DIURNAL RHYTHM OF THE FEEDING ACTIVITY OF GOLDFISH IN WINTER AND EARLY SPRING

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From the view point of fish culture, it is an important problem to investigate the feeding activity with which fish begin to feed in such special seasons as winter and early spring. In such a meaning, it is worthy to mention that Kinoshita[1] has discussed the existence of correlation between the initiation of the feeding behaviour in early spring and the environmental water temperature in wrasse-fish. Krayuhin[2] has reported also that the feeding-latent period in carp varies considerably corresponding to change either rise or fall in the water temperature. Additional to these works, some careful studies have been reported with the purpose of rationalizing the various problems in fish-culture.[3]-[6]

The writer has reported his studies made concerning the influence of the environmental factors on the pattern of the feeding activity of goldfish in autumn and early winter, using an automatic fish feeding apparatus.[7] In the present paper, similar studies made in winter and early spring are described.

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MATERIAL AND METHOD

All the experiments were performed in a greenhouse of the Faculty of Fisheries; the kymographic records of the fish feeding were taken every day during the period from January 9 to April 2, 1956. The size of the tank used is approximately 140 cm long, 70 cm wide and 45 cm deep. The depth of the water was maintained at about 35 cm, a little well-water flowing into the tank. Throughout the present experiment, 30 goldfishes one year old were used. The average total body length of them was 52 mm at the outset of the experiment and 62 mm at the end.

The feeding activity was investigated using the feeding recorder as indicated in the preliminary report,[8] and the relative value of the said activity was judged by the feeding frequency recorded on the kymograph. That is, to obtain the feeding records automatically, a bait box was suspended about at the center of the tank of water to tempt the fish to peck it. Minced crustacean larvae were used as food throughout the present experiment. The bait was changed every day for the fresh material which had been proved

preliminarily in quantity sufficient for a day's ration. As already stated in the previous paper,[8] the disturbance of the feeding behaviour by the changing of the bait was negligible.

RESULTS

Diurnal rhythm of the feeding activity in winter and early spring

The daily frequency of the feeding was highly variable. So, to show the general appearance of the diurnal rhythm of the feeding activity, the average frequency per hour was calculated for every ten-day period of the months during which the observations were continued. The results are illustrated in Figs. 1 and 2. As is clear from these figures, the feeding activity in the period shown in Fig. 1 is much lower than that of Fig. 2. Therefore, from the ecological point of view, the writer called the period of the former case (Fig. 1) "winter" and that of the latter case (Fig. 2) "early spring" in the feeding activity of the goldfish in Hakodate.

As already reported in the previous paper,[8] the feeding activity of the goldfish in the seasons of the autumn and early winter was found to decrease gradually with days. However, in the period from winter to early spring, such activity was found to increase suddenly, especially, after the second decade of March. That is, until the last decade of February, the feeble daily feeding is almost restricted to a few hours from about the 13th hour to the 15th, in which time the water temperature was highest. Further,

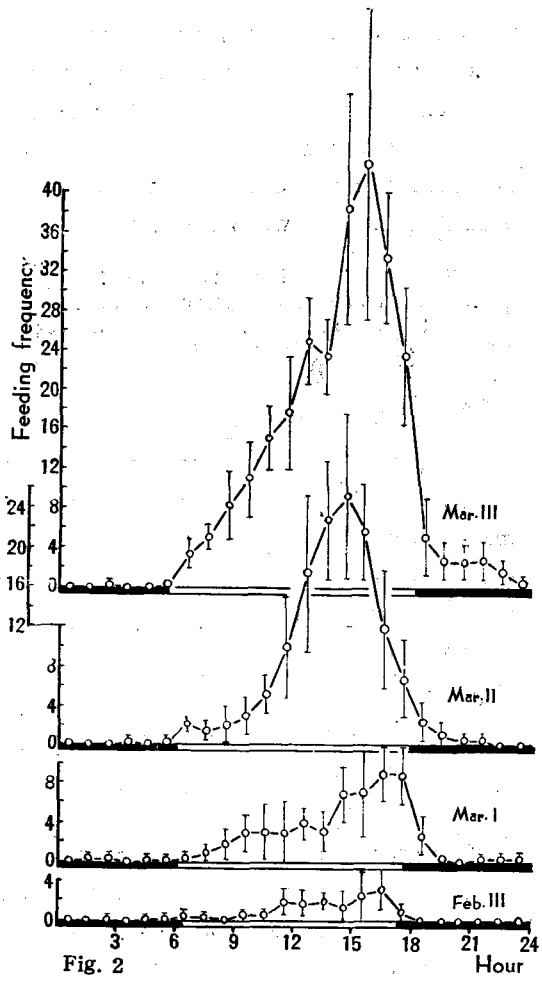


Fig. 1 & 2. Time and diurnal rhythm of the feeding activity in the goldfish are shown in the average of every decade of days from January to February. The Roman numerals I, II and III mean the first, middle and last decade of every month, respectively. Each bar indicates the standard deviation of the feeding frequency.

the writer has considered that it is doubtful whether all the feeding records obtained in this special season are those which were marked by the actual feedings or only recorded by accidental touches of the fish body to the bait box. At any rate, it can be said that the feeding of the goldfish almost ceases in the "winter" season.

Then, with the passage of the season from winter to early spring the feeding of the fish becomes active suddenly, being highly accentuated after the second decade of March. Such a relationship will be seen also in Table 1.

Table 1. Daily fluctuation of the feeding frequency of the goldfish in the period extending from the first decade of January to the first decade of April. Number and the mark "+" mean that the recording was interrupted in the course of the experiment on that day.

Month	Decade \ Date	1	2	3	4	5	6	7	8	9	10	11
Jan.	I	—	—	—	—	—	—	—	—	7+	1	
	II	21	5	27	18	10	1	2	5	1	16	
	III	13	8	3	6	8	23	24	10	1	3	1
Feb.	I	4	8	15	16	1	2	3	1	1	2	
	II	0	0	0	1	0	0	6	3	11	5	
	III	30	25	15	17	18	21	12	5	10		
Mar.	I	24	39	36	28	31	48	56	40	160	75+	
	II	24	208	56	464	56	—	—	—	—	—	
	III	134	449	497	245	72	34	182	362	464	359	266
Apr.	I	111	13+	—	—	—	—	—	—	—	—	

The general appearance in the diurnal rhythm of the feeding activity in winter is slightly different from that of the autumn and early winter. In the autumn and early winter, the feeding begins one or two hours before sunrise, and reaches the peak in the time from about the 11th hour to the 15th. While in the period of winter and early spring the feeding begins a few hours after sunrise, and reaches the peak at the time of sunset, though the times of the peaks in the period of the middle and last decades of March are found to approach to those of the autumn and early winter.

Correlation between the feeding activity and the environmental factors

As stated in the former section, the feeding becomes active with the passage of the seasons from winter to early spring. Feeble feedings were found, even in the winter season, to occur in the period when the water temperature showed the highest degree. Considering from these facts only, it seems to be clear that the water temperature is one of the most important factors effecting the feeding activity, at least, in the seasons of winter and early spring.

Generally saying, in these seasons the feeding of the goldfish begins at the time of

sunrise and ends at the time of sunset, i. e., it is restricted to the daylight hours. Consequently, it is clear that the diurnal rhythm of the feeding is closely associated with light environment.

An analysis was made concerning the correlation between the feeding activity in these seasons and the other environmental factors, in addition to the factors of light and water temperature.

Feeding activity in winter

An example is given in Fig. 3 to show the correlation between the feeding activity and certain environmental factors. The feeding frequency in winter is very low though

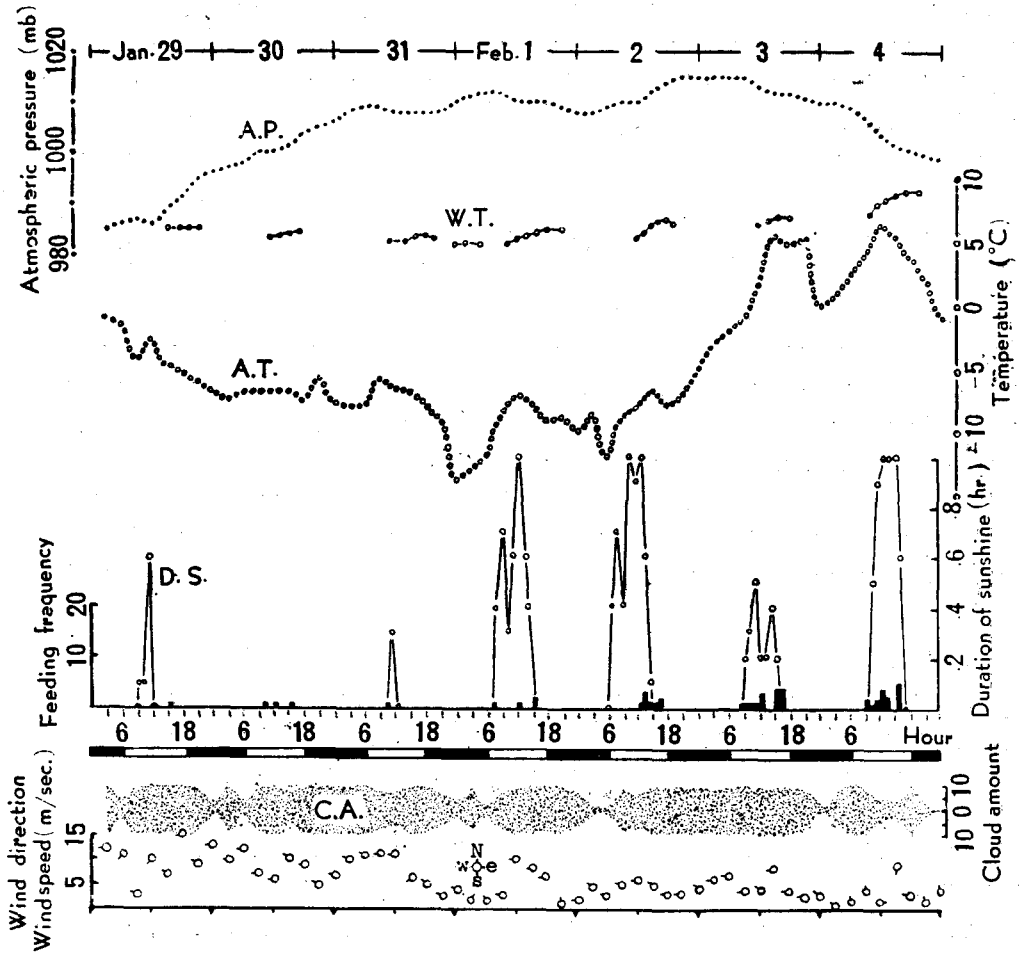


Fig. 3. An example of the diurnal rhythm of the feeding activity in the goldfish in winter, in relation with the environmental conditions. Environmental factors; o-o-o-o-o-o water temperature (W. T., C°); oooooooo air temperature (A. T., C°), o——o duration of sunshine (D. S., hours); ••••••• atmospheric pressure (A. P., mb), ▨ cloud amount (C. A., every-hour index of 0-10); ◇ wind speed (m/sec.) and wind direction.

10 times or more were often recorded. During the days from January 29 to 31, only 1–3 times of the feeding were recorded. As a sharp depression of the atmospheric pressure occurred on January 28 and 29, that factor might have influenced the feeding activity of those days. According to the previous study,[8] the supernormal feeding was usually found to occur following the recovery of the depression of atmospheric pressure, if the other environmental factors are favorable for feeding. However, such a supernormal feeding was found neither on January 29 nor on the 30th. From these circumstances, it is considered that the feeding activity of these days decreased possibly owing to the occurrence of some other unfavorable environmental factors. The maximum water temperature during the days from January 29 to February 1 was below 6.5 °C. From February 2 onward, the water temperature begun to rise just a little, the maximum value of February 4 showing 8.4 °C. Even because of such a slight rise of the water temperature it appears that the fishes became a little more active. The assumption will be supported by the fact that 15 and 16 times of feeding were recorded on February 3 and 4 respectively. So, some combination of the environmental factors which bring about elevation of the air temperature is considered to exert an important influence upon the feeding in winter. Possibly, the gradient of atmospheric pressure and increases of both solar radiant energy and duration of sunshine may be cited as such factors. However, as is clear from Fig. 2, at least in the winter season, the water temperature does not always rise corresponding to increase of the duration of sunshine. Consequently, of the three factors cited above, the gradient of the atmospheric pressure may be a principal factor which encourages the active behaviour of the fish in the last phase of the winter season. The feeding activity of the goldfish in winter may be said to be severely inhibited or to be forced to the state of complete cessation by low water temperature, and the fishes appear to feed a very little only in the environmental conditions which are exceedingly favorable for their life in this special season.

Feeding activity in early spring

Fig. 4 presents an example of the correlation between the feeding activity in early spring and the environmental factors. The daily feedings within the three days from March 22 to 24 showed more than 245 times (cf. Table 1). The water temperature during these days was high, that of the daytime showing more than 9 °C. The duration of sunshine was 3.2, 7.8 and 10.5 hours respectively. The atmospheric pressure varied through these three days without any marked fluctuation.

The feeding activity was severely depressed on both March 25 and 26, though the water temperature during these days did not appear to be different from that of March 22, showing equally more than 9° C. The duration of sunshine was 0 and 0.8 hours respectively. The atmospheric pressure continued throughout these days with a relatively low value. A combination of the depressions of the atmospheric pressure, duration of

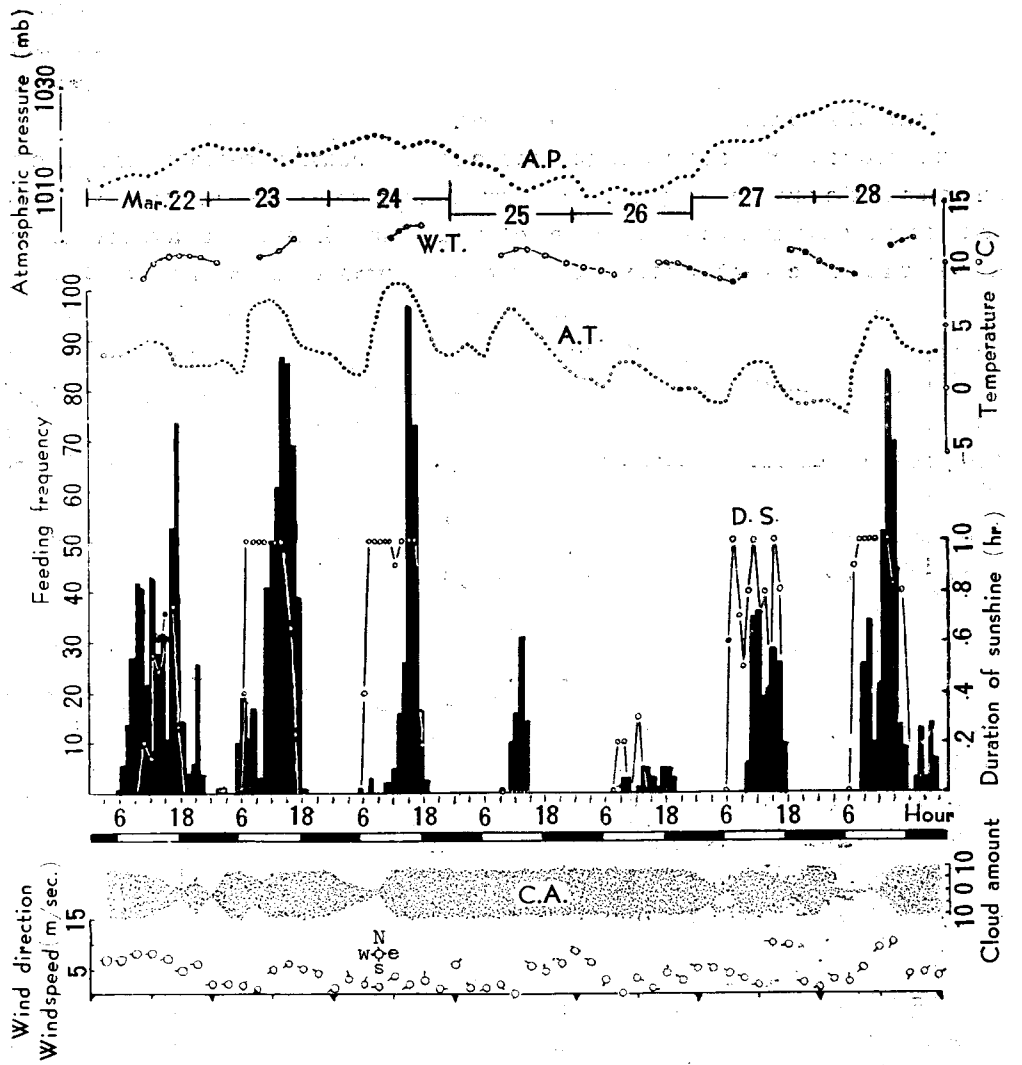


Fig. 4. An example of the diurnal rhythm of the feeding activity in the goldfish in early spring, in relation with the environmental conditions. Environmental factors; o-o-o-o-o-o water temperature (W. T., C°); oooooooooo air temperature (A. T., C°); °——° duration of sunshine (D. S., hours); ••••••• atmospheric pressure (A. P., mb); cloud amount (C. A., every-hour index of 0–10); ⊹ wind speed (m/sec.) and wind direction.

sunshine and some other factors might have caused a lowering of the air temperature in comparison with that of the preceding days. Possibly, it seems that such a decline of the weather as a whole might bring about the depression of the feeding activity of these days.

Following the cloudy days of March 25 and 26, it was fine for several days consecutively. In company with such a recovery of the weather, the feeding frequency

increased very distinctly as shown in Fig. 3 and also in Table 1. On March 27 and 28, the water temperature in the daytime showed more than 11 °C. The duration of sunshine of those two days was 8.4 and 9.5 hours respectively. The atmospheric pressure remained steady with a high value throughout these days.

It is presumable from these facts that the feeding activity in the season of early spring or in the period when the said activity is in the state of increasing phase, may not be so severely distorted as either in the period of falling phase such as autumn and early winter or as in the winter season, even if the environmental factors change considerably,

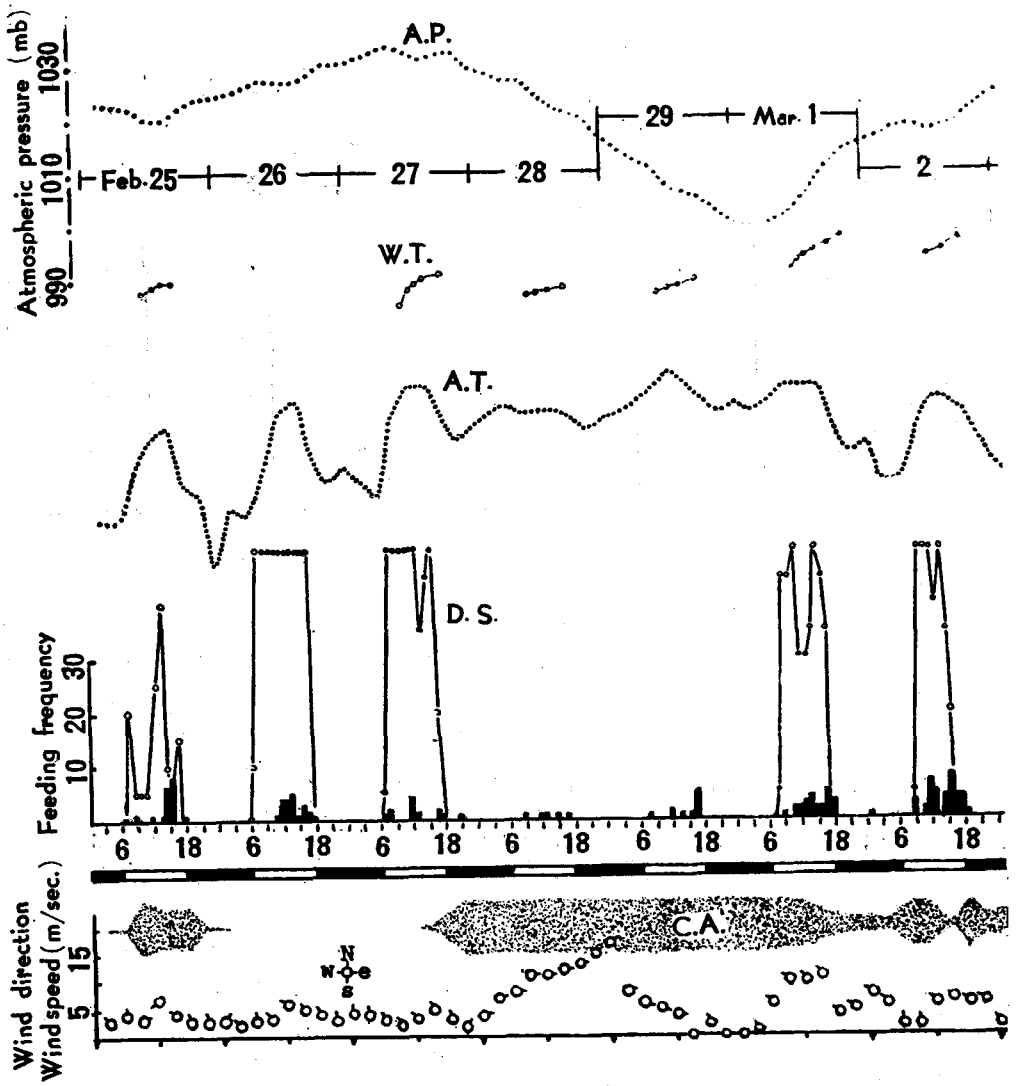


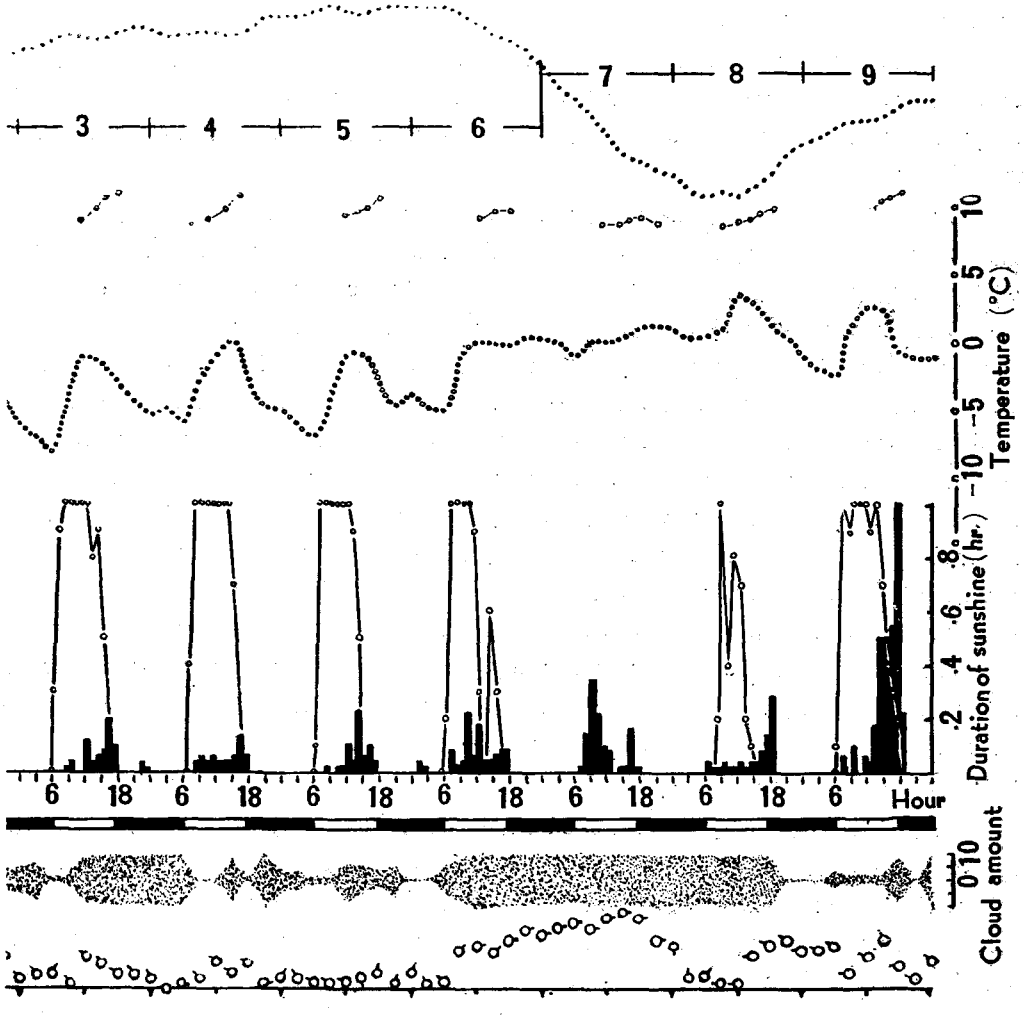
Fig. 5. An example of the diurnal rhythm of the feeding activity in the goldfish factors; o-o-o-o-o-o water temperature (W. T., C°); oooooooo air temperature (A. T., C°); cloud amount (C.A., every-hour index of 0-10); ◇ wind speed (m/sec.) and wind

in case the inititiation of the feeding has once started vigorously.

Initiation of the feeding activity in early spring

In view of food-supply for fish, it is an important problem for the fish-culturists under what environmental conditions the goldfishes begin to feed in early spring waking from the long period of hibernation in winter.

As indicated in Table 1, until about February 20 the fishes almost did not feed. But, in the period from the last decade of February to the first decade of March, the daily feeding frequency increased gradually with the days within the approximate range



in winter and early spring, in relation with the environmental conditions. Environmental
o——o duration of sunshine (D. S., hours); ••••••• atmospheric pressure (A. P., mb);
direction.

of 20 to 30 times. Following such a transitional period of activity, the distinct recovery was found to occur with the daily frequency more than 50 times. Thereafter, it was not rare that the daily feedings are beyond a few huudreds.

Fig. 5 shows the correlation between such a transitional pattern of the feeding activity and the environmental factors. In the period from February 25 to March 1, 5–24 times of feeding were recorded. The water temperature of the daytime during this period varied within the range of about 7–9 °C, except for March 1 on which day the maximum water temprature showed as high as 12 °C. Such a temperature as 12 °C was the highest degree during the neighbouring days. Yet, the feeding frequency of this day was small in number, recorded as only 24 times.

The decrease of the feeding activty on both February 28 and 29 might mainly be caused by the bad weather such as the sharp depression of the atmospheric pressure from about 1028 to 1000 mb and the lowering of the duration of sunshine which showed almost zero on both days.

In the period from March 2 to 8, the feeding activity increased gradually, and on March 9 the said activity rose up suddenly being recorded as 160 times. Analyzing the environmental factors which may have induced such increase of the said activity, every one will first notice the fact that the fine days continued from March 2 to 6. The maximum water temperature during these days was about 11°C. The duration of sunshine varied showing high values in the range of 6.0–8.4 hours. Meanwhile, in the afternoon of March 6, a snow storm came on, accompanied with a sharp depression of the atmospheric pressure from 1032 to 997 mb and also with the lowering of the duration of sunshine to zero on March 7. However, the feeding activity was not depressed on those days; as already reported in the previous paper the said activity in all cases, at least, in those studied in autumn was severely distorted by such a sharp depression of the atmospheric pressure. Consequently, at first glance, this case appears to be somewhat exceptional. But, it will be recognizable from Fig. 5 that in the period of the snow storm the air temperature rose to 0°C, possibly resulting from the change of the wind direction. Such a compensatory factor might prevent depression of the feeding activity which would bo expected to occur.

A high feeding activity was recorded on March 9. This may be said to be a distinct recovery of the feeding from the hibernation period of the fish. Possibly, such a recovery might mainly be resulted from some favorable environmental conditions such as the fine weather of the consecutive five days from March 2 to 6. So, if the bad weather of March 7 had not occurred, recovery of the feeding activity might have occurred earlier, for example, on March 7 or 8. Considering from these facts and also from the assumption described above, it seems that recovery of the feeding activity of the goldfish occurs following good weather of several consecutive days, under the condition of a water

temperature higher than 10°C.

DISCUSSION

Recently, Kariya[4] emphasized the importance of study of the feeding activity in fish culture. The writer has stated in his preceding paper[8] that the studies on the feeding rhythm in fish are important from the view point of food-supply for all fish-culturists. Although the writer is now working on the perfection of an automatic recording apparatus available for field investigations, even the apparatus used in the present experiment was useful to analyze the approximate tendency of the feeding activity in relation to the environmental factors.

It is considered that as the goldfishes in the tank of water are surrounded by many factors such as micro-organisms, chemical solutions, physical forces and so on,[9)-11)] the diurnal rhythm of the feeding activity also is influenced by them.[6),12)] Accordingly, relationship between the said activity in the goldfish and the environmental factors must be studied in detail in future. However, in agreement with the results of Spoor's experiment in goldfish,[6] it can be said from the present results that the feeding activity in the goldfish shows a distinct diurnal rhythm, and also that an annual variation of the said activity is clearly recognizable. The present finding seems to be noteworthy from the fish cultural point of view that the young goldfish waking from the winter hibernation begins to feed in early spring when the water temperature rose to more than 10°C. However, besides the circumstances described above, it appears to be essential for the initiation of the feeding in early spring that good weather continues for several days. It was clarified that the water temperature for encouraging the initiation of the feeding of the goldfish in early spring is a little higher than 8.5°C at which temperature they cease to feed in early winter. With regard to fish feeding in relation to the water temperature, Krayuhin[2] has found that feeding-latent period at the water temperature of rising from 4° to 10°C was longer than that of falling from 10° to 4°C, in the experiment of carp one year old. Kinoshita[1] has stated in his paper that in wrasse-fish the feeding initiates at a temperature higher than that at which they begin to hibernate. Therefore, the present results are in agreement with the findings of the previous workers who have studied on other species of fish.

In both seasons of winter and early spring it was ascertained that the water temperature is the most important factor controlling the feeding activity of the goldfish. The air temperature, solar radiant heat and duration of sunshine are considered respectively to be factors of the temperature environment. However, it appears that so far as the seasons of winter and early spring are concerned, the air temperature is the major factor in the temperature environment. In such a meaning, it is presumable that measurement of the gradient of the atmospheric pressure, the wind direction and some other factors

may produce change of the air temperature environment is necessary in any analysis of the correlation between the feeding activity in fish and the environmental factors. Having such a purpose in mind, investigation in this field is now in progress.

SUMMARY

1. Using an automatic recording apparatus, the feeding activity of the goldfish was studied in the period from winter to early spring.

2. It was clearly found that the feeding rhythm in these seasons is slightly different from that of the autumn and early winter already reported in the preceding paper. That is, in winter, the very feeble feedings are found to be restricted definitely to the time of the beginning of the afternoon at which time the water temperature showed the highest degree. In early spring, the said activity rises suddenly with a marked increase of the feeding. In such a period, the feeding begins after sunrise, reaches the peak from about the 13th hour to the 18th, and ends one or two hours after sunset.

3. In the period of winter and early spring, the water temperatue appears to be the most important factor which influences the feeding activity. In winter, even if the duration of sunshine is apparently favorable for feeding, it was not rare that only few feeding records were found. So, it may be presumable that in winter and also in early spring the air temperature is a main factor which causes change of the water temperature. For analysis of the correlation between the feeding activity in fish and the environmental factors, it seems to be also necessary to study such causes of change in the air temperature environment as gradient of the atmospheric pressure and wind direction.

4. Initiation of the feeding of the goldfish in early spring occurs on some days after fairly fine weather has continued for several days under the condition of the water temperature being higher than 10°C. Preceding such recovery, a transitional period of the feeding was found to occur under the conditions such as that the environmental factors, especially, the water temperature shows a distinct increasing phase. It appears that in such an improving phase of the environmental conditions the feeding activity is not so severely distorted by any unfavorable environmental factors as in the case of falling phase of feeding activity.

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