10-1971

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TO INCREASE THE AVAILABILITY OF AERIAL INSECTS
TO CAGED BLUEGILL SUNFISH

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A POND'S CARRYING CAPACITY for fish is usually limited by its food supply. The addition of inorganic or organic fertilizers increases the production of natural forage organisms in a pond, and the natural food supply can be supplemented with artificial food or by introducing forage organisms produced elsewhere. Ultraviolet light offers a means of supplementing the natural food supply with aerial insects derived from both the aquatic and terrestrial biotopes. Of the aquatic larvae that metamorphose and leave the water, 75 percent never return (Vallentyne, 1952). Thus, considerable biomass which is potential forage is lost from the pond habitat. It is possible to recycle a portion of these adult insects into the pond by the use of ultraviolet light. Ultraviolet light can also be used to concentrate and make terrestrial insects available as food for fish. This is particularly significant in small lakes, since the terrestrial area is greater and can contribute a greater insect biomass.

METHODS AND RESULTS

Study Sites

An investigation of the growth of bluegill sunfish (*Lepomis macrochirus* Rafinesque) confined in illuminated cages was conducted from May to September, 1969. The bluegill sunfish was chosen for the experiment because aquatic and terrestrial insects normally constitute a large percent of its diet (Leonard, 1940; Scidmore and Woods, 1960). Study sites consisted of three dissimilar pond habitats in Jackson County, southern Illinois. The ponds were Stripmine Lake, Research Pond, and Fountain Bluff Ponds.

Stripmine Lake, formed approximately 35 years ago during the stripmining of coal, is 2 kilometers north of Desoto. This lake of 5 hectares is protected from surface wind by high spoil banks. It has a maximum depth of 14 meters and thermally stratifies. During most of summer, the hypolimnion is devoid of oxygen.

Research Pond is one of 18 similar manmade ponds located just north of the Carbondale City Reservoir dam. The pond has an area of 0.06 hectare and an average depth of 1.25 meters. The Reservoir (32 hectares), forested land, and fallow fields surround these ponds.

The Fountain Bluff Ponds are located a short distance from Gorham, Ill., in the old flood plain of the Mississippi River. Ponds 9 and 41 were used in this study. Unless otherwise noted, Fountain Bluff Pond refers to pond 9. Each of these manmade ponds is 0.21 hectare in area and averages 0.9 meter in depth. In the immediate area there are 33 other 0.21-hectare ponds. The ponds are surrounded by fertile farm land and forested land that is poorly drained.

Lights and Light Traps

A number of studies have shown that ultraviolet lights attract more insects than do incandescent, neon, or mercury vapor lights (Frost, 1954; Glick, 1954; Pfrimmer, 1967; Weiss, 1943). Fifteen-watt fluorescent black bulbs were used as an ultraviolet light source throughout this study. These bulbs produce ultraviolet light (1800 fluorens) at wavelengths of 2800 to 3800 angstroms and visible light (154 lumens) at wavelengths of 3800 to 7600 angstroms. Peak radiation is at 3500 angstroms (Pfrimmer, 1955).

In order to induce bluegill sunfish to feed at night, a 15-watt Pennsylvania light trap (Frost, 1957) was modified by attaching a 25-watt incandescent bulb below the ultraviolet bulb. The Pennsylvania light trap is characterized by four baffles mounted at right angles to each other. As insects spiral into the light source, many hit the baffles and fall into the water. The 25-watt incandescent bulb was positioned at the intersection of the baffles so that there was little or no reflection from the metal. The metal on the light traps was painted flat black to reduce reflections. This apparatus was used in experiments designed to determine the distance at which insects are attracted to lights. When a light trap was used to attract insects to a cage containing fish, the funnel was removed, and the trap was suspended vertically over the center of the cage 15 centimeters above the water surface (see figure). This system allowed insects hitting the trap to fall directly into the water.

Cages

Nine cages of two designs were used. Cages of the first design were divided into four equal cells, while cages of the second design were undivided. Cages of the first design were 1.9 meters long, 1.9 meters wide, and 1.3 meters deep. The cages and dividers were constructed of 16-gauge welded wire having a mesh size of 1.27 by 1.27 centimeters. When floated by styrofoam blocks, each cell contained approximately 1 cubic meter of water. A single light trap was placed vertically over the center of each cage. To randomize the food supply to each cell, all cages were rotated 90 degrees fortnightly.
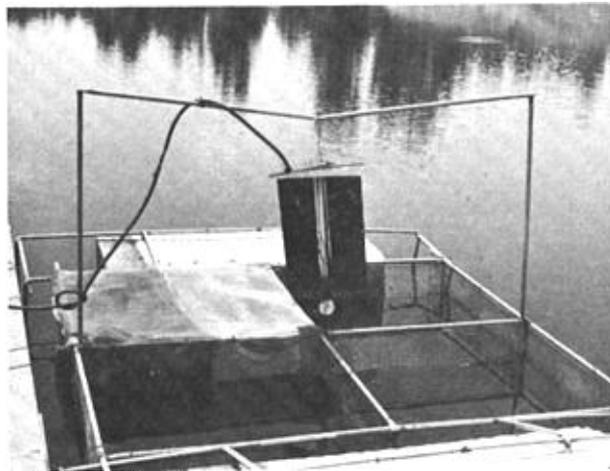
A modified Pennsylvania light trap, with the funnel removed, suspended vertically over the center of a compartmentalized cage.

Unpartitioned cages of the second design were constructed of the same material as those of the first design. These were 1.1 meters long, 1.1 meters wide, and 0.9 meter deep. They contained approximately 0.7 cubic meter of water when floated by styrofoam blocks.

Placing the Light Trap

In order to obtain maximum efficiency of aerial insects as a food supply for caged fish, the cages were placed at some minimal distance from each other so that there was no interaction between the lights. When light traps A and B were placed 15 or 30 meters apart, there was no significant difference (alpha = .05) between the dry weight of insects caught by light trap A operated alone or in combination with trap B (table 1). When both lights were on, there was no significant difference in the weight of insects caught by light A and by light B. When the light traps were placed 3 meters apart, however, there was a significant difference between the dry weight of insects caught by light trap A when it was operated alone and when it was used in combination with trap B. On any given night when both lights A and B were on, 95 percent of the insects attracted were caught by one light. Thus, one light was interfering with the other.

Light traps were placed 3 meters and 9 meters from the shoreline to determine if distance

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[Samples taken in July and August]

Location	Distance between traps (meters)	One light on [1] Light A (grams)	Both lights on	
			Light A (grams)	Light B (grams)
Stripmine Lake_____	3	0.34	0.23	0.16
Research Pond_____	15	0.35	0.40	0.29
Fountain Bluff Pond_____	30	2.92	2.46	2.71

[1] Lights were turned on for 30 minutes, 1 hour after sunset.

had an effect on their catch efficiency. The lights located 50 meters apart were turned on simultaneously 1 hour after sunset for 30 minutes. A t-test was used to test for significant difference between the mean dry weight of insects caught by each light trap in 20 trials. There was no significant difference (alpha = .05) in the catch of a light trap placed 3 meters (average 0.36 gram) from the shoreline as compared with one placed at 9 meters (average 0.42 gram). This was true even when only terrestrial coleopterans and hemipterans were considered.

Thus, light traps used in this study could be placed at least 9 meters from shore and within 15 meters of each other without reducing the insect catch, and approximately 25 illuminated cages could be placed around the edge of a 1-hectare pond without a decrease in efficiency.

Effect of Pond Location and Stocking Rate

In order to determine the effect of locale and stocking density on bluegill growth, two partitioned cages were placed in each of the three ponds. All cages were placed a minimum of 30 meters apart. The four cells of each cage were stocked with 5, 9, 18, and 27 fish (average weight 44 grams) in early May 1969. In each of the three ponds an unilluminated cage of the second design was stocked with nine bluegill (average weight 44 grams). After 80 days there was, depending on density, a 2.5 to 7 times greater weight gain of fish flesh at Fountain Bluff Pond than at either Stripmine Lake or Research Pond (table 2). There was no significant difference (alpha = .05) in weight gain at the four densities used in either Strip-

mine Lake or Research Pond, but there was a significant difference in weight gain among the four densities at Fountain Bluff Pond. The largest gain of fish flesh occurred in the cell initially stocked at the highest density, while the smallest gain occurred in the cell stocked at the lowest density. In the high density cell (cell D) at Fountain Bluff Pond, there was no significant change in total weight of fish between 80 and 140 days. However, there was a significant change in total weight (alpha = .05) in cells B and C. Although no significant change in total weight occurred in cell A, this is probably due to the death of a fish in this cell.

Thus, in 80 days approximately 1,400 grams of fish flesh were produced in the high density cell at Fountain Bluff Pond with a maximum standing crop in this cell of 2,600 grams. At Stripmine Lake and Research Pond approximately 200 grams of fish flesh were produced in each cell with a maximum standing crop of 1,400 grams. In this experiment the final mean weight of bluegill was greater in cells stocked at a lower density than in the cells stocked at a higher density (table 2). At corresponding densities fish were larger at Fountain Bluff Pond than at Research Pond or Stripmine Lake.

After 80 days the total weight of fish confined in unilluminated cages at Stripmine Lake and Research Pond decreased from 402 to 313 grams and from 412 to 326 grams, respectively. There was no mortality in these cages. The fish escaped from the unilluminated cage at Fountain Bluff Pond.

From August to October, 1969, an experiment was conducted to determine what percent of the bluegill growth was attributable to aerial

Table 2.—*Weight change of bluegill[1] confined in cages under ultraviolet illumination[2]*

| Cell type | Initial number of fish | 80 Days | | | 140 Days |
		Strip-mine Lake [3]	Research Pond [3]	Fountain Bluff Pond [3]	Fountain Bluff Pond [4]
Total weight gain per cell (grams)					
A	5	220	160	400	[5] 430
B	9	220	180	520	710
C	18	180	160	890	1,270
D	27	190	190	1,460	1,340
Final mean weight (grams)					
A	5	87	75	123	152
B	9	70	64	103	124
C	18	57	53	96	118
D	27.	52	52	98	97

[1] Initial average weight 44 grams (34 to 51 grams).
[2] Survival average 97 percent (80 to 100 percent).
[3] Values are the average of two cells.
[4] Values are based on one cell.
[5] This figure is low because one fish died in this cell.

insects and what percent was attributable to food organisms coming into the cells from the water. To exclude aerial insects from the food supply, window screen was placed over one cell of each of four partitioned cages. The screen wire extended 20 centimeters below the water's surface. Four male and five female bluegill (average weight 50 grams) were placed in one unscreened cell and the screened cell. Three cages were set up in Stripmine Lake and one in Fountain Bluff Pond. An unilluminated cage containing four male and five female bluegill was placed in each of these ponds. After 60 days the fish were harvested and weighed individually.

Fish in screened cells exhibited approximately two-fifths the growth of fish in unscreened cells (table 3). Fish in unilluminated cages at both ponds lost weight. Therefore, 100 percent of the food utilized for weight gain was attracted to the cages by the lights.

Food Organisms Eaten by Bluegill

An experiment was designed to determine to what extent bluegill of the size used in this study were feeding on net zooplankton as opposed to other aquatic organisms and aerial insects. A cage and light trap were placed in Fountain Bluff Pond (No. 41). Fifteen bluegill were initially stocked in this cage. Ten fish were harvested at each of five irregular intervals throughout the summer. After each harvest 10 different fish were placed in the cage. Stomach contents were examined under a dissecting scope, assigned to one of four categories, dried to a constant weight at 100°C., and weighed on an analytical balance. By dry weight, 74 percent of the forage organisms eaten by bluegill were aerial insects, 14 percent were aquatic insects, and 11 percent were miscellaneous food items. Even though preliminary investigation showed that the light concen-

Table 3.—*Percent weight change of bluegill[1] confined in cages[2] for 60 days[3]*

| Location | Illuminated | | Unilluminated |
	Screened	Unscreened	Screened
Stripmine Lake	[4] 18	[4] 41	[5] −20
Fountain Bluff	[5] 58	[5] 147	[5] −9

[1] Initial average weight 50 grams (39 to 59 grams).
[2] Initial number of fish per cell was 9 (4 males plus 5 females).
[3] Survival 100 percent.
[4] Average of three cells.
[5] Based on one cell.

trated the zooplankton 10 to 15 times, only 1 percent of total weight was net zooplankton.

General Observations

There was no bluegill mortality due to fighting at any density used.

Many insects, instead of falling directly into the water, landed on the cage. Some insects fell into the water and then flew away. Whether they eventually returned and were eaten by the fish could not be determined.

Except in inclement weather, a large number of insects were present around the ultraviolet lights by dusk.

For bluegill to feed at night, the 15-watt ultraviolet bulb had to be supplemented with an incandescent bulb. Although a 25-watt incandescent bulb was used in the present study, a 15-watt incandescent bulb radiates sufficient visible light to induce bluegill to feed.

DISCUSSION

Bluegill Growth in Relation to Pond Location and Population Density

The growth rate of bluegill confined in illuminated cages is a function of both pond location and the density at which the fish are stocked. An estimate can be made of the total weight of aerial insects attracted to an ultraviolet light. The carrying capacity of a cell at Fountain Bluff Pond was 98 grams times 27 fish or 2.6 kilograms. Because of the symmetry of the light over the four cells, it is assumed that cages at Fountain Bluff Pond could support a maximum standing crop of 4 times 2.6 kilograms or 10.4 kilograms of fish. Since three-fifths of the food is aerial insects, this source must support three-fifths times 10.4 kilograms or 6.24 kilograms of fish. If the maintenance level is assumed to be 3 percent of body weight per day, then the total weight of insects eaten per day would be 187 grams. At Research Pond or Stripmine Lake the value is 7/13 (1400 g/2600 g) of 187 grams or 100 grams per day.

The weight of insects eaten by the fish per day is less than the weight of insects attracted to the cage area by the lights. If the fish were in a pond and the light were suspended directly over the water, those insects that landed on the

floats or fell into the water outside the cage, in the present study, would be available to the fish.

It is possible to extrapolate the figures on bluegill growth in illuminated cages to a fish population in a pond. If 25 light traps were evenly spaced around the shore of a 1-hectare pond located in an area comparable to Fountain Bluff Pond, production of fish flesh above the pond's former carrying capacity should be increased by 351 kilograms (180 days divided by 80 days times 6.24 kilograms times 25 lights) in 180 days. This increase would be due entirely to aerial insects. The cost of electricity for a 15-watt incandescent and a 15-watt black bulb used 8 hours a night is 10 cents per kilogram of fish flesh produced (assuming 4 cents per kilowatt per hour).

By dusk many insects were already attracted to the ultraviolet lights; therefore, before the carrying capacity is obtained, it would be possible to utilize a light trap for only 1 or 2 hours after dusk. This procedure would reduce the electrical cost 80 to 90 percent. Once bluegill fill their stomachs, they do not feed again until their stomachs are partially empty. Thus, at high densities, it may be more efficient to use the lights for 1 hour after dusk, 1 hour—4 hours later, and 1 hour before dawn.

Light traps increase the carrying capacity of ponds by adding aerial insects to the fishes' food supply. They also increase the vulnerability of aquatic organisms (Fore, 1969). Thus, fish expend less energy searching for and catching food organisms, and more of the food intake can be utilized for growth.

Food Organisms Attracted by the Light

If the stomach contents of fish in the illuminated cage at Fountain Bluff Pond are representative, then that part of the weight gain (two-fifths) contributed by food organisms coming through the water was due primarily to adult aquatic insects and aquatic insect larvae. Fish confined in unilluminated cages have very little benthic fauna available to them. Lights attracted some of this fauna to the caged fish. Since ultraviolet light is absorbed by the first few centimeters of water, the 25-watt incandescent bulb was probably responsible for attracting most of the food organisms through the

water. In natural populations, plankton constitutes an important food item for small bluegill (Bennett, 1948; Lux and Smith, 1960; Scidmore and Woods, 1960; Swingle, 1949). Insects become more important and zooplankton less important as bluegill increase in size. The stomachs of bluegill larger than 55 millimeters contain less than 10 percent (by volume) zooplankton (Leonard, 1940). Bluegill longer than 200 millimeters in Cedar Lake, Mich. did not eat zooplankton (Lux and Smith, 1960). The fact that bluegill used in the present study exceeded 100 millimeters in total length may account for the limited utilization of zooplankton.

It is not known if aerial insects would constitute a complete diet for bluegill. Furthermore, the essential amino acids required by bluegill are not known. However, aerial insects are relatively high in protein content. Since the difference in a low-cost incomplete fish food and a high-cost complete fish food is in the amount and type of protein, it may be practical to feed a low-cost incomplete food to caged fishes if they can complete their dietary requirements by eating insects attracted by lights.

SUMMARY

1. Bluegill stocked in illuminated cages at rates of 5 to 27 fish per cubic meter exhibited growth and high survival. Fighting among the fish did not occur at these densities.
2. Interaction between light traps occurred when they were placed 3 meters apart. There was no interaction between light traps positioned 15 meters from each other.
3. There was no significant difference in the quantity of insects caught by a light trap located 3 meters from shore and one 9 meters from shore.
4. An illuminated cell in Fountain Bluff Pond supported 2,600 grams of fish, while a cell at the Research Pond or Stripmine Lake supported 1,400 grams of fish.
5. Two-fifths of the fish growth was attributed to food organisms entering the cage through the water, and three-fifths to aerial insects.
6. Bluegill held in an illuminated cage at Fountain Bluff Pond consumed, in descending

order of magnitude (by weight), the following: aerial insects, aquatic insects—including larvae, miscellaneous food items, and net zooplankton.

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