Possible Physiological Clock Associated with the Feeding Habits of the Central Mudminnow (*Umbra limi*) Kirtland

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Introduction

Predator-prey relationships of fish and aquatic insects have functioned in the regulation of both vertebrate and invertebrate populations throughout history. The idea of fish predators as means of insect control has been widely adopted. Although emphasis has been on *Gambusia affinis*, a number of small fish with broad tolerance levels for temperature changes and organic pollutants have possibilities for such biological control.

It should not be surprising, therefore, to consider the central mudminnow, *Umbra limi*, along these same lines. Peckham and Dineen (9) reported that mudminnows are a carnivorous species, feeding generally on the bottom. Principle food items are small crustaceans, molluscs, and most important, insect larvae.

Analysis of the feeding habits of the mudminnow is necessary in considering the fish for biological control. Population distributions of prey and predator tend to follow a sinusoidal rhythm. Since most aquatic insects reach their peak numbers in early summer, it is necessary to see just when the predator population has its maximum influence on the prey. Washino (11) reported that the greatest number and variety of food organisms consumed by predatory fish occurred in the early summer and that predation on mosquitoes intensified in the later summer period as a result of the relative scarcity of other food sources. To consider *Umbra limi* for mosquito control, one would have to show that it followed this basic pattern and was most effective as a predator during these times.

The ability of organisms to respond to their environment in rhythmical cycles has proven to be of selective value. Periodicity in organisms, cued either by some external or internal factor, allows them the advantages of obtaining basic energy requirements and reproductive needs at the most opportune time.

The idea of synchronized rhythms, especially in the interaction of the predator and prey, is not new. However, the idea of finding a rhythmic pattern intrinsic in the predator itself which is involved in the regulation of its feeding activity towards the prey is a different matter. This study provides information on the feeding behavior of the mudminnow, with special emphasis on a possible physiological cycle involved with their feeding activity. It is an effort to improve our understanding of the fish in its natural environment. This knowledge can then be applied as needed to make this proposed method of insect control as effective as possible.

Materials and Methods

This investigation consisted of two experiments. Experiment I was designed to analyze the feeding behavior of groups of mudminnows while they were maintained solely on a diet of mosquito larvae. Experiment II was designed to analyze the feeding responses of individual fish with the same diet, under controlled light and temperature, and in isolated conditions.

Central mudminnows were taken from Juday Creek, a small stream in St. Joseph County, Indiana, which empties into the St. Joseph River north of South Bend, Indiana.

For the first experiment, dealing with the feeding behavior of groups in *Umbra limi*, a total of 15 fish was placed in three 20-gallon tanks, which were barren except for sand on the bottom. Five *Umbra* were introduced to each tank according to relative size, with one tank containing fish of 3 to 4 cm. standard length, the second 5 to 6 cm., and the third 7 to 8 cm.

Part two of the research, which analyzed individual responses, was conducted after the first experiment had been completed. It consisted of fifteen 10-gallon tanks placed in an enclosed room where temperature was regulated at 17.2° C and light was constant. Each tank contained only one fish, with five tanks per size class of fish.

Mosquito type-form *Aedes aegypti aegypti* of the ROCK strain (Rockefeller Institute) were used throughout the study, and were reared at 31° C and 80% relative humidity. Properly conditioned egg strips were hatched in water of 21° C and the resulting first instar larvae were placed in pans filled with tap water. Liver powder was used as food for the larvae. When the larvae became fourth instar, they were then fed to the fish.

All fish were fed to repletion. In the group tanks, the fish were fed by placing mosquito larvae in the tank continously until all fish refused to respond to the larvae. For the second experiment, each fish was given a predetermined number of larvae depending on the size of the fish and was restricted to a fixed amount of time consumption. All fish were given an excess of mosquito larvae. Small fish received 200 mosquito larvae per feeding; the medium sized fish 250 larvae; and the large fish, 350 larvae. Fifteen minutes was shown by the first experiment to be sufficient time for all fish to reach repletion. Therefore, at the end of fifteen minutes the remaining larvae were removed, and the amount eaten by each fish was determined. The fish were fed every two days.

This information was collected from July 17 to October 14, 1976 and January 31 to March 8, 1977. Graphs of the number of larvae consumed per day, the total number of larvae consumed per size-class, and the number of larvae consumed by each fish were prepared for comparison of the feeding activity per individual fish and per size range. Similar comparative graphs were made of the following: barometric pressure, temperature, relative humidity, sky cover, precipitation, and phases of the moon to determine any correlations between feeding habits and these factors.

Statistical analysis by the nonparametric Friedman Two-Way Analysis of Variance by Ranks was performed to compare the number of larvae consumed at the observed peaks in the feeding activity (10).

Results

The total number of larvae eaten by each size of fish during the first experiment is shown in Figure 1. The graph shows that the total amount of larvae eaten was dependent on the relative size of the fish, with the total amount consumed by small fish being less than the total amount eaten by medium or large fish.

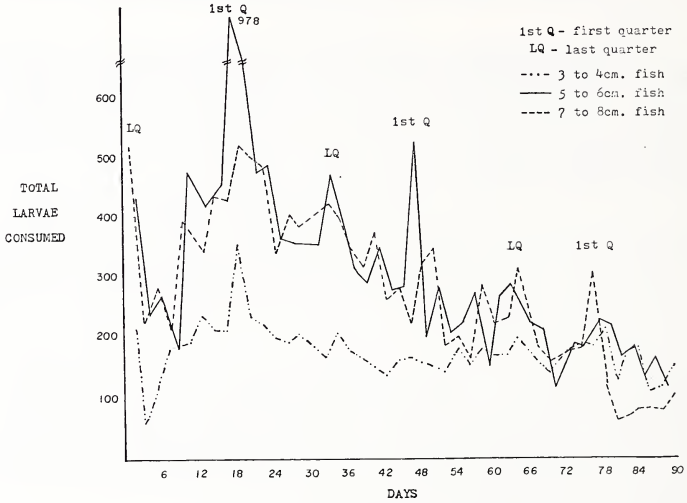

FIGURE 1. *Total larvae consumed per size class.*

Independent of the size of the fish are patterns of high and low points in the consumption of larvae. Figure 1 shows increases in the level of consumption approximately every 14 days, with the greatest amount eaten during the first quarter and last quarter phases of the moon. Alternatively, the lowest consumption periods occurred approximately every 14 days during the new moon and full moon. The total number of larvae consumed by all fish in Experiment I (see Fig. 2), emphasizes this general trend of a near-14-day feeding response exhibited by all three size classes.

Statistical analysis of the amount of consumption for the group tanks revealed the differences in larval consumption during different phases of the moon are significant at the 0.001 alpha level.

The *Umbra* exposed to external factors also exhibited an overall decrease in response to mosquito larvae during the three-month experimental period. However, statistical analysis of the third month alone showed that there was still a highly significant difference (= 0.001) in the rates of larval consumption between the first and last quarter phases of the moon, and the new moon and full moon, indicating that the feeding pattern, although diminished overall, was still present.

Each fish responded to the prey with varying degrees of consumption, but

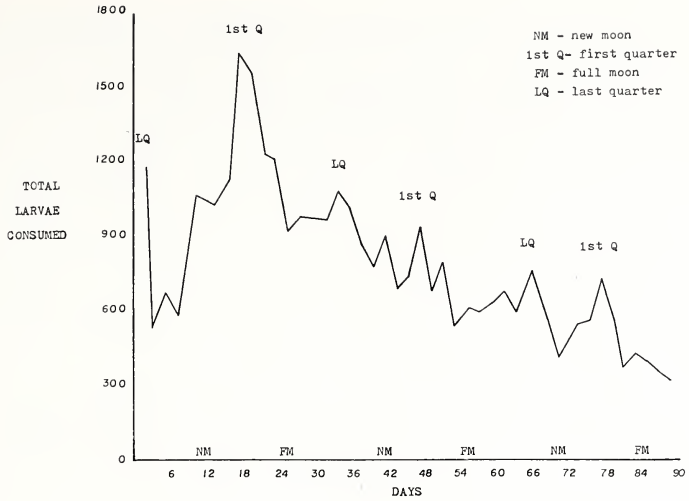

FIGURE 2. *Total larvae consumed.*

nevertheless with regular fluctuations approximately every 14 days. The amount of consumption by individual fish in the group tanks is shown in Figure 3. The feeding behavior of two fish from the medium size category is shown to emphasize similarities in the feeding activities of some fish, while also revealing characteristic differences in the feeding behavior of each fish.

Data collected from the second experiment indicate that the 14-day cycle was present in all fish in the controlled environment, regardless of size. Figure 4 shows the total number of larve consumed per size class for Experiment II.

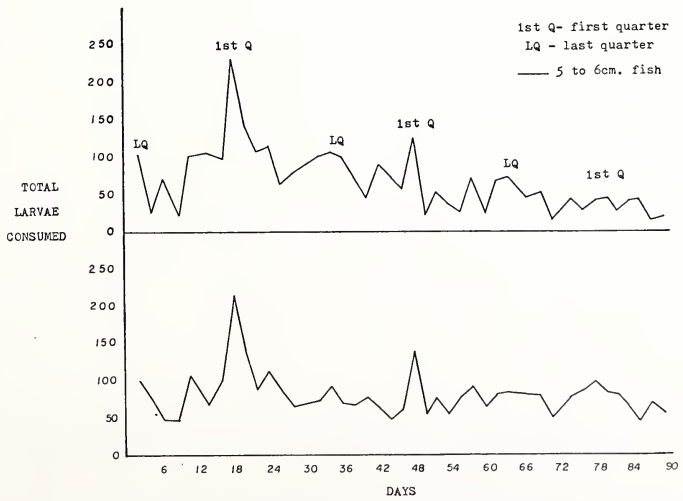

FIGURE 3. *Consumption per individual.*

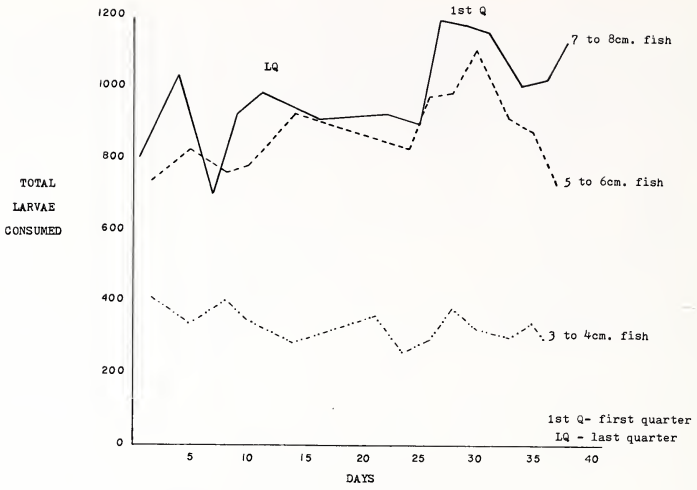

FIGURE 4. *Total larvae consumed per size class.*

Analysis by Friedman's Xr^2 test again supports the hypothesis of a 14-day cycle, and possible correlation to lunar periodicity, but with significance only at the 0.1 alpha level.

The feeding activity under constant light appeared to be slightly out of phase among the fifteen fish. Not all fish increased the amount eaten on exactly the same day. Figure 5 shows the feeding pattern of three individual fish of various sizes superimposed on each other and shifted to coincide with each other

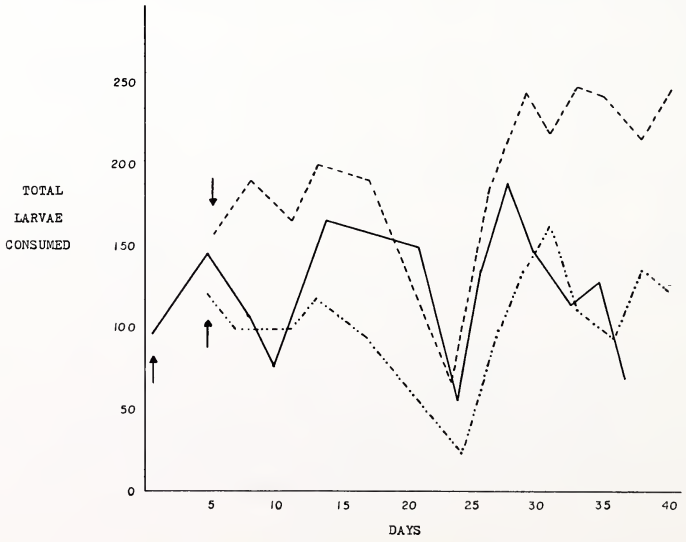

FIGURE 5. *Desynchronization of feeding cycles under controlled conditions.*

(arrows indicate first day of feeding). Even though there is a desynchronization in their feeding behavior, the approximate 14-day feeding pattern is still found. This deviation resulted in a more lengthy period of increases or decreases (see Fig. 4), and also in a lesser significant difference between peaks and troughs as shown by the 0.1 alpha level obtained by statistical analysis.

Results from the second experiment also suggests the presence of damping. The feeding rhythm was still present, but continued exposure to constant conditions resulted in reduced amplitude of the cycle.

Graphs of corresponding temperature, relative humidity, sky cover, and precipitation revealed that there is little, if any, correlation between these parameters and the feeding habits of the mudminnow.

Discussion

Results obtained by the first experiment suggest the presence of a physiological clock associated with the feeding behavior of the central mudminnow. Regardless of the size of the fish, there is present a rhythmic feeding response with an approximate 14-day period and possible lunar correlation.

Fish exposed to natural light cycles, as in the first experiment, possess a rhythmic pattern in feeding. However, the first trials can only suggest the presence of a physiological clock. Whether it was only chance that these fish increased or decreased their consumption of larvae approximately every fourteen days, or if this behavior was actually a mechanism incorporating a physiological process along with external cueing factors still needed to be ascertained. The second experiment pursued this aspect in more detail.

The periodicity found in the feeding habits of the first fish could be purely exogenous, where the environment is the real and only cause of the rhythm which in turn ceases in artificial constant conditions. Contrary to this endogenous rhythms, are controlled from within the organism itself. In this case the periodic environmental factor operates only as a synchronizing agent.

Results obtained from the second experiment, in which mudminnows were placed in a constant environment, indicate the presence of an endogenous rhythm.

The 14-day periodicity continued in artificial conditions but with a frequency that deviated slightly from the exact amount of a lunar cycle. Aschoff (1) states that under artificial conditions, if a periodicity continues but deviates by a certain, more or less constant amount from the external factor, then the periodicity is endogenous. The results obtained show that phase shifts were found in some individuals. At present, it is not possible to determine if these deviations were constant. However, the possibility exists, that by excluding external stimuli, which in this case appeared to be the light intensity of the moon, the physiological clock involved with the feeding of the mudminnow was unable to be synchronized and the fish became out of phase with one another.

Fade-out, or damping of an oscillation, is dependent on the conditions in which the organism is placed, Bunning (4). Continuous light often causes fade-

outs more rapidly than continuous darkness. These results show that there is a damping effect on the feeding cycle under constant conditions.

What is the significance of a rhythmic cycle in the feeding behavior of the central mudminnow? Does the feeding rhythm present an adaptive value for the species in its natural environment? Such questions must be looked at in the entire context of the interaction of the species with the physical and biological environment around it.

Structural characteristics of species are related to their food niches. Keast (7) described the morphological adaptation of *Umbra limi* which enable them to capture both hard and soft bodied insects. Physiological adaptations are equally important for the survival of the species. The presence of a physiological clock involved with the feeding habits of the mudminnow provides a selective advantage for the species by keeping the individuals of a population in phase with the environment in which they live. Exploitation of resources is maximized and intraspecific competition is limited.

Lunar cycles have been shown to exist in chironomids, ephemeropterans and trichopterans. Such cycles deal with the synchronization of hatching, emergence and reproduction. The effectiveness of the predator would be greatly increased if it possessed a synchronizing agent that enabled it to follow the prey in such a cycle.

Some chironomids have been show to hatch within a few days of the full moon and new moon. A maximum number of larvae would therefore be present during the first and last quarter phases of the moon, a time when the mudminnow would be at its peak point in the consumption of larvae. At times of low prey densities the predator would also be at the low consumption point in its cycle.

Umbra limi also possess a seasonal response in their feeding behavior. The results from these experiments, in accordance with Maw (8), show that the mudminnow consumed the largest amount of larvae during the summer months, the season when Washino (11) indicates that mosquito larvae numbers increased. Maw noted a decrease in the numbers of larvae consumed by the mudminnow toward the later summer and suggested this relative state of inactivity could reflect a parallel period of aestivation that might occur during adverse conditions in its normal habit. The overall decline in larvae consumption found in the first experiment agrees with these findings. The effect of a continuous laboratory environment is also a possible factor involved with this apparent decline.

The selective advantage of the predator population in synchronization with prey is evident. The availability of food along with reduction of intraspecific competition operates to maintain the species at its optimal level.

As a possible agent for biological control, *Umbra limi* appears to be highly qualified. Findings from this research support Maw (8) who recommended the central mudminnow for integrated control programs. The species is adapted morphologically and physiologically to capture and assimilate prey such as aquatic insects with great efficiency, at the most opportune time to insure their growth and reproduction for the continuation of their species.

Acknowledgements

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