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THE DAILY ROUTINE OF CHANNEL CATFISH, *ICTALURUS PUNCTATUS*, IN CULTURE PONDS

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THE DAILY ROUTINE OF CHANNEL CATFISH, *ICTALURUS PUNCTATUS*,

IN CULTURE PONDS

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THE DAILY ROUTINE OF CHANNEL CATFISH, *ICTALURUS PUNCTATUS*, IN CULTURE PONDS

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ABSTRACT

Three distinct behavior patterns were recognized in the daily routine of channel catfish in culture ponds: (1) occupancy of a home area, (2) daily trip to the feeding station, and (3) feeding. When the fish were not in home areas they were going to or from the feeding station by specific routes or swimways.

Home areas were relocated from deep to shallow areas or from shallow to deep areas depending on the temperature conditions. In the spring and fall, home areas were in shallows but during summer and winter they were in deeper parts of the pond. Likewise, fish seasonally adjusted their swimways. Perimeter swimways were used during spring, but were discontinued for direct swimways when water temperatures reached 18 C.

Throughout most of March to October, marked fish made a daily trip to the feeding station. In the spring, fish did not utilize demand feeders until temperatures were 12 C. Fish stopped demand feeding in the fall at approximately 15 C, following an abrupt decrease in temperature of approximately 11 degrees (C).

In the spring, intermittent feeding appeared to be primarily

temperature related. At cold temperature fish did not feed daily. Fish shifted feeding periods from midday to evening as the feeding season progressed. The shift is exlpained by the fish becoming acclimated to increasing temperature and selecting for warmer temperature.

During summer, low oxygen concentration often caused fish to adjust or miss their daily feeding period. Feeding was reduced at oxygen values below 5 mg/l, but small fish occasionally fed at values as low as 2 mg/l since they were acclimated to feeding at low values.

Contacts between different sizes of fish at the feeding station established a feeding hierarchy and subdominant fish often waited to feed. Large fish were dominant in feeding and sex did not appear to be a factor in determining feeding status. Length of waiting to feed ranged from 0 to 3 hr for the larger fish and from 0 to 12 hr for the smaller fish.

INTRODUCTION

A major part of the daily routine of an animal is feeding and likewise the kind of food and method of feeding are important steps in its domestication. Channel catfish (Ictalurus punctatus), an important game and food fish, have been reared in ponds since before the turn of the century by state and federal governments. However, commercial production was virtually unknown before 1957 and its development was first launched on the research efforts of Clemens and Sneed working with Saltonstall-Kennedy funds from 1955 to 1959 (U. S. Dept. of the Int., 1973). Now channel catfish are commercially reared in over 54,000 acres in 21 states (Mayo Martin, 1975, personal communication).

Studies of channel catfish have been concerned more with the kind and amount of food and method of feeding rather than with the responses of the fish which cannot readily be seen in the turbid waters of culture ponds. Clemens and Sneed (1957), in a study of the reproductive behavior, observed a discontinuation of feeding during spawning season. Hastings et al. (1972) monitored the use of demand feeders by channel catfish in culture ponds, Knable (1972) studied the effects of size and sex upon food intake of caged channel catfish, and Konikoff and Lewis (1974) examined the contribution of behavior to variations in weight gain of channel catfish in cages. However, these studies did not describe the daily routine. Stevens and Tiemeier (1961) followed the daily movements of marked channel catfish in a farm pond and noted that fish spent most of their time in a particular area of the pond but swam at random during certain periods of the day.

Feeding activity and food habits have been recorded for channel catfish in other than culture habitats (Bailey and Harrison 1948; Bonnean et al. 1972; Busbee 1968; Mathur 1970; Spencer 1939). Most studies of the influence of environmental factors on channel catfish have been limited to metabolism or growth (Allen and Strawn 1968; Andrews and Strickney 1972; Chowdhury 1971; Shrable et al. 1969) and have not examined the effect of these factors on the daily routine.

In my study channel catfish were marked and followed throughout the course of a day, for several days during each month of the growing season. In doing so, the daily routine of channel catfish was determined. I examined environmental factors influencing the daily routine, such as temperature, oxygen, and noises as well as biological factors, such as size, sex, and population density. Behavior was observed in aquaria, small pens, and large culture ponds to provide a comprehensive understanding of the daily routine.

DESCRIPTION OF THE STUDY AREA

Observations and experiments were conducted at two locations. From February, 1972 to March, 1973, the daily routine and behavior of channel catfish were observed and monitored at Sooner Fish Farm, Norman, Oklahoma (in eight 1.6 ha ponds) and from November, 1972 to October, 1973, at the University of Oklahoma Fisheries Research Center, Noble, Oklahoma (in a 0.1 ha pond and in 190 and 1590 liter aquaria).

The 1.6 ha ponds had mud bottoms and a water-depth gradient of 0.3 to 1.2 m. They were supplied with water from a well having a capacity of 5677 lpm. Each pond had a 30.5-cm draim which also served to regulate the water level. The banks of the ponds were covered with grass and weeds, with the top of the dike serving as a road. Food was distributed to the fish at a single feeding station (Fig. 1), with 2 to 6 demand mechanisms enclosed in a feeding chamber (1.2 x 1.2 m). The entrance to the feeding chamber was 0.3 x 1.2 m, and was located on the side of the feeding station opposite to the pond bank. Once inside the feeding chamber, fish had access to any of the demand mechanisms.

The 0.1 ha pond had a mud bottom and a water-depth gradient of 0.3 to 0.9 m. It was supplied with water from a well having a capacity of 1136 lpm, and had a 15.2-cm drain. The banks of this pond were also covered with grass and weeds. The pond was divided into several pens with 0.4-cm mesh poultry wire. Each pen was equipped with one or more feeding stations that had single demand mechanisms but no feeding chambers.

Fish kept in aquaria were supplied with aerated water which was exchanged at weekly intervals. Temperature was maintained at 30 ± 2 C except for a short period during water exchange, and the fish received natural light. Each aquarium had a demand feeder with a single mechanism but no feeding chamber.

The 1.6 ha ponds were divided into quadrats (30.5 x 30.5 m) by using painted markers on the banks and painted floats anchored to bricks pressed into the pond bottom. In the 0.1 ha pond, one large pen (15.2 x 18.3 m) was divided into quadrats (1.5 x 1.5 m) with nylon string attached to stakes on the pond bank. This system prevented marked fish from becomming entangled with quadrate markers, which had occasionally occurred in the 1.6 ha ponds.

MATERIALS AND METHODS

Channel catfish from 25- to 46-cm in length were stocked in the study areas. At the Fisheries Research Center, the number of fish in the study areas ranged from 1 to 100. Stocking rates at Sooner Fish Farm were at 6,000 fish/ha, with the exception of one pond which was stocked at 2,000 fish/ha. An example of the size and percentage of fish in two 1.6 ha ponds (6,000 fish/ha) were as follows:

Pond A		31 cm(41%)	36 cm(59%)	
Pond B	25 cm(12%)	31 cm(21%)	36 cm(46%)	46 cm(21%)

A commercial fish pellet (Shawnee Complete Fish Food - 33% protein) was available on demand at the feeding station.

Fish used for observations were collected and marked at monthly intervals throughout the study. To mark the fish, I used a modification of the methods of Hasler and Wisby (1958) and Stevens and Tiemeier (1961). A ping-pong ball was attached to one end of a 0.9 m length of piano steel (0.5 mm diameter for small fish and 0.6 mm for large fish) and the other end was attached to the dorsal spine by a swivel and short piece of nylon line. To attach the marker, a small incision was made behind the dorsal spine and the first dorsal ray with a sharp instrument. The ping-pong balls were numbered with Scotchlite waterproof, reflective tape.

By using piano steel which is light in weight, the effects of the marker on the performance and health of marked fish was reduced. Furthermore, the rigidness of the piano steel reduced entanglement with other marked fish, floating quadrate markers, and the foundation of the feeding station. However, the piano steel generally deteriorated from rust by 40 days. Fish that became entangled usually escaped, unless freed within a few hours after entanglement.

The attachment of the markers caused an irritation around the dorsal spine, as evidenced by a slight inflammation. However, these areas generally healed within two weeks and marked fish evidently suffered no ill effects, since fish with markers at the Fisheries Research Center had weight gains comparable to unmarked fish during the summer of 1973.

Observations were conducted on an hourly and daily basis. Values for time were rounded off to the nearest one-half hour and adjusted to central standard time. During the day, observations were made using Wuest binoculars (10 x 50 power), and at night, a flashlight and spotlight aided in identifying individuals. Observations at night were recorded on a tape recorder and later transcribed to data sheets.

Hourly rates of food delivery were recorded for the population during the 72-hr periods of observation. When rates were not recorded hourly, they were made once a day. In the latter part of the 1972 feeding season, feeding demands were monitored at the 1.6 ha ponds with a Simpson event recorder (Type 2755, 24 volts). Archer mercury switches (Type SPDT, 1 amp, 120 volts) were attached to the perpendicular demand rods and served to signal the movement of the rod during feeding. The feeding chamber prevented the wind and waves from moving the rods and activating the event recorder. Feeding demands were monitored in aquaria and pens throughout the 1973 feeding season at the Fisheries Research Center using the event recorder. The high banks of the 0.1 ha pond served to reduce wind and wave activity.

Water temperature was recorded with a Temp-scribe 7-day recording thermometer, at a depth of 0.6 m, which approximated the average depth of the ponds. Dissolved oxygen was measured at the onset and termination of the feeding period and at 1-hr intervals throughout the continuous 72-hr observation periods, using a Hach kit (Model Ca-24-WR).

Procedures for the statistical treatment of the data are from Sokal and Rohlf (1969). Data from my observations and experiments were subjected to the chi-square or G-test for goodness of fit. The STP a posteriori test, was used to test the homogenity of the sets of replicates tested for goodness of fit. The Student-Newman-Keuls a posteriori test was used to test the significance of multiple comparisons among means from hourly periods of food delivery. Yate's correction for continuity was used when n was less than 200. Conclusions on statistical significance were based at the 95% probability level. Basic statistical programs in FORTRAN IV were used to analyze these data, with the aid of an IBM 360 computer.

Over 1200 fish were marked for observation during this study. The fish were separated into size classes (25, 31, 36, and 46 cm), five or more individuals to a class. Detailed descriptions of their activities with quantitative records of their distribution provided the raw data. Unless stated otherwise, values were the mean of five marked fish for each size for one or more monthly 72-hr intervals. The environmental factors analyzed were temperature, dissolved oxygen, and disturbances.

RESULTS

DAILY ROUTINES

Hourly observations on marked channel catfish, conducted for one or more 72-hr intervals for each month of the year, revealed the existence of a daily routine for pond cultured channel catfish. Marked fish were observed on successive dates to occupy home areas in the pond. When the fish were not in the home areas, they were swimming to or from the feeding station by specific routes or swimways (Fig. 2).

HOME AREAS

Home areas of marked fish were examined throughout the year, when the ponds were full, and in ponds that were drained. The pond bottom in the home areas was found to be hard and free from silt. The remainder of the pond bottom had a layer of soft mud and silt, from 5 to 30 cm in depth. The shape and size of the home areas varied, but generally they were large irregular rectangles or uniform circles from 1.0 to 3.7 m in diameter (Fig. 2). The depth of home areas ranged from 5 to 20 cm.

In comparing two 1.6 ha ponds with a stocking rate of 6,000 fish/ha, 23 home areas were found in the pond having 31- and 36-cm fish, while the similarly stocked pond with 25-, 31-, 36-, and 46-cm fish had 172 home areas (Table 1). The second pond had a larger number of small home areas (0.9 and 1.2 m in diameter) which were occupied by 46-cm fish. For example, when marked fish were observed for 7 consecutive days in June, home areas 1, 2, and 3 were occupied by 46-cm fish, and areas 4, 5, and 6 were occupied by 25- and 31-cm fish (Fig. 2-B3). During this period the marked 46-cm fish returned to the same home areas 91% (32 of 35 observations) of the time as opposed to 83% (58 of 70 observations) for the marked 25- and 31-cm fish.

Relatively few small areas occurred in the first 1.6 ha pond, which was stocked at the same rate of 6,000 fish/ha, but with smaller fish (31 and 36 cm). It appeared then, that there were larger schools of small fish and smaller schools of large fish in the home areas of the two ponds.

In the 1.6 ha ponds, it was not practical to determine the number of fish occupying each home area, but in a 0.5 ha pen stocked at 750 fish/ha, there were 0.14 fish/sq m of home area. However, in the larger ponds, the average density of fish/sq m of total home area was 0.11 and 0.14.

INFLUENCE OF ENVIRONMENTAL FACTORS. The behavior of channel catfish in home areas was influenced by temperature, oxygen concentration, and other factors. Adverse conditions of these factors on a daily and/or seasonal basis resulted in changes in both the location of and the time fish remained in home areas.

Channel catfish relocated their home areas from deep to shallow areas or vice versa depending on the temperature conditions. They selected for warmer temperature in the spring and fall and for colder temperature in the summer. During the course of a year, relocations included two complete moves from deep to shallow areas of the pond.

During summer, small fish tended to occupy home areas near the feeding station, while large fish relocated farther away in the deeper end of the pond, which often was the deepest water to be found. However, during June and July large fish remained in the shallow areas of the pond to spawn before returning to the deep end. For example, the small areas in the shallow end and around the perimeter (0.6 m) of the pond (Fig. 2-B3) represents summer home areas for the large fish during the spawning period, while the areas in the middle of the pond (Fig. 2-B1) represent home areas occupied by a mixture of sizes during the winter and almost year-around by 25- and 31-cm fish.

The influence of oxygen concentration was limited to summer. During this time, concentrations of oxygen tended to cause fish to remain in or return to their home areas where values were from 1 to 2 mg/l higher than those in the area of the feeding station. For example, in the 1.6 ha ponds, all fish generally occupied their home areas from 4 to 7 am or when low oxygen concentrations existed (2-4 mg/l). When values decreased below 2 mg/l, fish swam to the pond surface or into the shallow areas around the pond perimeter where it appeared they were attempting to be in the area of the highest available oxygen concentration.

Channel catfish, 46-cm in length, were in the home areas of the pond 87 to 100% of the day (Table 2). A reduction in metabolism and subsequent decrease in swimming and feeding rates would appear to account for the lower spring values for large fish; however, the distance between home areas and the feeding station was greatest during this period. During the summer, in a population of mixed sizes stocked at 6,000 fish/ha, a highly significant difference in percent time spent in home areas was observed. Low values for the 21- and 31-cm fish in this population represented the influence of size. In a pond stocked at 2,000 fish/ha with 25- and 31-cm fish, there was no significant difference among sizes for the time spent in the home area.

SWIMWAYS

In the 1.6 ha ponds, home areas were located 30 m or farther from the feeding stations. Throughout most of March to October, marked fish were observed swimming daily to and from the feeding station following swimways (Fig. 2). There were one or more direct and perimeter swimways for each pond, and each swimway served a number of home areas. The established areas of direct swimways were from 0.6 to 4.6 m wide, 60 to 274 m long, 0 to 45.7 cm deep, and over hard areas of the pond bottom but avoided home areas. The unestablished areas of these swimways were over muddy and hard areas with one or more possible connections to home areas.

Ponds stocked with similar size fish had fewer and shorter, but wider swimways, than ponds stocked with mixed sizes. For example, in a 1.6 ha pond stocked with 31- and 36-cm fish, the hard area of the swimways totaled 132 m in length with an average width of 2.1 m. In another pond stocked with 25-, 31-, 36-, and 46-cm fish, the total length of hard area was 289 m, with an average width of 1.4 m.

In swimming to the feeding station during April, 25-cm fish had an average rate of 2 m/min ($s = 0.61$, $n = 15$), requiring from 60 to 90 min to swim approximately 152 m. However, intermittent swimming suggested grazing on the invertebrate populations. The 46-cm fish had an average swimming rate of 6 m/min ($s = 0.40$, $n = 15$), requiring from 20 to 30 min to swim the same distance. If large fish grazed on large invertebrates or fish enroute to the feeding station, they did so without stopping.

The time required to return to home areas for large fish was approximately the same since they did not stop enroute to or from the feeding station. Less intermittent swimming for small fish returning to home areas suggests they were successful in feeding.

INFLUENCE OF ENVIRONMENTAL FACTORS. During spring, when water temperatures were from 12 to 18 C, marked fish were observed to swim to and/or from the feeding station along the pond perimeter (Fig. 2-A2 and B2). The use of perimeter swimways followed the spring relocation of home areas into the shallow areas of the pond.

Perimeter swimways were 274 m or less in length, 1 to 2 m from the pond bank, in 0.4 to 0.6 m of water and had muddy bottoms. Fish in the shallow end of the pond, with the exception of the 46-cm fish who did not use perimeter routes, often swam the length of the pond (274 m) to reach the feeding station during March and April. However, during this period, 68% (190 of 280 observations) of the marked fish returned to their home areas by the direct swimways rather than by perimeter routes.

When water temperatures increased to 18 C, smaller fish relocated into the deep area of the pond and discontinued the use of perimeter swimways. Thus, during summer, routes to the feeding station were by direct swimways and less than 152 m in length (Fig. 2-A3 and B3). Swimways were not used in the fall since demand feeding stopped prior to the fall relocation into the shallow area of the pond. Throughout winter, marked fish made no attempt to go to the feeding station and as a result swimways were not used.

Low values of temperature and oxygen concentration decreased swimming rates. However, temperature did not appear to influence swimming rates from June to October. During this period, the percent time swimming to and from the feeding station was not significantly different for all fish

(Table 2). During late spring, smaller fish had a greater decrease in percent time swimming than larger fish, since the distance between their home areas and the feeding station decreased following relocation back into the deep area of the pond.

FEEDING STATION

Upon arriving at the feeding station, a fish must enter the feeding chamber and bump or push a perpendicular rod to trigger the release of food (Fig. 1). The rate and amount of food delivered from demand feeders was dependent upon the degree, time, and number of displacements of the feeding rod. The minimum displacement required to deliver food was 2.5 cm, which delivered an average of 1.5 g. A displacement of 17.8 cm provided a continuous flow if the displacement was maintained. The maximum rate of bumps at minimum displacement was approximately 60/min.

Channel catfish were conditioned to use demand feeders in the spring by placing a less than adequate ration of food under the feeding rod on successive dates until self-feeding was established. This generally required from 3 to 5 days as hungry fish soon discovered that a bump of the rod provided food.

A number of factors, such as the number of individuals and turbidity of the water, made observations of the feeding act for individual fish in the 1.6 ha ponds difficult. Therefore, conditioned individuals were transferred from the ponds to aquaria and pens for isolated individual and group observations. Fish transferred from the ponds to aquaria required an acclimatization period (as defined by Folk, 1974) of 3 to 5 days. Feeding routines were quickly established after the acclimatization period, and maintained throughout my 30-day observational periods.

IN AQUARIA

Small and large individuals (25 and 46 cm) fed one or more times a day. Small fish were less effective in operating the feeding mechanism with their snout than were large fish. While part of the feeding time for isolated small fish was related to their inefficiency in operating the feeding mechanism, another difficulty was ingesting standard size commercial fish pellets (0.5 x 1.3 cm). Because of the hardness and large size of the pellets, small fish mouthed the pellets. Between periods of mouthing, they would expell the pellets. Conditioning of the pellets, making them suitable for ingestion, generally required from 1 to 3 minutes. As a result, small individuals averaged 55 min of feeding/day as compared to 34 min for large individuals (Table 3). All fish left the feeding station upon completing feeding.

Groups of similar size fish (25 and 46 cm) fed one or more times a day, as individuals or in a group(s). Small fish fed as one group while large fish fed as individuals or in small groups. Group feeding resulted in physical contact, which included pushing, tail slapping, and occasional biting and spining. The influence of physical contact on feeding in groups of small fish was not significant since individuals had shorter feeding periods than isolated individuals of the same size during a 30-day period (Table 3). Physical contact in groups of large fish was comparable to that of small fish, except there was more biting and some chasing. As a result of the increase in biting and chasing, feeding time/individual was comparable to those of isolated large individuals (Table 3).

Large males and females fed at any time. Therefore, sex did not appear to be a factor in determining feeding status. Upon completing feeding, all fish left the feeding area to join one or more groups in the home areas.

IN PENS

Fish in groups of mixed sizes (25, 31, 36, and 46 cm) fed one or more times a day, individually or in groups. The increase in group feeding resulted in greater efficiency in feeding for individuals of all sizes. Individual small fish average 32 min of feeding/day while individual large fish had an average of 27 min (Table 3).

Physical contact increased among fish in groups of mixed sizes, but remained as pushing, tail slapping, and spining in the smaller sizes. Biting and chasing increased, usually being directed from larger to smaller fish. Therefore, size was important in determining feeding rank and smaller or less aggressive fish waited to feed. However, large fish occasionally allowed small fish to feed while they fed. Fish returned to home areas upon completing feeding.

IN LARGE PONDS

Fish fed once a day at different times, individually or in groups. As group feeding increased, the time of feeding/individual decreased to points that appear to represent minimum feeding time (Table 3).

Daily demand feeding activity was characteristic of the stocking rate and population structure. For example, in a 1.6 ha pond stocked at 2,000 fish/ha with 2 sizes, hourly food delivery was continuous for 8 hr a day, during a 72-hr interval in June (Fig. 3). In another pond stocked at 6,000 fish/ha with 4 sizes, hourly food delivery was continuous for 21 hr a day during the same period. The maximum hourly rate of food delivery for the 1st population occurred at 2200 hr and at 2300 hr for the 2nd population (Fig. 3). The results of a Student-Newman-Keuls a posteriori multiple range test on the rates of food delivery for these populations showed that 2100 and 2200 hr were significantly different from all other hours in the 1st population, however, in the 2nd population, 2300 hr was significantly different from all other hours of feeding. The earlier period of maximum food delivery in the 1st population is apparently the result of the population structure, rather than stocking rate. Another pond stocked at 6,000 fish/ha with 3 sizes also had maximum hourly food delivery at 2200 hr.

INFLUENCE OF SIZE. Upon arriving at the feeding station, a fish was either successful in feeding and returned to its home area, or after one or more attempts to feed, it was unsuccessful and waited to feed. Attempts to feed were characterized by swimming back and forth in front of the feeding chamber entrance with periodic efforts to enter the chamber. The frequency and the intensity of attempts to feed were influenced by several factors, including size of the individual and time of day.

In populations with mixed sizes, fish of all sizes waited to feed. There was a correlation between the stocking rate, size of fish, and waiting. For example, in a 1.6 ha pond stocked at 6,000 fish/ha with 25-, 31-, 36-, and 46-cm fish, 54% (42 of 78 observations) of the marked 25-cm fish waited 3 hr or more daily to feed during June, as compared to 13% (3 of 24 observations) of the 46-cm fish. However, in a pond stocked at 2,000 fish/ha with 25- and 31-cm fish, 17% (8 of 47 observations) of the 25-cm fish waited 3 hr or more to feed during the same period. Waiting for the large fish in the 1st population ranged from 0 to 3 hr, and from 0 to 12 hr for the small fish. Large fish had the least number of attempts to feed while waiting. Attempts to feed for the small fish were greatest during their first 3 hr of waiting, with individual fish attempting to feed from 30 to 53% of that period, but decreased after 1 to 3 hr of waiting. Intermediate sizes (31- and 36-cm) fit this trend appropriately.

During June, waiting distances ranged from 1.5 to 30.5 m from the feeding station. The average distance for large fish was 6.0 m ($s = 2.19$, $n = 9$) and 26.7 m ($s = 3.69$, $n = 13$) for small fish. Distance between the waiting area and the feeding station decreased with the onset of darkness and an increase in the number of individuals at the feeding station.

There was a significant difference in the time of feeding for all sizes in a population of mixed sizes stocked at 6,000 fish/ha from June to October. The effect of size on the time of feeding is seen when the percentage of marked fish ($n = 75$ for each size) feeding within 30 min of a given time on successive days is compared to the size of the fish as follows:

25 cm	-	35%	36 cm	-	73%
31 cm	-	41%	46 cm	-	77%

INFLUENCE OF ENVIRONMENTAL FACTORS. Observations on marked channel catfish indicated several environmental factors, working singly or in combination, were important in directing feeding behavior. Adverse conditions of temperature and oxygen on a daily and/or seasonal basis resulted in changes in the activity and behavior of the fish. Other factors such as noises interrupted feeding but appeared to be significant only when temperature and oxygen had minimal influences.

Temperature was monitored throughout the day, and found to influence the regularity of feeding and the time of day individuals fed. Minimal values of temperature, as well as wide fluctuations in the daily range served to inhibit individuals from feeding.

Demand feeding was seasonal from March through October. Feeding began in March when the water temperature reached 12 C and stopped in mid-October following an abrupt decrease (11 C) in temperature (Fig. 4). Throughout spring, channel catfish usually did not feed at temperatures below the lowest feeding temperature of the previous week even though values appeared to be acceptable for feeding. As temperature increased in the spring and decreased in the fall, fish adjusted their feeding periods accordingly with the result that they did not feed at the same time in different seasons (Fig. 5).

Smaller fish, as a group, had feeding periods throughout the temperature range for feeding, but did not generally feed at the same time as large fish. However, in a pond stocked at 2,000 fish/ha, 25- and 31-cm fish had seasonal feeding periods comparable to those of 46-cm fish in a pond stocked at 6,000 fish/ha with 4 sizes (Fig. 5).

When temperatures were marginal for feeding, individuals stayed in their home areas or went to the feeding station, but did not feed. Low temperatures often inhibited individual fish from feeding during spring and fall because of acclimation (as defined by Folk, 1974) to specific ranges of temperature (Figs. 6 and 7). When temperatures were below 12 C the entire population was inhibited from feeding (Table 4).

Throughout the feeding season, large fish generally fed at average daily temperatures from 1 to 3 degrees greater than the average daily mean (Table 4). Small fish generally fed at temperatures from 1 to 4 degrees lower than large fish. Day to day variations in temperature at the time of feeding for all fish were approximately 1 degree during spring and fall and from 1 to 2 degrees during summer. Variations usually increased when feeding was interrupted for one or more days.

High temperatures during summer did not inhibit feeding, but the hourly rate of food delivery was reduced during daily periods of high temperature (Fig. 3). In the fall as temperature decreased, channel catfish, as a group, did not adjust to earlier periods of feeding (Fig. 5). A 11 degree (C) decrease in water temperature during fall, accompanied by further fluctuations, stopped demand feeding for the season.

During spring and fall oxygen concentration did not appear to influence feeding. However, during summer low values of oxygen concentration reduced or inhibited feeding. In the fall, as the daily low range of oxygen concentration increased, feeding periods did not include early morning.

From July through September, the daily low oxygen concentration was sufficient to prevent feeding for part of the day (Fig. 8). In the 1.6 ha ponds, feeding was generally limited at values below 5 mg/l, but small fish occasionally fed at values as low as 2 mg/l (Fig. 9). Small fish, as a group, had feeding periods throughout the oxygen concentration range for feeding, but did not feed at the same time as large fish.

The influence of low oxygen concentration was similar to that of low temperature, as individuals stayed in their home area or went to the feeding station, but did not feed. Low oxygen concentration rarely prevented the entire population from feeding; individual fish were occasionally inhibited from feeding on a daily basis because of acclimation to values in the upper range of oxygen concentration (Fig. 10).

Large and small fish acclimated to different ranges of oxygen concentration for feeding, but had the same degree of variation (Table 5). Large fish generally fed at daily oxygen values from 1 to 4 mg/l greater than the average daily mean. Small fish fed at values approximately 1 to 6 mg/l less than large fish. Day to day variations in the oxygen concentration at the time of feeding for all fish were from 1 to 3 mg/l. Interruptions in feeding did not increase the degree of variation.

INTERRELATIONS BETWEEN ENVIRONMENTAL FACTORS (TEMPERATURE AND OXYGEN), METABOLISM, AND SIZE. During spring, the period between feeding bouts for individual fish indicated metabolism of the previous meal required from 28 to 30 hr (Fig. 6). Therefore, marked fish did not eat at the same time on consecutive days. Daily adjustments in the time of feeding tended to advance until they coincided with temperatures marginal for feeding. As a result, feeding during spring for individuals occurred every 3 out of 5 days (Table 4). Furthermore, when daily feeding was interrupted, the time of feeding generally adjusted from afternoon to forenoon periods (Fig. 6). When temperatures increased to approximately 22 C, metabolism of the previous meal appeared to be complete within 24 hr since fish fed on a daily basis during the summer (Table 4).

In the spring, both small and large fish occasionally waited to feed, but size generally did not prevent individuals from feeding (Fig. 6). As the temperature increased, food delivery rates and competition for feeding increased. Thus, during summer and fall, waiting to feed increased for all sizes.

Interruptions in feeding for large fish during summer were usually associated with acclimation to, and fluctuation of, oxygen concentration.

Apparently low oxygen decreased metabolic rates as large fish occasionally missed a day of feeding without adjusting their regular time of feeding to an earlier period (Fig. 10).

The establishment of feeding periods within a wide daily range of oxygen concentration values resulted in large and small fish acclimating to different ranges of the factor (Table 5). As a result of acclimation to different ranges, large fish could not feed when small fish fed, or vice versa.

Isolation to specific oxygen concentration ranges and the influence of size often prevented small fish from feeding daily. Thus, small fish continued to adjust their feeding periods during summer as they had in reference to temperature fluctuations during spring.

OTHER FACTORS. Pond cultured channel catfish were subjected to many disturbances which influenced their daily routine. Common disturbances which interrupted, reduced, or inhibited feeding were noises, seining, and chemical treatments for diseases and aquatic vegetation.

Noises which influenced feeding were associated with servicing of the feeding station, the landing and takeoff of jet aircraft at a nearby military base, and shotgun blasts during the October duck season. Reaction to some noises were positive and negative, i.e., sounds of the farm truck attracted fish when they were hungry, but disturbed them when they were satiated.

Disturbances associated with seining or cropping generally reduced feeding. Surrounding marked fish with a seine did not prevent those individuals from feeding on that date if they were not handled. Fish that were handled did not feed from 1 to 3 days.

As a result of the influence of different environmental factors, the rate of food delivery varied on a daily and seasonal basis. During the spring, delivery was from 1/3 to 1/2 that of summer (Fig. 11). Peak seasonal periods of food delivery are seen in May to June and September to October when the influence of temperature and oxygen concentration appeared to be minimal. Fluctuations and reductions in delivery rates during summer reflected several factors, such as cropping and chemical treatments. However, low oxygen concentrations appeared to have been the most important factor influencing feeding during summer.

DISCUSSION

The formation of home areas and swimways reflected aggregation or schooling of channel catfish in culture ponds. A comparison of the ponds showed the overall effect of stocking rates and population structure. Differences in the size of fish tended to split the aggregation into groups and increase the number of home areas and swimways. Size of the aggregation generally appeared to be dependent upon the number of similar size fish in the population. Harlan and Speaker (1956) reported that channel catfish fry school during the first weeks of their lives, but then break up. However, Brown et al. (1970) noted strong schooling and hiding tendencies in fingerling channel catfish 4 to 10 months of age; in my study it appeared that schooling continues to exist for sizes or year groups throughout the life of the channel catfish.

It appeared that the removal of silt from home areas and swimways in the 1.6 ha ponds occurred over a considerable period of time. Observations on marked fish indicated that the hard area of swimways were not occupied as home areas. Fish in one small 0.1 ha pond never developed a swimway with hard area during a complete feeding season, even though home areas became established within a few weeks in the same pond. Thus, the harder trails under the swimways developed long after the home areas. Consequently, since home areas were scattered, the hard trails did not connect with all of the home areas.

In home areas, the silt was swept out faster because fish spent more time in these areas. However, home areas and swimways tended to silt in during periods of abandonment. If ponds were completely harvested and restocked with small fish, many of the home areas disappeared.

The harder swimways and home areas developed faster with large fish. However, broader swimways occurred in ponds where there were greater numbers of similar size fish, which I interpret to mean that larger numbers of individuals were using the swimways at the same time.

The occupancy and/or use of home areas and swimways reflected the influence of environmental factors. In the case of home areas, it appeared that adverse conditions of temperature and oxygen concentration increased the time fish spent in home areas. Colder temperatures and lower oxygen concentrations probably reduced metabolic rates and fish responded by not moving about. The occupancy of home areas may also have been related to survival, since fish always returned to their home areas during periods of low values. However, such behavior appeared to be limited to oxygen values above 2 mg/l. Below 2 mg/l fish left their home areas and came to the surface and swam about, eventually swimming to the edge of the pond. It appeared they were attempting to be near the surface of the pond and at the same time to rest on the bottom, thus selecting the situation providing the highest available oxygen and with the lowest output of energy. Petrosky and Magnuson (1973) reported that the bluegill (*Lepomis macrochirus*) had similar responses to low oxygen concentration and Hubbs et al. (1967), also reported the activity of killifish (*Crenichthys baileyi* and *C. nevadae*) inhabiting warm springs to be adversely affected by values below 2 mg/l at 32 C.

The use of perimeter routes was limited to periods of low temperature and oxygen concentration. As a result, the pond bottom under such routes was never hard. During spring, many of the marked small fish used perimeter swimways in going to the feeding station, but used direct swimways in returning to their home areas. The use of two different routes suggests the influence of one or more factors. Since small fish were in the warmer water in the shallow end of the pond, the use of perimeter routes may have allowed the fish to avoid the lower temperature in the deep water between their home area and the feeding station. However, intermittent swimming and the use of perimeter swimways by small fish suggests grazing on aquatic invertebrates along the shallow perimeter swimways. Consequently, marked small fish who were successful in demand feeding during midday returned to their home areas by direct swimways and with less intermittent swimming. Fish who were unsuccessful in feeding by the end of daily feeding periods generally returned to home areas by perimeter swimways, probably because of decreasing temperatures or for grazing.

Large fish at this time occupied shallow but deeper home areas than small fish. Therefore, temperature variations between their home areas and the deep water of the direct swimways may not have been sufficient to encourage the use of perimeter routes. However, large fish generally fed at optimum temperatures since they were the dominant fish and could leave for the feeding station later in the day at warmer temperatures. In addition, the ponds had few large aquatic invertebrates; therefore, it would appear that there would be no particular advantage for large fish to use perimeter swimways.

Perimeter swimways were also used during summer by small fish leaving the feeding station at a time of low oxygen concentration. This was interpreted as an avoidance of lower oxygen areas in the deeper part of the pond between the feeding station and their home areas. However, as in the spring, grazing may have been a factor. The discontinuation in the use of swimways during late fall, following relocation into shallow areas of the pond, was probably related to a decrease in metabolic rate and the prime condition of a fish ready for winter.

The vigorous feeding activity of groups of fish enhanced the delivery of food from the demand feeder. Isolated small fish in aquaria took almost twice as long as large fish to feed, 55 and 34 min respectively, but group feeding in the intensive culture ponds was 15 and 12 min per fish. Thus, group feeding enhanced the feeding time of both sizes of fish. It appeared that fish fed more vigorously in groups and therefore took less time to feed.

Antagonistic behavior between individuals at the feeding stations resulted in the development of feeding hierarchies and subdominant fish waited to feed. Feeding hierarchies appeared to be determined primarily by size and related to feeding at optimum conditions. Large fish were the dominant fish and they tended to concentrate their feeding into periods coinciding with the daily mean values of temperature or oxygen. If subdominant large individuals waited, it was near the feeding station, where it would appear attempts to re-enter the feeding chamber were unnecessary since they were close enough to be aware of the departure of dominant fish. When small fish were chased out of the feeding chamber, the number of immediate attempts to re-enter the chamber by them appeared to be related to the distance they had been chased. Fish chased for short distances usually returned. Those chased for long distances, or with such vigor that their marker disappeared below the surface, waited to feed. Therefore, it appears that the size or aggressiveness of the chaser greatly influenced the feeding behavior of the one chased. This type of antagonistic behavior was observed more in populations with high stocking rates and mixed sizes.

Konikoff and Lewis (1974) addressed the problem of variation in growth in the cage culture of channel catfish on the basis that variation is a product of antagonistic behavior. They investigated the effects of two environmental variables: (1) variation in depth by water in the cage and (2) escape areas for small fish. They reported that hierarchies were more successful in deep water than shallow and that antagonism was more ongoing in shallow water and at lower densities. The difference in results between the cage and pond studies lies in the fact that limited space in the cages increased the antagonistic behavior, whereas in pond culture, environmental and metabolic factors were operative.

The rate of food delivery and feeding activity varied throughout the season and from pond to pond; each pond was actually a different entity. Since food delivery was greatest for all ponds during the late spring and early fall, it appears that the influence of limiting environmental factors was minimal. During summer, the greatest daily feeding activity for all of the populations was between 1800-2400 hr. This appeared to represent the period with the most favorable temperature and oxygen values. During this time, peak hourly periods were between 2000-2300 hr.

Hastings et al. (1972) also reported the period of greatest activity for fingerling channel catfish as occurring between 1800-2400 hr. In my study, large fish generally fed between 1800-2000 hr. Consequently, peak hourly feeding represented the feeding activity for the largest group of similar size fish in the populations rather than for any particular size of fish. When peak hourly feeding activity of different size fish in pens was compared, all fish had periods similar to those of large fish in the 1.6 ha ponds. Thus, the feeding period for large fish as a group probably represented optimum conditions and time for feeding throughout the season.

While it was not in the scope of this study to determine the efficiency of food to body weight conversion, the rate of food delivery per individual decreased as the stocking rate increased. Fish in aquaria may have tended to overeat since optimum temperature and oxygen concentration values were maintained. However, since the terminal demand for food often delivered more food than was eaten, fish in aquaria who had several bouts of feeding probably wasted more food per individual than individuals in the large ponds who fed once daily. There appear to be several factors operating in the large ponds which would reduce the daily delivery of commercial food such as grazing on a pond's natural food chain and the influence of daily adverse conditions of temperature or oxygen on metabolic rate.

Thus, the feeding activity of channel catfish in shallow culture ponds was influenced by the environmental factors, especially temperature and oxygen concentration. Temperature stimulated and inhibited feeding in the spring and fall but during summer it appeared to have little or no influence on feeding activity. However, its relationship to feeding activity during summer may have been masked by the influence of oxygen concentration, which appeared to be overriding.

Channel catfish did not use demand feeders when the water temperature was below 12 C. However, when food was placed in home areas and checked during winter and early spring, they ate limited amounts between 7 and 12 C. Bailey and Harrison (1948) reported that channel catfish in the

Des Moines River rarely fed in the winter, but temperatures between 10 and 34 C did not seem to inhibit feeding. Bulow (1967) also found that channel catfish stocked in strip mine pits would not eat floating fish food when the water temperature was below 10 C. In contrast to my observations, Hastings et al. (1972) reported reduced feeding from a demand feeder by large channel catfish in a 0.25 ha pond during the winter. The investigators did not report water temperature values, but the winter use of demand feeders in small ponds may have been related to the nearness of the feeding station to home areas. Thus, the type of food, manner of feeding, and location of feeding station appear to be factors influencing winter feeding.

In the spring, intermittent feeding appeared to be primarily temperature related. Colder temperature apparently decreased the metabolic rate to the point where the fish did not eat every day. This does not appear related to the rate of digestion, but rather to the onset of hunger. Shrable et al. (1969) studied digestive rates in channel catfish at various temperatures. Digestion times were well within 24 hr between 10 and 29.4 C, but they did not study the time between feedings. Fluctuations of temperature beyond the acclimation temperature range of the catfish were also operative in that, if a fish became hungry during a period of low temperature, it did not go to the feeder, but stayed in the home area until the temperature rose or until it had acclimated to the colder temperature. Thus, during spring and early summer increasing temperatures and continual acclimation to higher values resulted in catfish generally not feeding at temperatures lower than those of the previous week.

The shift from midday to evening feeding as the feeding season progressed is explained by the fish becoming acclimated to increasing temperature and selection for warmer temperature. Exceptions to this were found for smaller fish who had to wait until the larger fish had finished feeding. Thus, the influence of low temperature and/or oxygen concentration often acted to inhibit feeding after they had to wait. Such fish came early to feed the next day as soon as temperature and/or oxygen were compatible.

In the fall, channel catfish did not adjust to earlier periods of daily feeding. It appeared that decreasing temperature prolonged metabolic rates and tended to influence fish to feed later on successive days. Nonetheless, one would expect catfish to adjust to earlier periods or at least to intermittent days of feeding, but in the fall of 1972, such was not the case.

As temperature decreased through the months of September and October, channel catfish did not acclimate down but tended to concentrate their feeding into the higher temperature range. Finally in mid-October with an abrupt decrease in temperature of about 11 C, fish stopped feeding altogether and never again used the demand feeder. I assume that the rate of temperature change inhibited feeding. Furthermore, the continuing temperature fluctuations following the abrupt decrease probably served to prolong acclimation. When the fish finally became acclimated to the colder temperature, they were unable to operate the feeder. Brett (1944) reported that fish acclimate to decreasing temperature very slowly. However, as mentioned earlier, prime condition of channel catfish following a season of feeding, would also appear to be important in reducing feeding as temperatures decreased during fall.

During summer, low oxygen concentration evidently had an adverse influence on metabolism since catfish reduced food consumption. When catfish were prevented from feeding by low oxygen concentration they did not feed at values below their acclimation range the following day as when interrupted from feeding by low temperature. This suggests that catfish were slower to acclimate to oxygen than temperature which is expected since the oxygen concentration changed much faster and fluctuated more, and acclimation to low oxygen must surely involve such metabolic changes as increased hemoglobin. Stewart et al. (1967) and Whitworth (1968) reported that large mouth bass (Micropterus salmoides) and brook trout (Salvelinus fontinalis) exposed to diurnally fluctuating dissolved oxygen values showed a lower growth rate than fish held at constant levels, but they did not mention feeding. However, it can be assumed that fluctuating oxygen values reduced metabolism and, consequently, food consumption.

Smaller catfish fed at lower oxygen concentrations than larger fish in the same population. In the absence of larger fish they fed at oxygen values comparable to those for large fish. Thus, it appears that feeding during low oxygen resulted from the presence of larger fish.

Although the relationship between environmental factors, metabolism (hunger), and feeding hierarchy would appear to be intricate at first glance, it becomes apparent when all of the factors are considered on individual bases (Fig. 12). Hunger presumably brought fish to the feeder every day and feeding hierarchies were established, mainly as a result of contact between different sizes of fish. Interruptions of individual feeding routine resulted from adverse environmental conditions, such as low temperature or oxygen. Konikoff and Lewis (1974) addressing the problem of hierarchy on growth in cage populations, found it not to be a detrimental factor that reduces growth when fish were fed an adequate amount. It appears then, that a missed day of feeding from adverse environmental conditions would be more influencial in reducing growth than the result of a hierarchy. Usually adverse environmental conditions affected the low end of the hierarchy, but in certain instances, the high end of the hierarchy was affected. For example, oxygen level could drop to a point where it would be outside of the acclimation range for large fish to feed, but inside the acclimation range for small fish to feed.

When dominant fish were removed from populations of low stocking rates in the pens, another fish became the dominant individual without any apparent increase in antagonistic behavior. Thus, the hierarchy remained, but status of the individuals in the hierarchy changed. This was similar to Stringer and Hoar (1955) observations on underyearling trout (Salmo gairdneri). In the pen population, competition was probably limited to fish attempting to feed at the same time and in a well established hierarchy a minimum of antagonistic behavior would be expected.

Since large fish were dominant in feeding and preferred the optimum condition, small fish became acclimatized to and fed at a lower range of environmental conditions. Consequently, the isolation to different ranges of environmental conditions would appear to have reduced the pressures in feeding between large and small fish.

The influence of environmental factors on feeding behavior of channel catfish in culture ponds with demand feeders requires further investigation before the significance of the relationship on when, where, and how much to feed can be fully evaluated. Furthermore, the use of demand feeders in large ponds with high stocking rates should be examined. Since channel catfish aggregate or school, optimum production in large populations would appear to be related to establishing feeding at separate feeding stations to reduce competition and waiting. Growth is not likely to be maximum until every individual can adequately feed.

LITERATURE CITED

Allen, K. O., and K. Strawn. 1968. Heat tolerance of channel catfish (Ictalurus punctatus). Proc. 21st Ann. Conf., Southeast. Assoc. Game Fish Comm., 1967. pp. 399-411.

Andrews, J. W., and R. R. Strickney. 1972. Interactions of feeding rates and environmental temperature on growth, food conversion, and body composition of channel catfish. Trans. Amer. Fish. Soc. 101(1): 94-99.

Bailey, R. M., and H. M. Harrison, Jr. 1948. Food habits of the southern channel catfish (Ictalurus lacustris punctatus) in the Des Moines River, Iowa. Trans. Amer. Fish. Soc. 75: 110-138.

Bonnean, D. L., J. W. McGuire, O. W. Tiemeier, and C. W. Deyoe. 1972. Food habits and growth of channel catfish fry, Ictalurus punctatus. Trans. Amer. Fish. Soc. 101(4): 613-619.

Brett, J. R. 1944. Some lethal temperature relations of Algonquin Park fishes. Univ. Toronto Studies Biol. Ser. 52: 1-49.

Brown, B. E., I. Inman, and A. Jerald. 1970. Schooling and shelter seeking tendencies in fingerling channel catfish. Trans. Amer. Fish. Soc. 99(3): 540-546.

Bulow, F. J. 1967. The suitability of strip-mine ponds for producing marketable channel catfish. Prog. Fish-Cult. 29(4): 222-228.

Busbee, R. L. 1968. Piscivorous activities of the channel catfish. Prog. Fish-Cult. 30(1): 32-34.

Chowdhury, A. Q. 1971. Respiratory metabolism of channel catfish Ictalurus punctatus (Rafinesque), with respect to temperature and growth. Masters Thesis. The University of Oklahoma, Norman. 49 p. (Unpublished)

Clemens, H. P., and K. E. Sneed. 1957. The spawning behavior of the channel catfish, Ictalurus punctatus. U. S. Fish and Wildl. Serv., Spec. Sci. Rept., Fish No. 219. 11 p.

Folk, G. E. 1974. Textbook of environmental physiology. By G. Edgar Folk, Jr. 2d ed. Lea and Febiger, Philadelphia. 465 p.

Harlan, J. R., and E. B. Speaker. 1956. Iowa fish and fishing. Iowa State Consv. Comm., Des Moines. 377 p.

Hasler, A. D., and W. J. Wisby. 1958. The return of displaced largemouth bass and green sunfish to a "home" area. Ecology 39(2): 289-293.

Hastings, W. H., B. Hinson, D. Tackett, and B. Simco. 1972. Monitoring channel catfish use of a demand feeder. Prog. Fish-Cult. 34(4): 204-206.

Hubbs, C., R. C. Baird, and J. W. Gerald. 1967. Effects of dissolved oxygen concentration and light intensity on activity cycles of fishes inhabiting warm springs. Amer. Midl. Nat. 77(1): 104-115.

Knable, A. E. 1972. Effect of size and sex upon food intake of caged channel catfish (Ictalurus punctatus). Ph. D. Thesis, Southern Illinois University, Carbondale. 50 p. (Unpublished)

Konikoff, M., and W. M. Lewis. 1974. Variation in weight of caged-reared channel catfish. Prog. Fish-Cult. 36(3): 138-144.

Mathur, D. 1970. Food habits and feeding chronology of channel catfish Ictalurus punctatus (Rafinesque), in Conowingo Reservoir. Proc. Annu. Conf. Southeast. Assoc. Game Fish Comm. 24: 377-386.

Petvosky, B. R., and J. J. Magnuson. 1973. Behavioral responses of northern pike, yellow perch, and bluegill to oxygen concentrations under simulated winterkill conditions. Copeia 73(1): 124-133.

Shrable, J. B., O. W. Tiemeier, and C. W. Deyoe. 1969. Effects of temperature on rate of digestion by channel catfish. Prog. Fish-Cult. 31(3): 131-138.

Sokal, R. R., and F. J. Rohlf. 1969. Biometry. W. H. Freeman and Co., San Francisco. 776 p.

Spencer, W. P. 1939. Diurnal activity rhythms in freshwater fishes. Ohio J. Sci. 39(3): 119-132.

Stevens, E. D., and O. W. Tiemeier. 1961. Daily movements of channel catfish Ictalurus punctatus (Rafinesque), in a farm pond. Trans. Kansas Acad. Sci. 64(3): 218-244.

Stewart, N., D. Shumway, and P. Doudoroff. 1967. Influence of oxygen concentration on the growth of juvenile largemouth bass. J. Fish. Res. Board Can. 24: 475-494.

Stringer, G. E., and W. S. Hoar. 1955. Aggressive behavior of underyearling Kamloops trout. Can. J. Zool. 33: 148-160.

U. S. Department of the Interior, Bureau of Sport Fisheries and Wildlife. 1973. Second Report to the Fish Farmers. U. S. Government Printing Office, Washington. Resource Publication 113. 124 p.

Whitworth, W. 1968. Effects of diurnal fluctuations of dissolved oxygen on the growth of brook trout. J. Fish. Res. Board Can. 25: 579-584.

TABLE 1.--Number and size of home areas in ponds A and B, each with 16,772 square meters

		Number	Size(m)	Area(sq m)
A	Circular	2	3.1	14.6
		3	3.7	31.5
		2	5.5	47.3
		1	6.7	35.3
	Rectangular	1	3.1 x 9.1	28.2
		1	4.6 x 6.1	28.1
		2	4.9 x 10.7	104.8
		4	6.1 x 9.1	223.0
		1	6.1 x 12.2	94.4
		2	6.1 x 18.3	223.2
		2	9.1 x 15.2	277.0
		1	9.1 x 18.3	166.5
		1	9.1 x 20.7	188.4
	Total	23		1,442.3
B	Circular	79	0.9	51.2
		47	1.2	54.8
		14	3.1	28.9
		24	3.7	252.0
	Rectangular	1	3.1 x 4.6	14.3
		1	3.7 x 9.7	35.9
		1	3.7 x 10.7	39.6
		1	5.5 x 7.6	41.8
		1	6.4 x 18.3	117.1
		1	7.3 x 17.4	127.0
		1	9.1 x 13.7	124.7
		1	9.1 x 18.3	166.5
		172		1,053.8

TABLE 2.--Seasonal variation in daily behavior routines, based on 72-hr observations. n = 15

Size (cm)	F	M	A	M	J	J	A	S	O	N
					Percent time in home areas					
25	100	68.8	62.5	45.8	22.9	16.7	18.8	25.0	37.5	100
31	100	70.8	66.7	54.2	28.1	24.0	32.3	40.6	40.6	100
36	100	83.3	82.9	81.4	85.6	83.5	85.6	84.8	85.0	100
46	100	87.5	87.5	91.9	94.6	94.9	94.3	94.6	94.1	100
					Percent time in swimways					
25	0	14.6	12.5	8.4	6.7	6.2	6.2	6.2	6.2	0
31	0	12.5	10.4	8.3	5.2	5.2	5.2	5.2	5.2	0
36	0	8.4	6.3	4.2	1.9	1.9	1.9	1.9	1.9	0
46	0	4.2	4.2	1.9	1.9	1.0	1.0	1.2	1.2	0
					Percent time at feeding station					
25	0	16.6	25.0	45.8	70.4	77.1	75.0	68.8	56.3	0
31	0	16.7	22.9	37.5	66.7	70.8	62.5	54.2	54.2	0
36	0	8.3	10.8	14.4	12.5	14.6	12.5	13.3	13.1	0
46	0	8.3	8.3	6.2	4.1	4.1	4.7	4.2	4.7	0

TABLE 3.--The influence of stocking rate and size of fish on individual feeding time at the demand feeder during June. n = 30

	Feeding time in minutes (standard deviation)				
	No. fish in population				
Size (cm)	1	20	100*	3,000*	10,000*
25	55(4.0)	37(3.1)	32(3.5)	17(2.6)	15(2.3)
46	34(3.5)	33(3.2)	27(2.3)	15(2.0)	13(1.7)

* Mixed sizes

TABLE 4.--Temperature at feeding for two marked (25 and 46 cm) channel catfish for 14 consecutive days during March, May, August, and October with food delivery rates for the population

Temperature(C)									
March					May				
Daily		At feeding			Daily		At feeding		
Range	Mean	46cm	25cm	Food	Range	Mean	46cm	25cm	Food
7.6-11.8	10.0			0	17.8-22.8	20.0	21.5	22.2	200
8.2-13.8	11.5		13.2	50	17.8-22.2	20.3	21.5	21.5	200
11.2-15.0	12.8	14.5	12.8	50	16.0-21.5	19.3	20.5	20.5	250
11.8-18.8	15.0			100	17.2-22.2	19.5	21.0	20.0	225
11.8-19.6	15.3	15.5	16.0	100	16.7-21.0	18.3	21.0		250
13.8-21.0	17.0	17.2	14.5	125	17.8-21.5	19.3	21.0	17.8	200
10.0-17.2	13.4			165	20.0-24.5	22.8	23.4	20.0	300
10.0-13.3	11.8			0	21.5-26.0	23.8	25.0	21.5	200
11.8-16.0	14.0	15.5	15.0	150	20.5-25.6	23.0	25.6	22.8	400
11.8-18.6	14.6	16.0	15.0	200	20.0-24.5	22.0	24.8	21.0	200
11.2-16.7	14.0			200	20.5-24.5	20.0	24.5	22.8	175
10.0-12.8	11.2			0	17.8-22.2	19.2	22.2		200
12.3-17.3	14.6	15.0	15.5	200	20.0-24.5	21.8	23.8	18.8	125
12.8-18.8	16.0	16.0	15.0	200	21.0-25.0	22.8	23.4	21.0	125
August					October				
24.5-28.3	26.2	28.3	24.5	125	19.3-23.8	22.2	23.8	22.2	150
23.8-27.8	25.9	27.2	24.5	100	21.0-26.0	23.4	24.5	22.2	125
24.5-30.0	27.0	29.3	25.0	150	21.0-26.7	23.8	25.6	22.8	185
22.8-27.8	25.7		26.7	50	22.2-26.7	24.7	25.0	22.8	185
23.4-27.2	25.0	26.0	26.7	100	20.5-26.0	22.8	23.8	21.5	300
24.5-27.2	25.8	26.0	26.0	275	21.0-27.8	24.5	24.5	22.8	300
25.0-27.8	26.0	27.8	25.6	100	21.5-27.2	24.5	25.6	24.5	250
25.0-28.3	26.7	27.3	25.0	150	22.2-26.7	24.7	26.0		180
25.8-28.9	27.4	28.9	27.3	150	22.2-26.7	23.4	26.0	23.3	180
25.8-29.3	27.2	29.3	26.7	75	21.0-24.5	22.7		23.8	125
26.0-29.3	27.4	28.9		75	17.2-20.0	18.6			50
26.7-30.0	28.2	30.0	26.7	75	15.5-18.8	17.4			25
26.0-31.2	28.3		28.3	50	15.5-18.4	17.3			25
26.0-29.3	28.0	29.3		125	15.0-16.7	15.7			

TABLE 5.--Oxygen concentration at feeding for two marked (25 and 46 cm) channel catfish for 14 consecutive days during July and August with food delivery rates for the population

Oxygen(mg/l)									
July					August				
Daily		At feeding			Daily		At feeding		
Range	Mean	46cm	25cm	Food	Range	Mean	46cm	25cm	Food
3-9	6.2	8.0	5.0	170	4-10	7.0	8.0	6.0	125
4-11	7.4	9.0	6.0	250	3-10	6.2	8.0	7.0	100
4-14	9.0	12.0	8.0	260	5-11	8.0	9.0	8.0	150
2-11	6.3	10.0	5.0	140	4-8	6.0		8.0	50
4-10	7.0	9.0		180	3-11	8.0	11.0	8.0	100
4-9	6.5	9.0	6.0	110	3-14	8.6	12.0	8.0	275
4-11	7.5	10.0	6.0	140	4-9	6.0	9.0	5.0	100
4-12	8.2	10.0	7.0	180	4-11	7.5	10.0	6.0	150
3-9	6.0	9.0	5.0	120	4-12	8.3	11.0	5.0	150
4-10	7.2	9.0	5.0	160	4-9	6.6	8.0	4.0	75
4-8	5.5		4.0	40	4-8	6.0	8.0		75
3-8	5.0		6.0	50	4-8	6.5	7.0	7.0	75
4-11	7.0	10.0		170	3-8	5.4		5.0	50
4-10	7.0	9.0	6.0	105	4-11	7.2	11.0		125

FIGURE 1.--Platform-mounted demand feeder used in culture ponds.

FIGURE 2.--Seasonal variation in the occupancy of home areas and use of swimways by channel catfish in two 1.6 ha ponds stocked at 6,000 fish/ha. A. 31- and 36-cm fish. B. 25-, 31-, 36-, and 46-cm fish. Data collected from actual measurements of the pond bottom after draining. The intermediate and large areas are drawn to scale, whereas the small areas reveal the location only. Dark areas represent the established swimways, whereas the dotted areas indicate one or more possible connections with the home areas.

FIGURE 3.--Hourly food delivery for channel catfish in two 1.6 ha ponds, June 1972.

FIGURE 4.--Weekly range of temperature at which channel catfish fed in 1.6 ha ponds, 1972.

FIGURE 5.--Seasonal variation in time of feeding (72-hr observations) for channel catfish in two 1.6 ha ponds, expressed as the first and last of five marked fish to feed. n = 15.

FIGURE 6.--Daily temperature curves for 14 days in March, 1972, with the time of arrival and feeding for two marked (25 and 46 cm) channel catfish in a 1.6 ha pond stocked at 6,000 fish/ha.

FIGURE 7.--Daily temperature curves for 14 days in October, 1972, with the time of arrival and feeding for two marked (25 and 46 cm) channel catfish in a 1.6 ha pond stocked at 6,000 fish/ha.

FIGURE 8.--Weekly range of oxygen concentration at which channel catfish fed in 1.6 ha ponds, 1972.

FIGURE 9.--Percentage of marked channel catfish feeding at various oxygen concentrations in the 1.6 ha ponds during June to August (1972), regardless of time of day.

FIGURE 10.--Daily oxygen concentration curves for 14 days in August, 1972, with the time of arrival and feeding for two marked (25 and 46 cm) channel catfish in a 1.6 ha pond stocked at 6,000 fish/ha.

FIGURE 11.--Mean weekly and monthly rates of food delivery for a mixed population of channel catfish stocked in a 1.6 ha pond at 6,000 fish/ha, 1972.

FIGURE 12.--Factors influencing daily routines. Thickness of the arrow indicates the relative importance of the influence of a factor on daily routine.

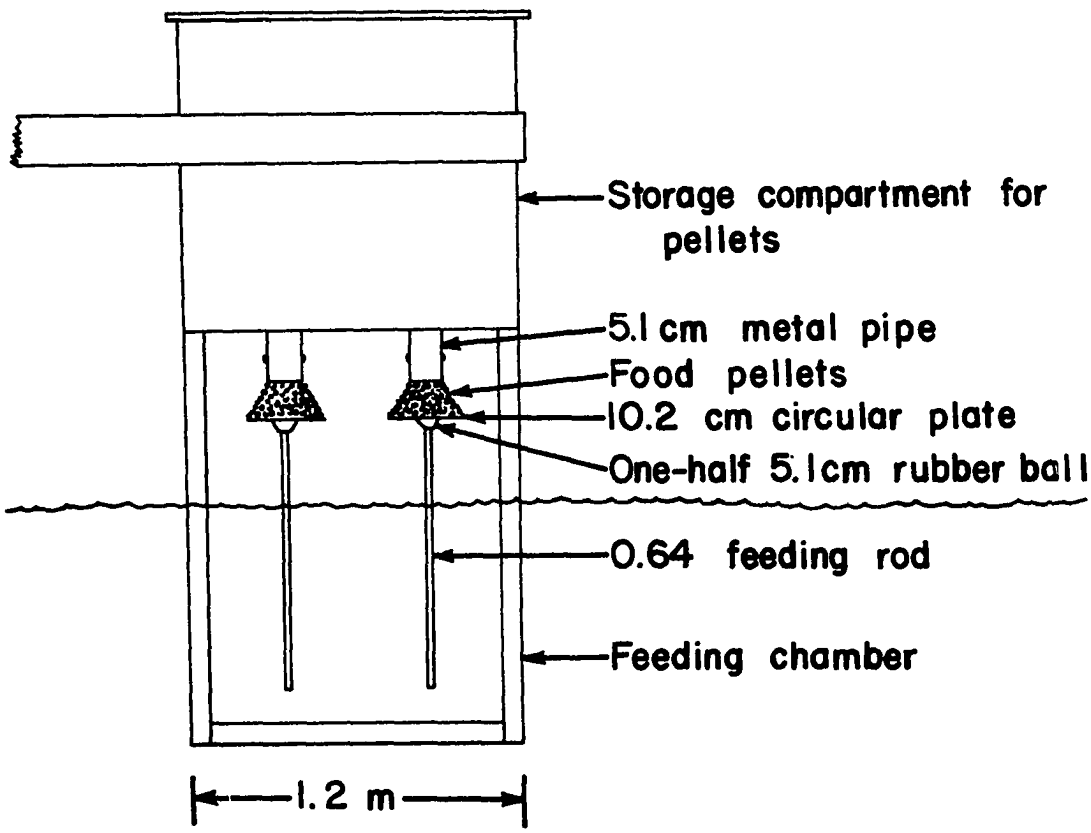


FIGURE 1.--Platform-mounted demand feeder used in culture ponds.

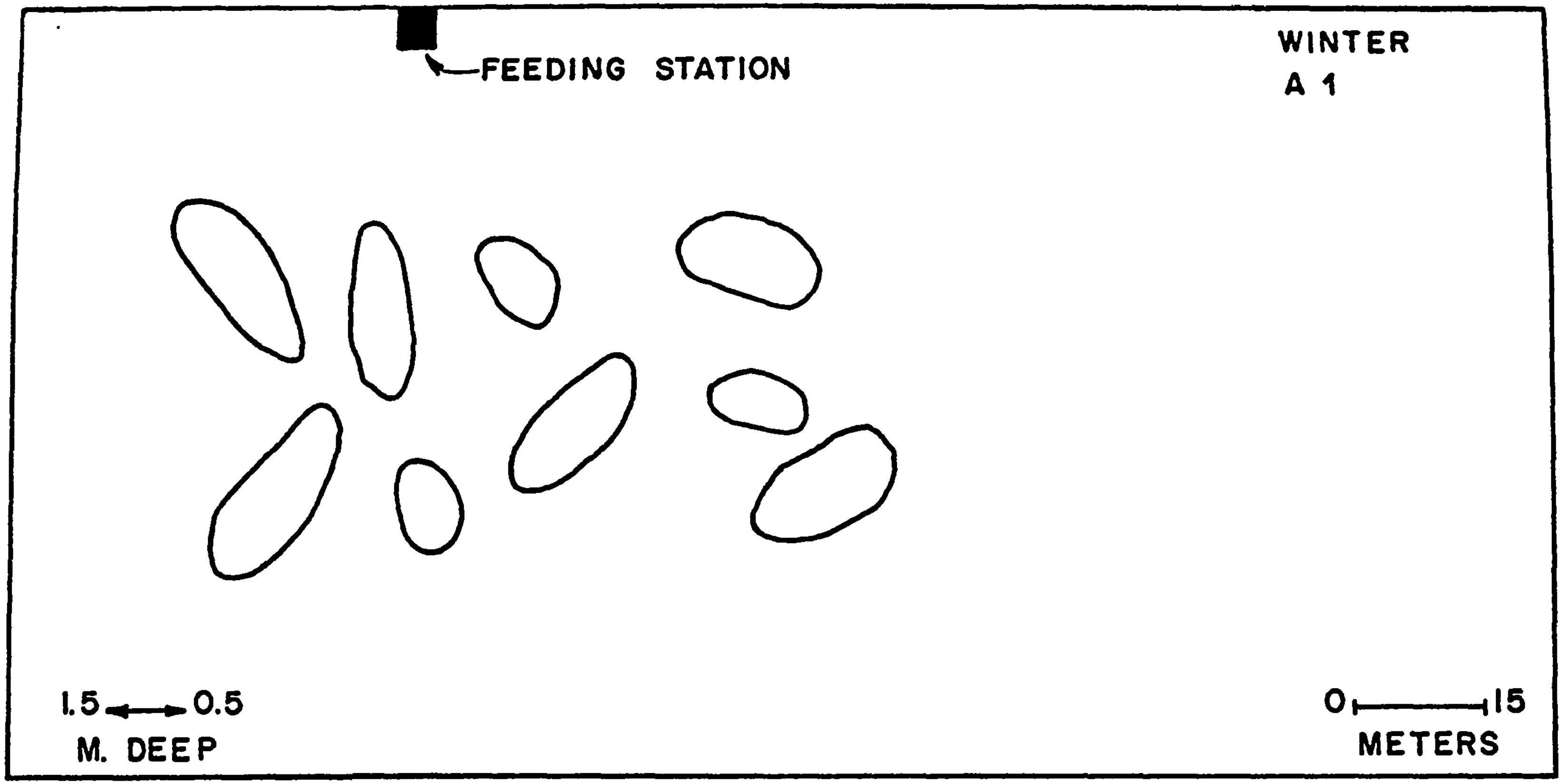
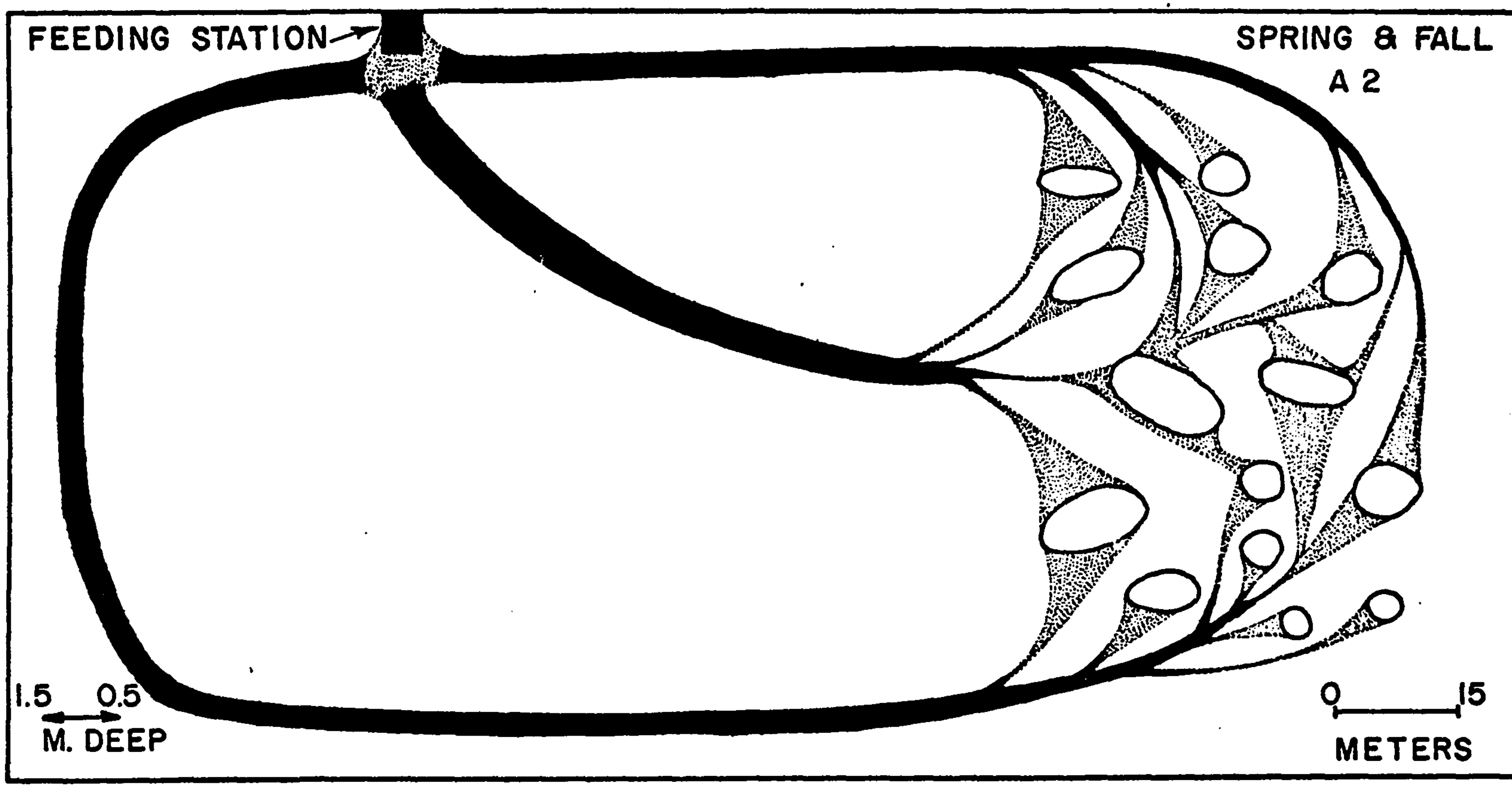
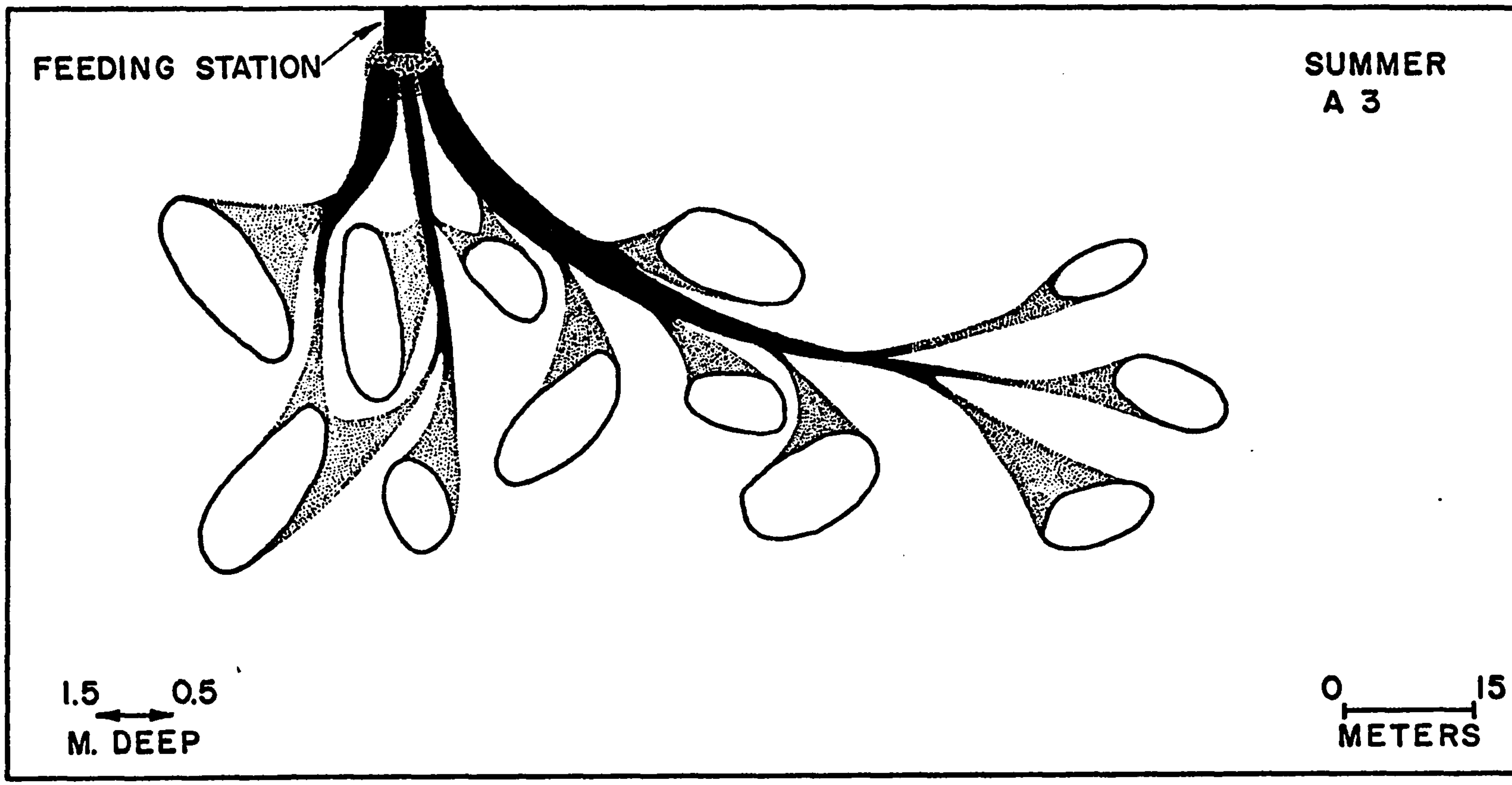
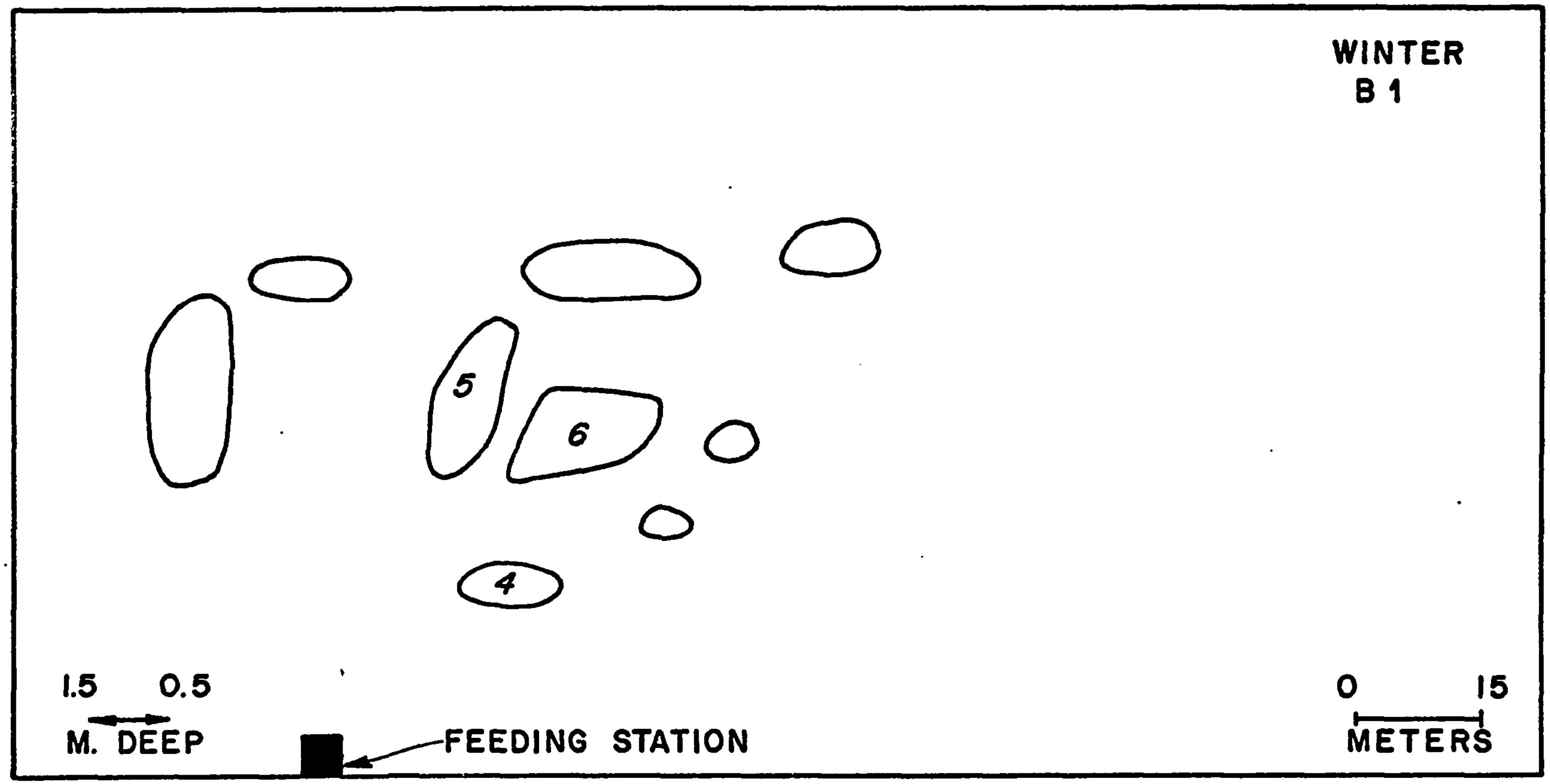
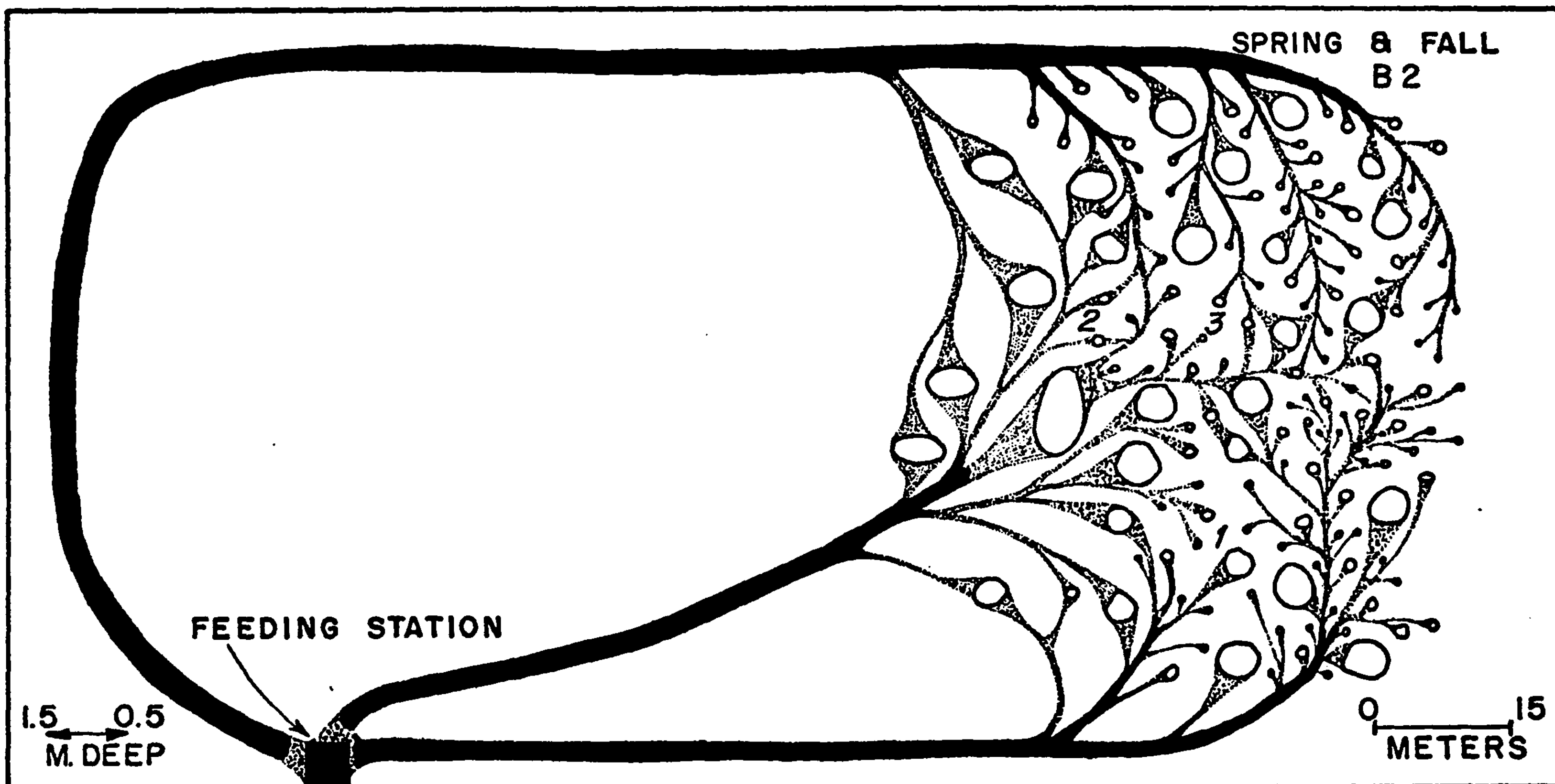


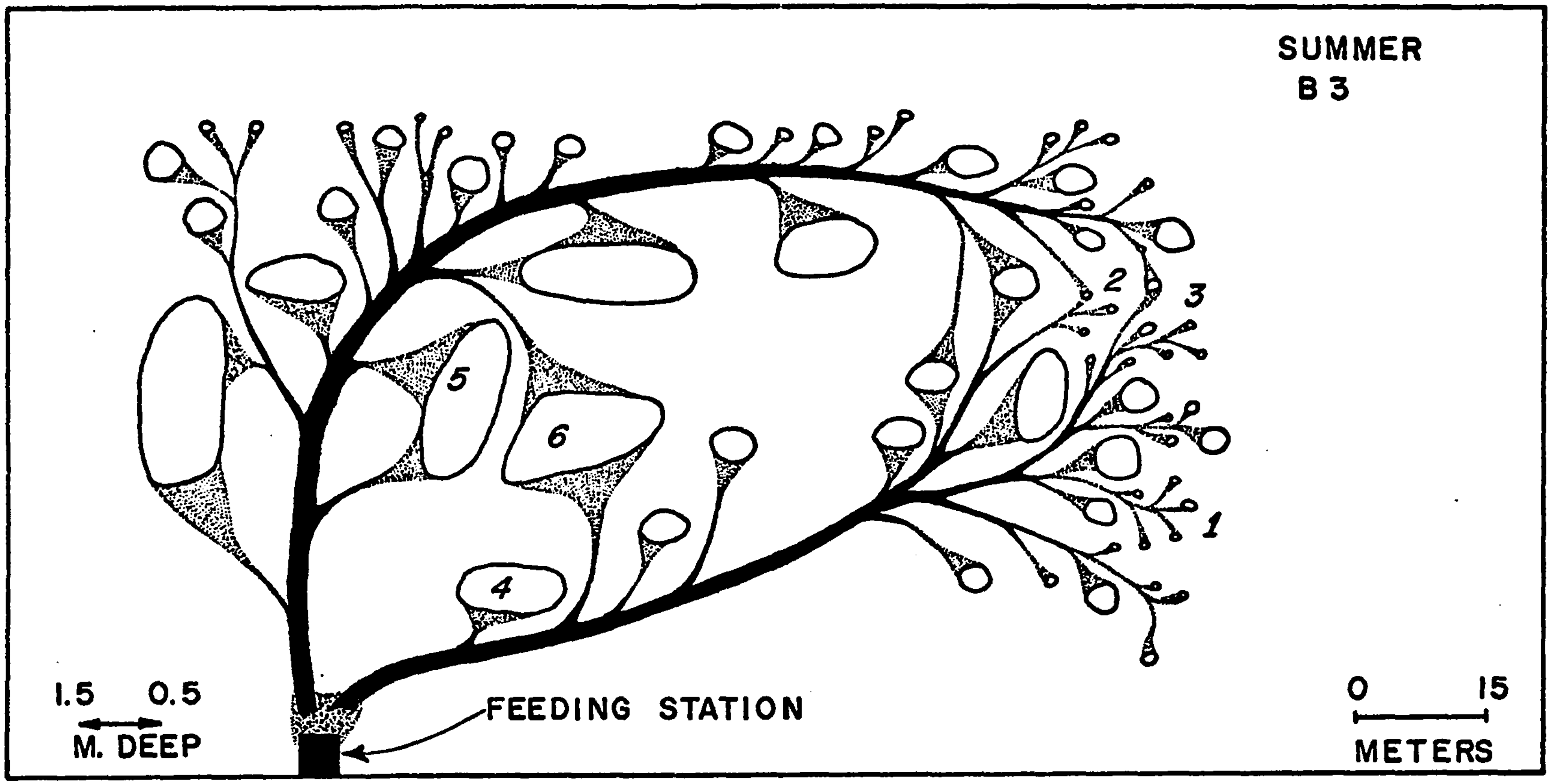
FIGURE 2.--Seasonal variation in the occupancy of home areas and use of swimways by channel catfish in two 1.6 ha ponds stocked at 6,000 fish/ha. A. 31- and 36-cm fish. B. 25-, 31-, 36-, and 46-cm fish. Data collected from actual measurements of the pond bottom after draining. The intermediate and large areas are drawn to scale, whereas the small areas reveal the location only. Dark areas represent the established swimways, whereas the dotted areas indicate one or more possible connections with the home areas.


FEEDING STATION
SPRING & FALL
A 2
1.5 0.5
M. DEEP
0 15
METERS


FEEDING STATION
SUMMER
A 3
1.5
0.5
M. DEEP
0
15
METERS


WINTER
B 1
5
6
4
1.5 0.5
M. DEEP
FEEDING STATION
0 15
METERS


SPRING & FALL
B2
FEEDING STATION
1.5
0.5
M. DEEP
0
15
METERS
2
3
1


SUMMER
B 3
1
2
3
4
5
6
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M. DEEP
FEEDING STATION
0 15
METERS

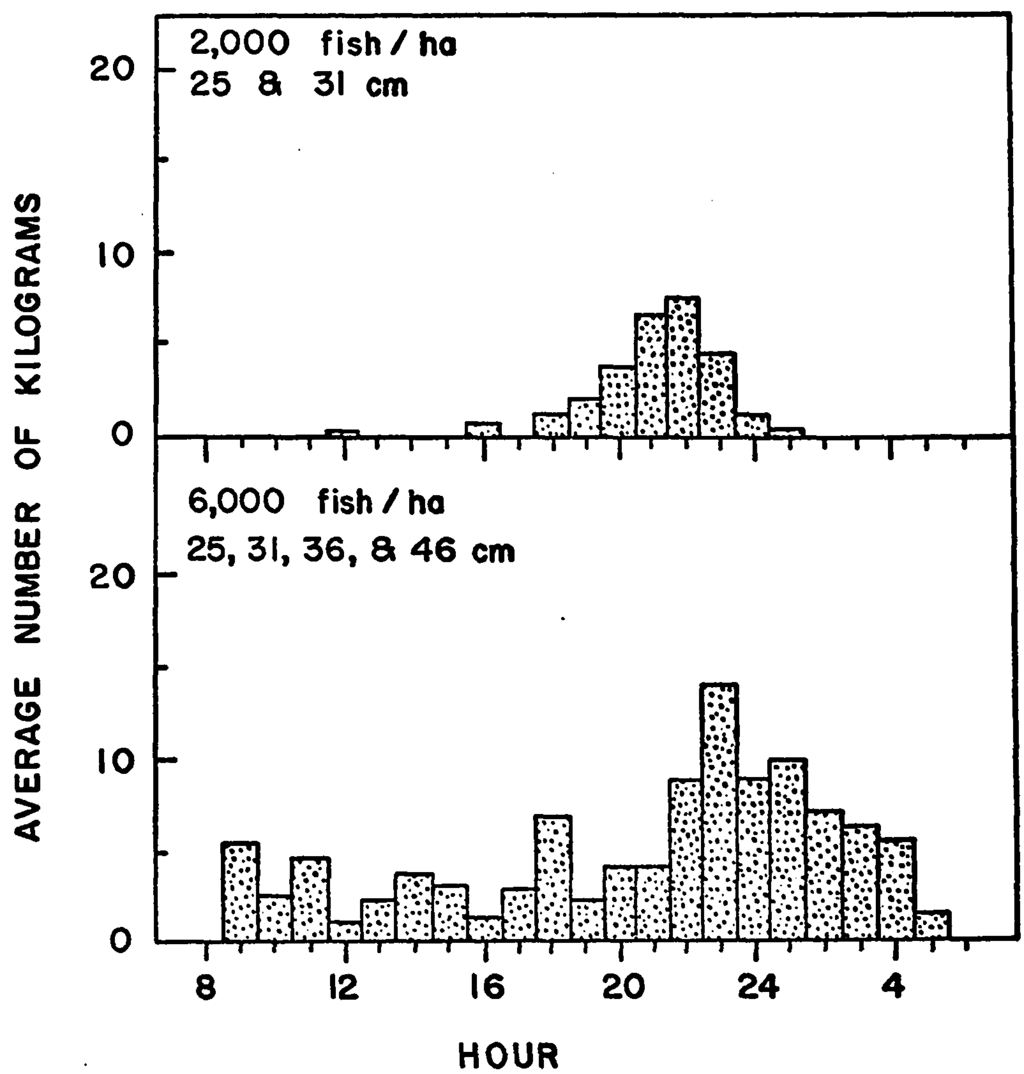

FIGURE 3.--Hourly food delivery for channel catfish in two 1.6 ha ponds, June 1972.

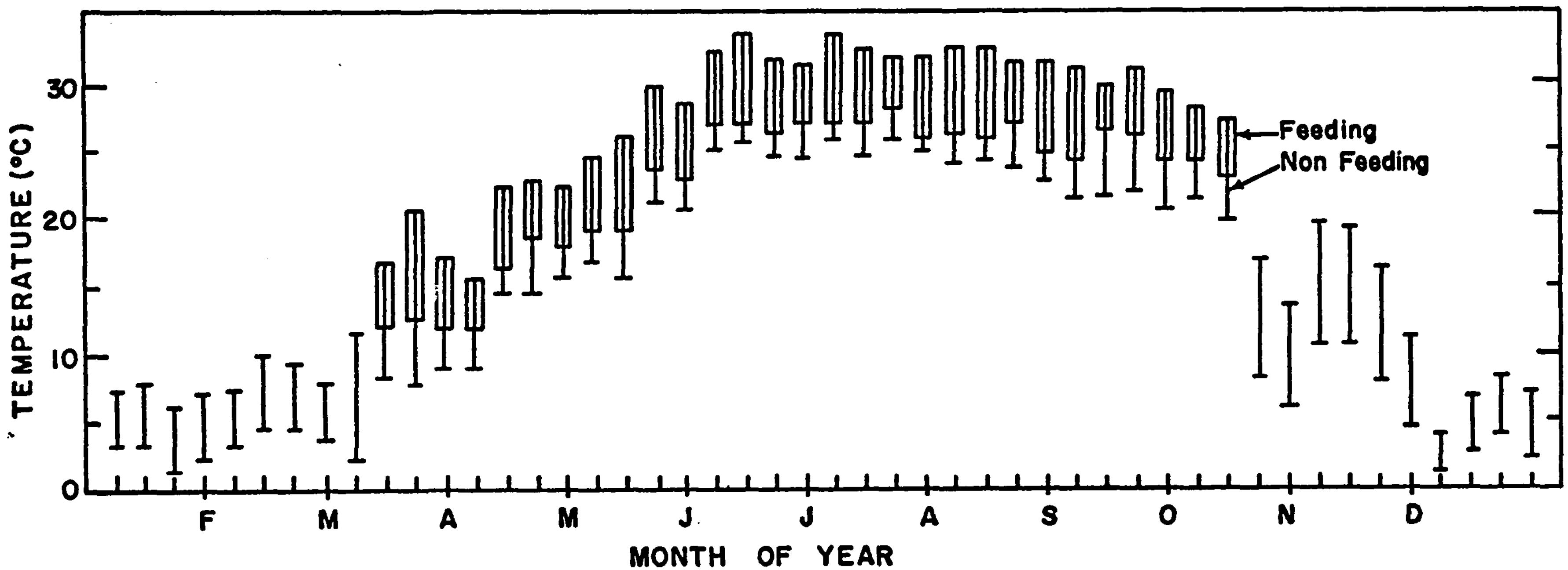

FIGURE 4.--Weekly range of temperature at which channel catfish fed in 1.6 ha ponds, 1972.

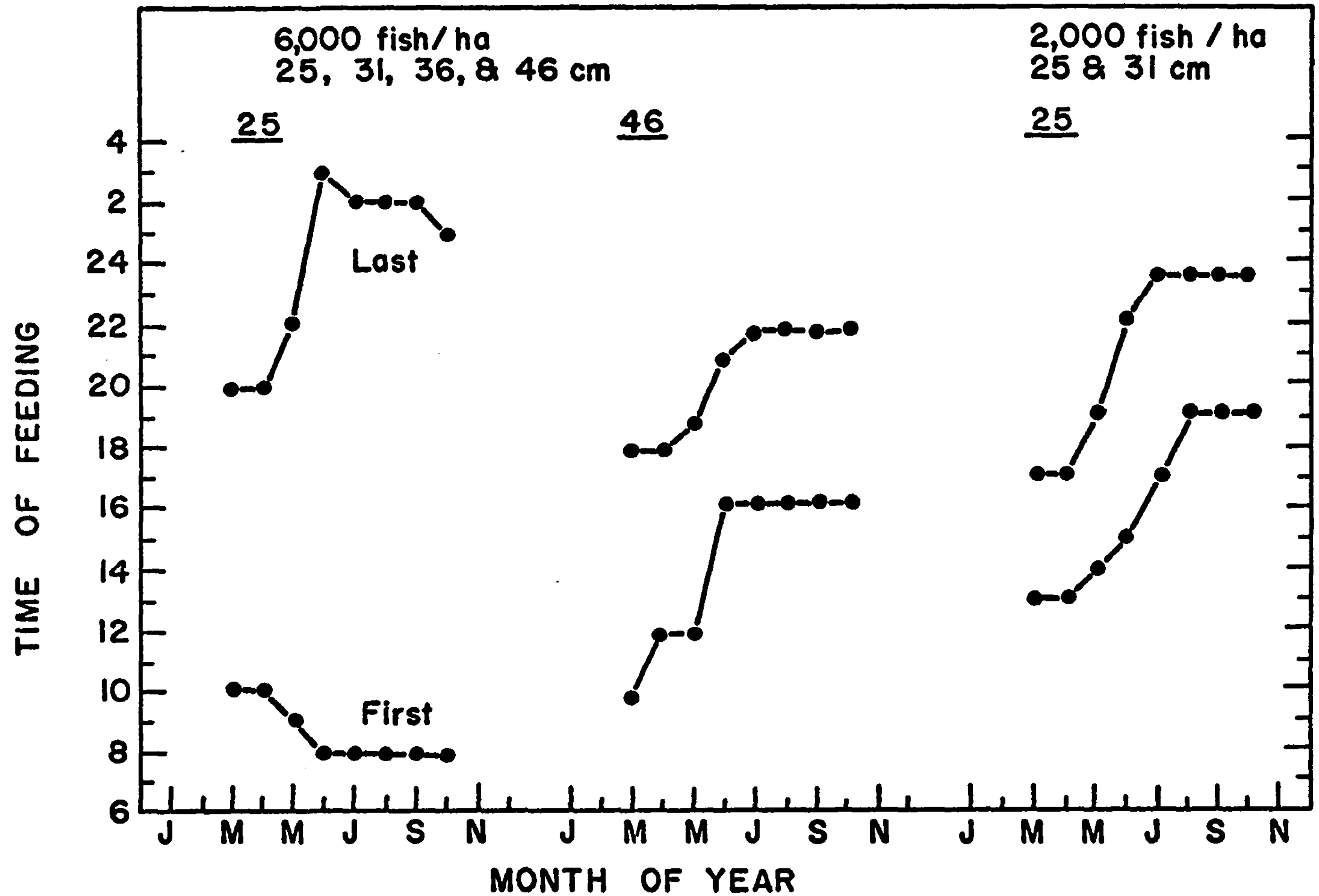

FIGURE 5.--Seasonal variation in time of feeding (72-hr observations) for channel catfish in two 1.6 ha ponds, expressed as the first and last of five marked fish to feed. n = 15.

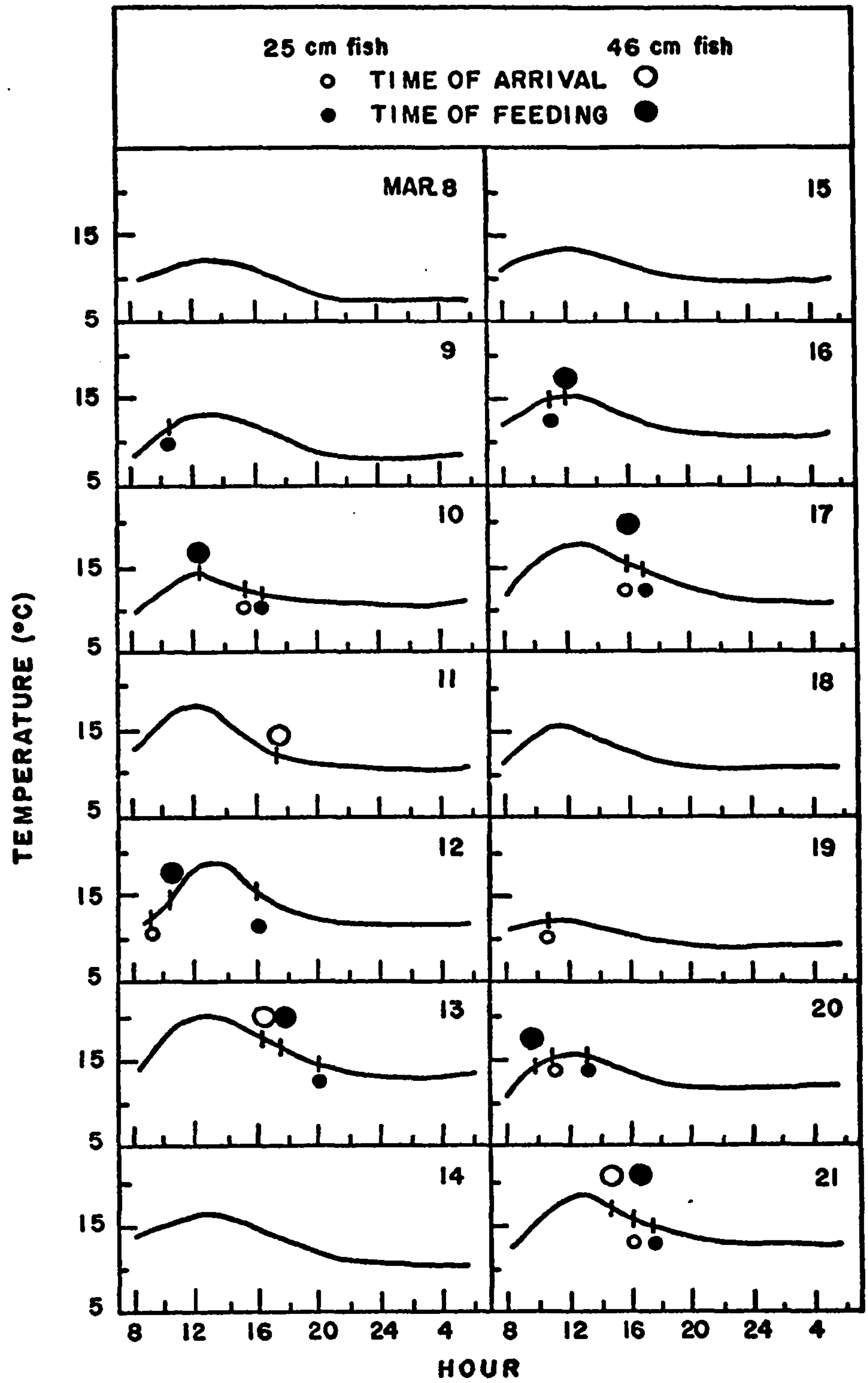

FIGURE 6.--Daily temperature curves for 14 days in March, 1972, with the time of arrival and feeding for two marked (25 and 46 cm) channel catfish in a 1.6 ha pond stocked at 6,000 fish/ha.

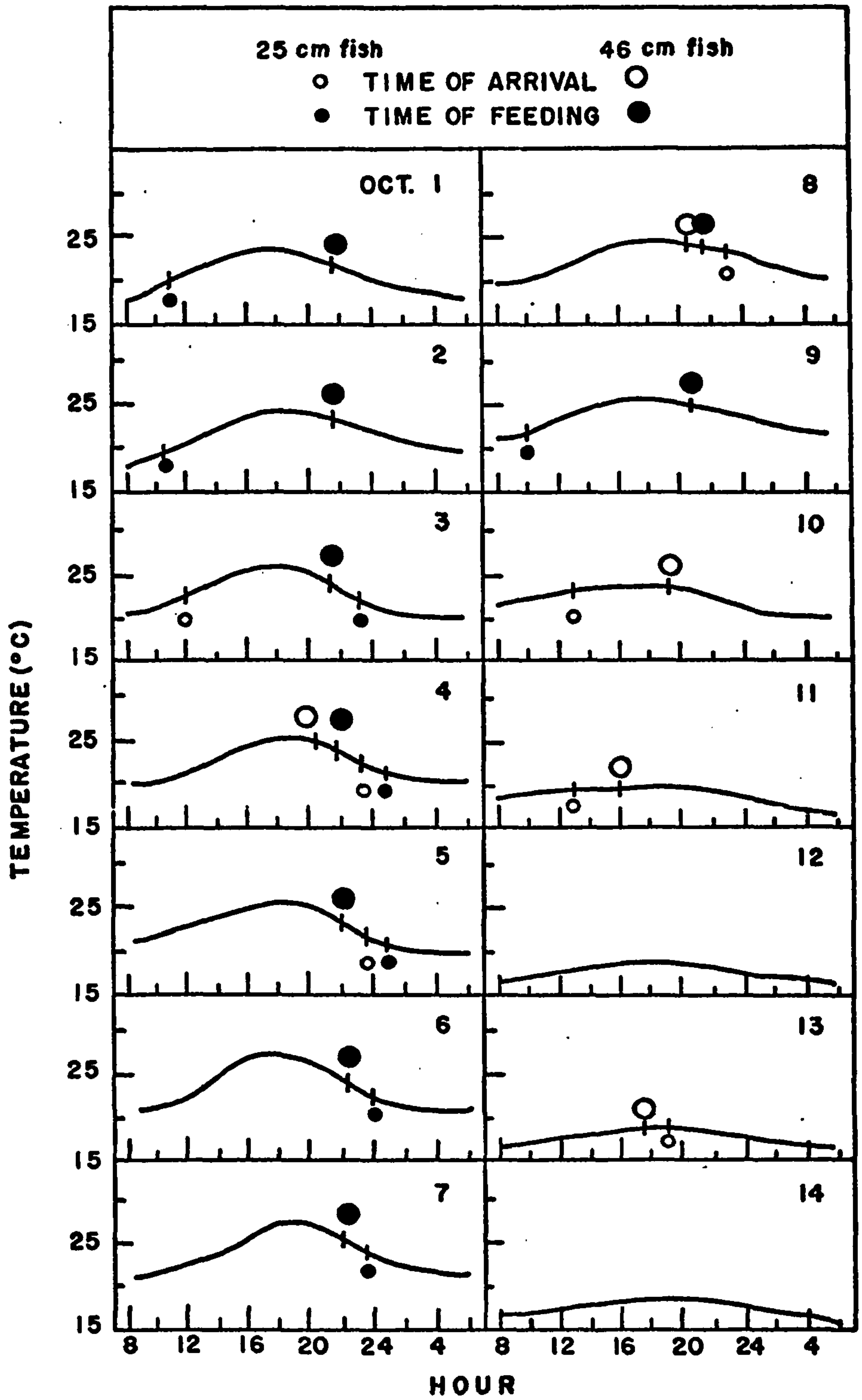

FIGURE 7.--Daily temperature curves for 14 days in October, 1972, with the time of arrival and feeding for two marked (25 and 46 cm) channel catfish in a 1.6 ha pond stocked at 6,000 fish/ha.

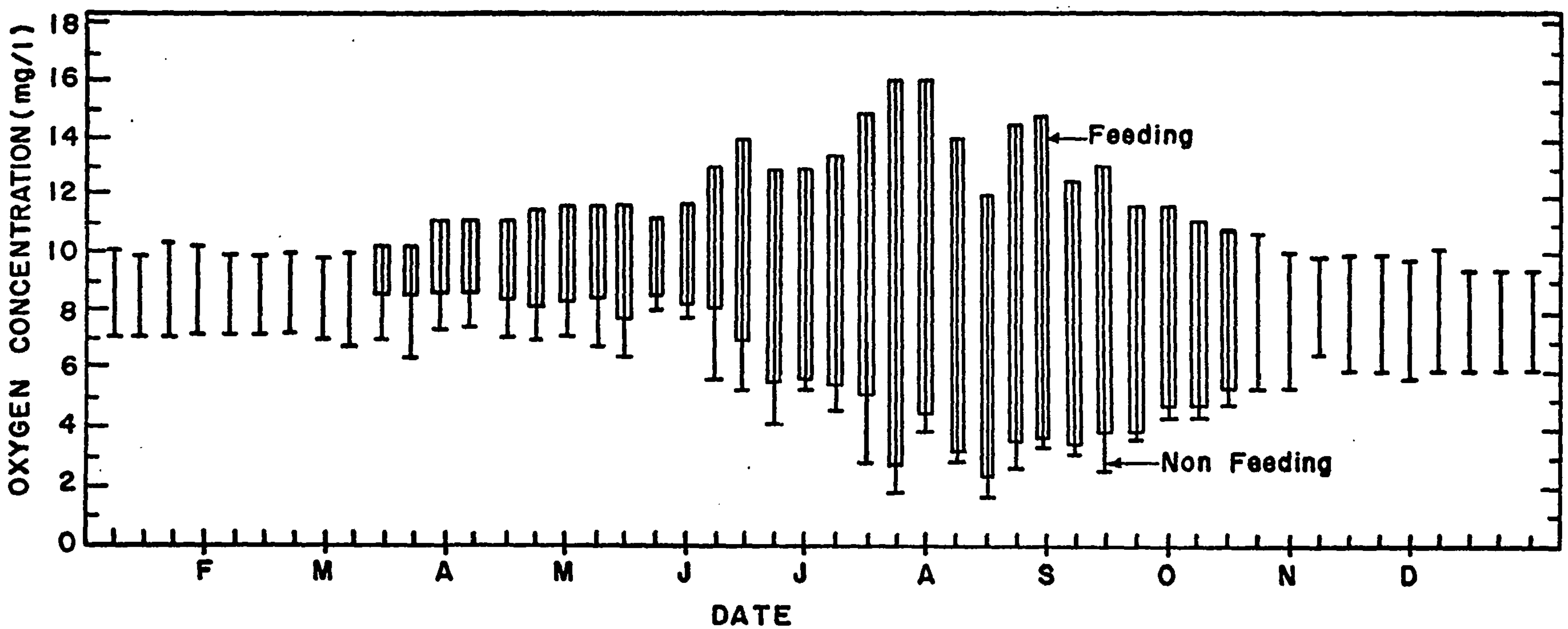

FIGURE 8.--Weekly range of oxygen concentration at which channel catfish fed in 1.6 ha ponds, 1972.

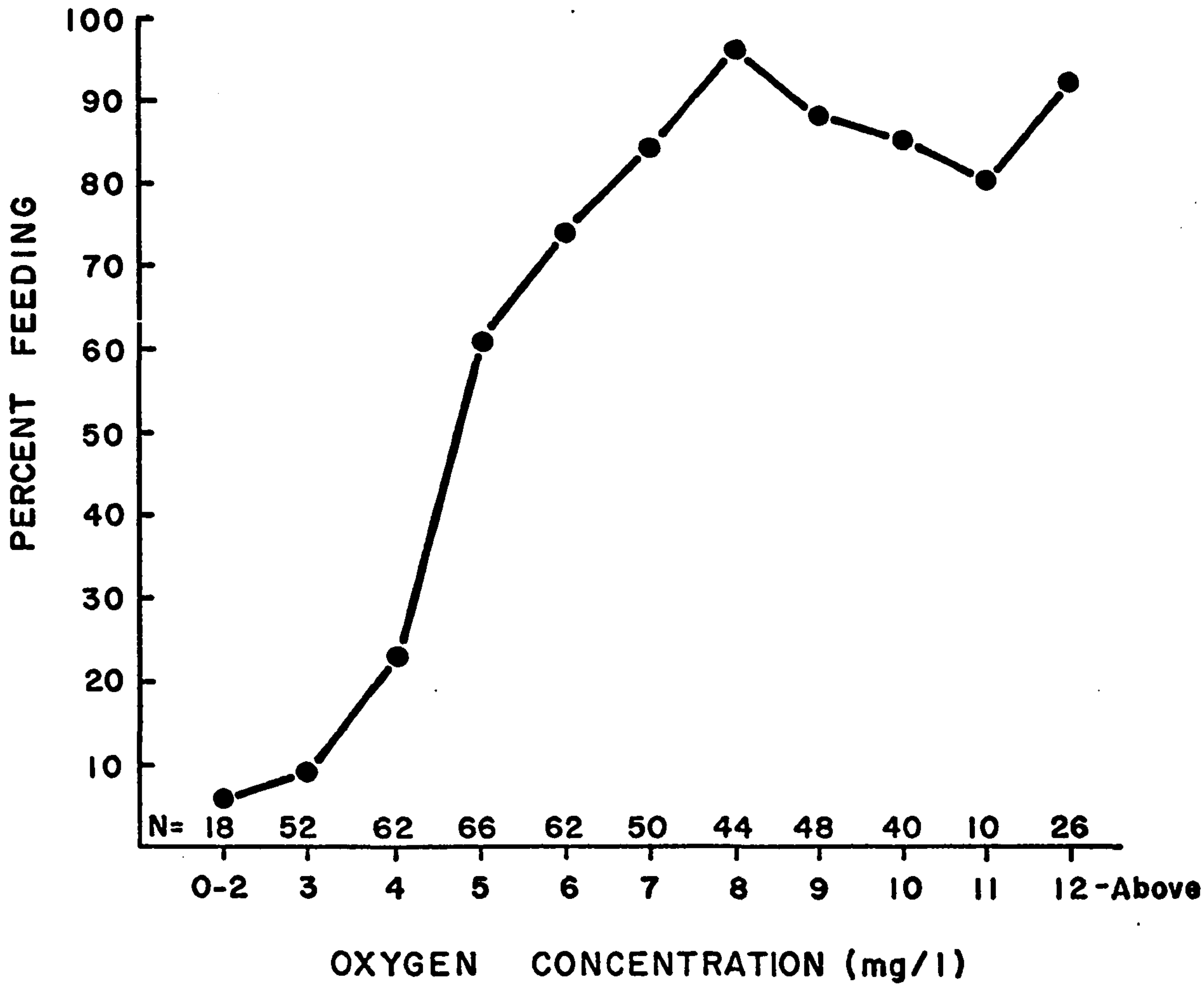

FIGURE 9.--Percentage of marked channel catfish feeding at various oxygen concentrations in the 1.6 ha ponds during June to August (1972), regardless of time of day.

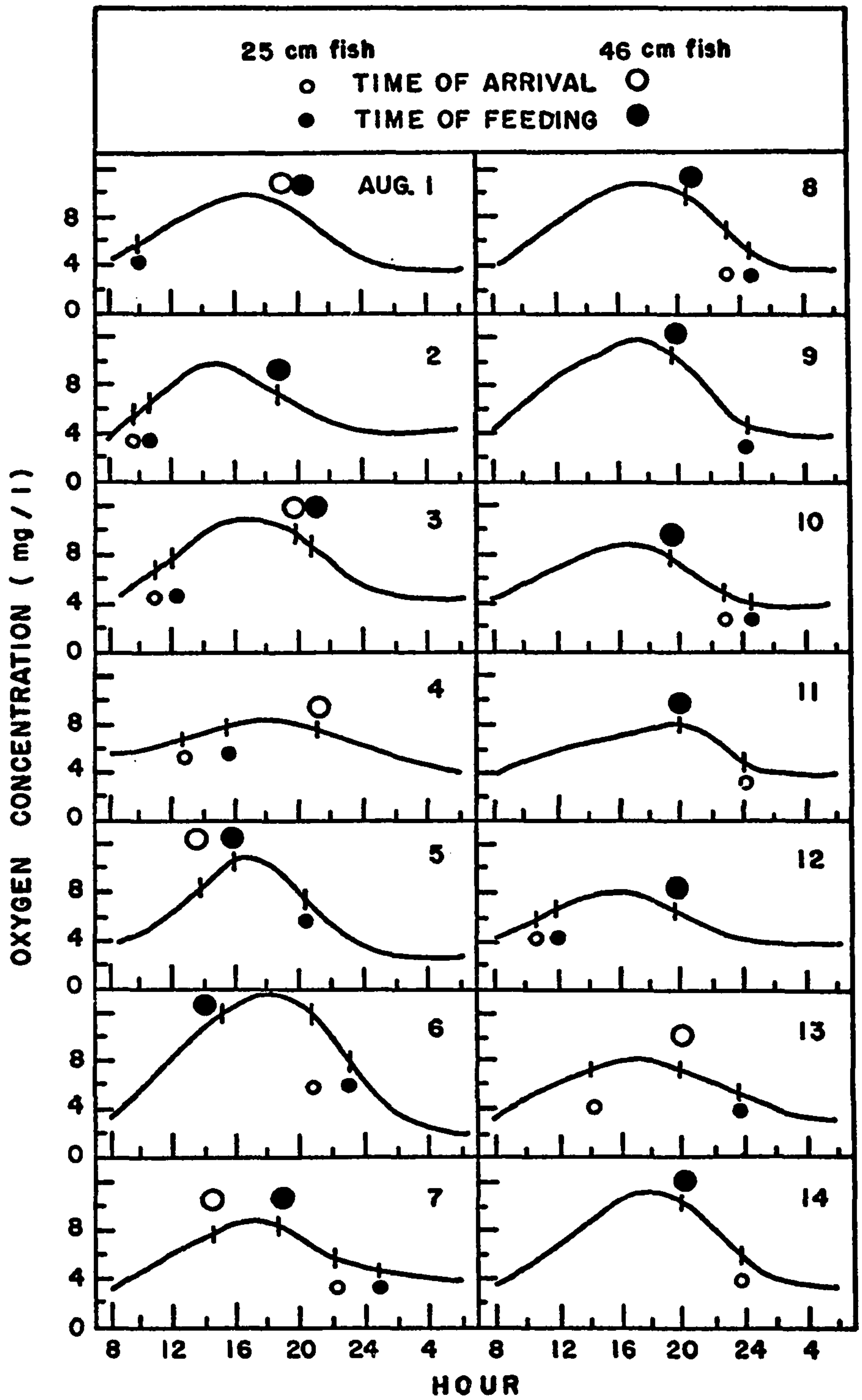

FIGURE 10.--Daily oxygen concentration curves for 14 days in August, 1972, with the time of arrival and feeding for two marked (25 and 46 cm) channel catfish in a 1.6 ha pond stocked at 6,00 fish/ha.

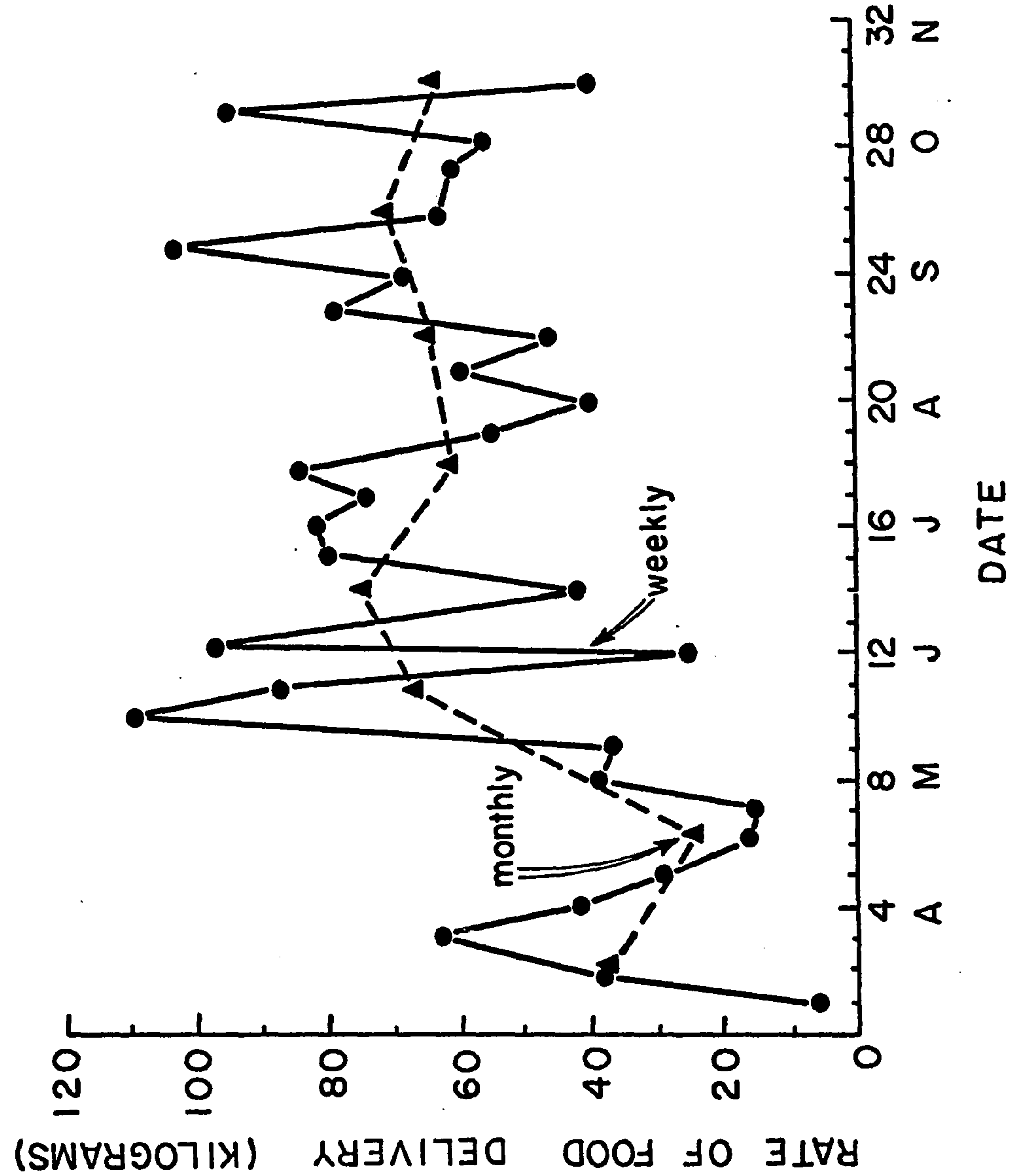

FIGURE 11.--Mean weekly and monthly rates of food delivery for a mixed population of channel catfish stocked in a 1.6 ha pond at 6,000 fish/ha, 1972.

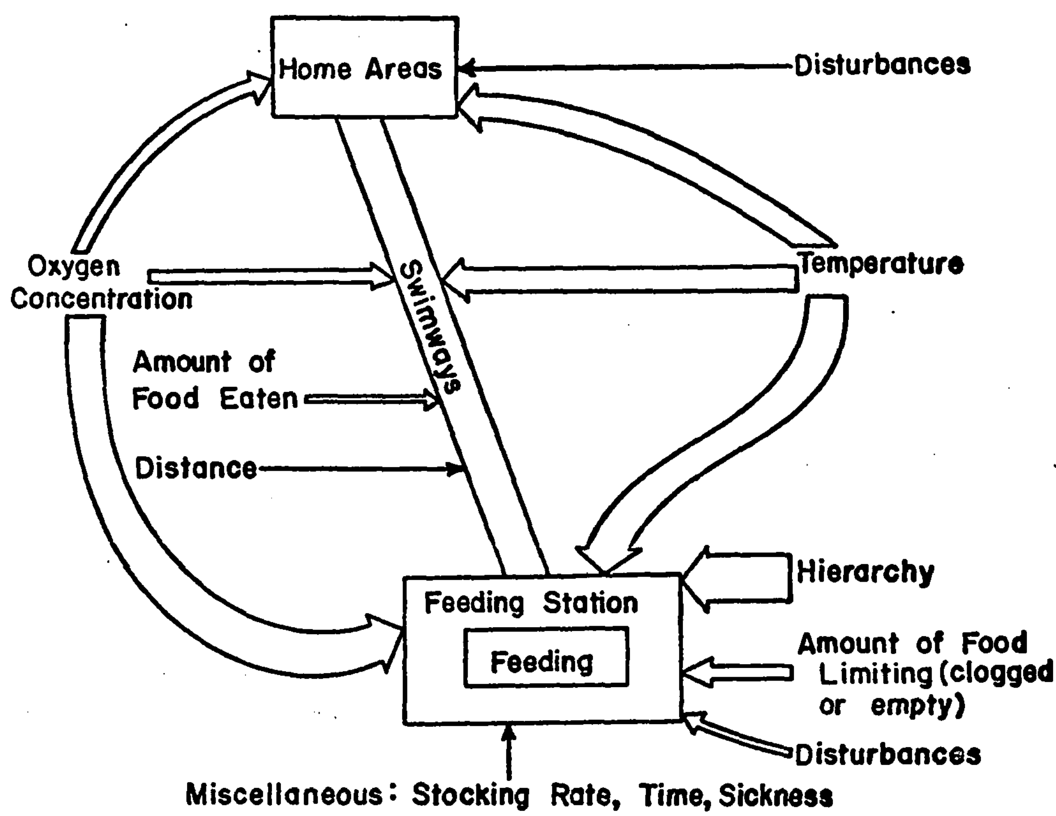

FIGURE 12.--Factors influencing daily routines. Thickness of the arrow indicates the relative importance of the influence of a factor on daily routine.