.0	n
〃	〃	R	11.0	10.8	10.0	10.1	− 1.0	p
〃	〃	R	11.0	10.6	9.7	9.8	− 1.3	p
〃	〃	R	10.7	11.2	14.0	13.0	+ 3.3	O
〃	〃	L	12.0	11.5	9.2	9.5	− 2.8	n
〃	〃	L	11.7	11.4	9.5	9.8	− 2.2	n
〃	〃	L	11.2	11.0	10.2	10.2	− 1.0	O
13th Apr.	16.5	R	16.0	16.0	14.0	14.2	− 2.0	N
〃	〃	R	16.5	16.4	15.0	15.0	− 1.5	N
〃	〃	R	17.5	17.5	16.5	16.7	− 1.0	N
〃	〃	R	17.2	17.0	14.2	14.8	− 3.0	N
〃	〃	R	17.5	17.5	18.5	18.5	+ 1.0	N
〃	〃	R	17.8	17.5	15.6	16.6	− 2.2	N
14th Apr.	14.5	R	14.5	14.6	16.0	15.6	+ 1.5	p
〃	〃	R	14.8	15.0	18.8	17.1	+ 4.0	n
〃	〃	L	16.0	16.2	19.3	18.2	+ 3.3	O
〃	〃	L	17.0	17.0	19.2	18.8	+ 2.2	O
〃	〃	L	16.0	16.2	17.0	16.8	+ 1.0	O
〃	〃	L	16.0	16.0	18.5	18.0	+ 2.5	P
16th Apr.	15.0	L	16.9	16.9	18.1	17.5	+ 1.2	P
〃	〃	R	17.1	17.1	18.5	18.0	+ 1.4	p
〃	〃	L	17.3	18.5	21.5	19.2	+ 4.2	O
〃	〃	R	17.1	17.3	19.3	19.0	+ 2.2	O
〃	〃	L	17.5	17.8	20.5	19.3	+ 3.0	P
17th Apr.	13.0	L	16.8	16.2	13.1	13.2	− 3.7	n
〃	〃	L	17.0	16.5	13.2	13.5	− 3.8	N
〃	〃	L	14.1	13.8	12.6	12.8	− 1.5	n
〃	〃	R	16.2	15.7	12.7	13.0	− 3.5	n
28th Apr.	20.0	L	18.8	18.8	16.1	17.0	− 2.7	N
〃	〃	R	20.5	20.5	17.8	18.5	− 2.7	n
〃	〃	L	20.0	19.8	17.8	18.1	− 2.2	N

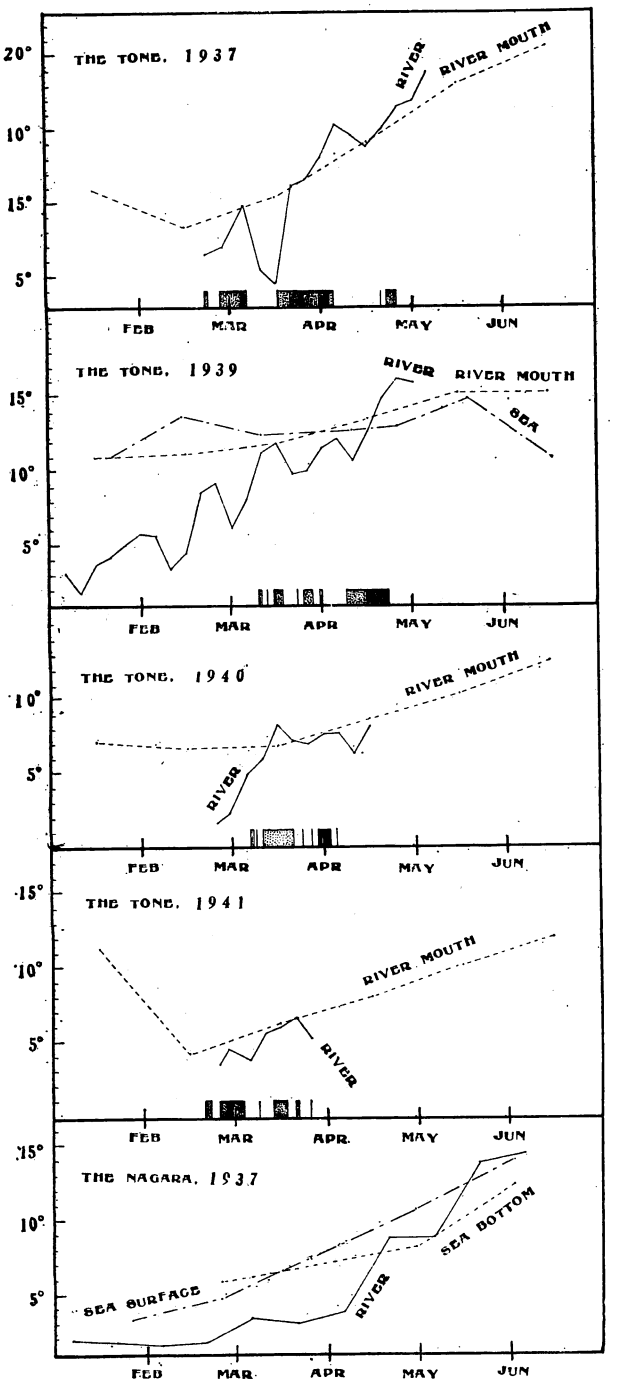

Fig. 4 Change of water temperature in Spring time, hoth river and sea. and the abundance of eel fry (dots in square) got by experimental fishing is compared. Source:-The Tone. water temperature of river is measured at Ushibori, 40km distant from river mouth, by Ibaraki Prefectural Fisheries Experimental Station. The abudance of ell fry is measured at same locality and by the same organization. The water temperature of river mouth and sea is measured by Marine Meteological observatory, the former at Choshi and the latter at the point 5 miles off from there. The Nagara. Data got by Marine Mete ological Observatory. That of river is at Nagara Bridge, 40 km up from the mouth, qy Mr. Y. Matsudaira (Journal of Oceanography Vol. 12, No. 3, 1940, p. 409) That of sea is at Himaka, about 100 km off from the mouth.

COMPARISON OF THE RESULTS WITH NATURAL CONDITION

The tendency of thermotaxis of eel fry thus obtained as the results of these experiments shows interesting coincidence with the fact we know about the temperature of the water when and where eel fry ascend river from sea.

In general, water temperature of river is lower than that of sea in Winter, and higher in Summer. In some days of Spring time the water temperature of both river and sea should be nearly the same in general speaking. The eel fry in central part of Pacific coast of Japan comes to river mouth in Spring time, usually from late Feburuary to early June, most abudantly in March and April. During the season they push to river mouth, there is the time when the two thermal curves of river and sea water should cross each other, i. e. when the same water temperature in river and sea.

The data of survey on water temperature about two rivers, the Tone in Ibaraki prefecture and the Nagara in Aichi prefecture, and those of neibouring

sea water, got from several sources were cmpiled and shown in Fig. 4. These data can be able to represent the general tendency of change of water temperature in this season at this area.

Seeing these graphs, it can be roughly said that the water temperature of when both river and sea is same is usually about from 11° to 14° C, mostly from 12° to 13° C, and it is about from middle of March to middle of April, when usually the eel fry most abundantly push to river mouth.

This fact has close coincidence with the evidence of the thermotaxis got as the result of the experiments mentioned in foregoing chapters. That is, if the fish are originally in cold (about 11° C) water, they have tendency to go to more cooler water, as river water in early season. On the contrary, if they are in warmer water (over 14° C) as sea water in later season, they prefer to go to warmer water like river water of this season. While, if the temperature of the water is between these extremity (about 12 to 13° C), as that of the middle of the season when eel fry push to river mouth, and that of both river and sea water are the same, the fish behave to prefer to stay in original water without showing remarkable taxis.

By these evidence, although other factors such as change of salinity or presence of currents of water would be considered as well as water temperature, thermotaxis of eel fry is one of the factor to let them ascend river mouth from sea. In other words, this is one of the causes of river-ward migration of eel fry.

The author is waiting the chance to do same sort of experiment on other factors, salinity and current, and also about other kind of fish of same anadromous character like *Plecoglossus altivelis* later on.

The author is in the circumstance hard to find out foreign literature to refere on this problem by now, and waiting information and criticism.

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