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INVESTIGATION OF POND SPAWNING METHODS FOR FATHEAD MINNOWS[1]

Stephen A. Flickinger
Colorado Cooperative Fishery Unit
Colorado State University
Fort Collins, Colorado 80521

ABSTRACT

For transfer of fingerling fathead minnows *(Pimephales promelas)* from spawning ponds to growing ponds, the optimum combination of brood-fish population density and sex ratio in the spawning pond was 19,200 fish per surface acre and five females to one male. Fingerling production from this combination amounted to 1,524,500 fish. Fathead minnows utilized spawning boards placed up to 5 ft deep, and they also utilized boards placed without reference to the substrate. Larger nest sites encouraged larger egg deposits. Nests were crowded together as effectively by restricting available nest sites as by providing visual isolation or territorial markings. Post-spawning mortality of adults ranged from 20% to 91% with higher survival of females than males.

INTRODUCTION

As long ago as the early 1930's, certain areas of the United States began to experience a decline in natural populations of bait fishes (Radcliffe, 1931; Hubbs, 1933; and Markus, 1934a). The problem was solved temporarily by pond culture of bait minnows. Though early attempts were inefficient and production was low, with accumulated knowledge and experience, bait minnow culture became more intensive and productive. At the same time, though, popularity of warmwater sport fishing increased due to construction of reservoirs, larger human populations, more leisure time, and greater human mobility. Demand for bait minnows increases concurrently with the popularity of warmwater sport fishing. Therefore, to serve the large market and yet control increasing costs, bait minnow culturists must seek highly intensive propagation techniques to produce maximum yields of salable fish with minimum space and expense.

The fathead minnow is a small, hardy, easily propagated minnow that is probably second to the golden shiner *(Notemigonus crysoleucas)* in importance as a commercial bait fish. Adults usually become sexually mature the second year, but occasionally young-of-the-year that hatch early in the spring mature late in the first summer (Markus, 1934b). Spawning starts between March and May when water temperatures reach 60 to 70 F and extends into August or September (Markus, 1934b; Surber, 1940; Hutchens, 1946; Wascko and Clark, 1948; Hedges and Ball, 1953; Prather et al., 1953; Martin, 1954; Dobie et al., 1956; Forney, 1957b; Bell, 1960; and Altman and Irwin, n.d.). However, if the water temperature rises above 85 F, spawning ceases until the temperature falls (Dobie et al., 1956). The fathead minnow will deposit eggs on the under surface of almost any kind of material (Hubbs and Cooper, 1936), and substrate choice in order of preference is sand, marl, and gravel (Halser et al., 1946). Most spawning occurs at night (Markus, 1934b, and Isaak, 1961). Incubation time depends on water temperature but averages 9 days (Lord, 1927). A typical recommendation for stocking brood fish for semi-intensive culture is 1,000 fish per surface acre (hereafter abbreviated fpsa) with an expected production of 168,000 fpsa (Prather et al., 1953).

Ponds devoted to spawning, though necessary, increase overhead costs. Consequently, fish farmers strive for maximum production from spawning ponds so that few ponds are needed for spawning. To optimize spawning pond management for the fathead minnow, my study was designed to investigate: (1) yield of fingerling fathead minnows as related to brood-fish population density and sex ratio, (2) flexibility of the spawning behavior of the fathead minnow, and (3) extent of post-spawning mortality.

Eleven ponds were constructed on the Foothills Campus of Colorado State University for this study. These ponds were steep sided (3:2) and each was approximately 0.09 surface acre (40 ft by 90 ft). The depth ranged from 4 ft at the shallow end to 5 ft at the deep end. A kettle located in the pond bottom in conjunction with the drain allowed complete harvest of the fish. These ponds were located side by side and received water from two shallow wells. Water flowed in all ponds at a rate of approximately 3 to 4 gpm to replace evaporation and seepage and to provide limited flushing. The volume of water in each pond was exchanged about once every 15 days. Maintenance of phytoplankton populations to give Secchi disc readings of 18 to 24 inches was accomplished either by adding inorganic fertilizer (20-20-0), by increasing the fresh water flush, or by adding a herbicide (diuron).

Predacious aquatic insects were controlled each year by one treatment of 0.25 ppm methyl parathion. A prophylactic treatment of 0.25 ppm Dylox to control external parasites was administered once each summer.

BROOD-FISH DENSITY AND SEX RATIO

Because past researchers have not dealt with highly intensive culture techniques, the published literature has discussed production from low brood-fish population densities and also from the normally expected equal sex ratio. Brood-fish densities proposed for semi-intensive culture range from 500 to 25,000 fpsa (Altman and Irwin, n.d.; Bell, 1960; Dobie et al., 1956; Forney, 1957a; Hedges and Ball, 1953; Martin, 1954; and Prather et al., 1953). Since the female fathead minnow spawns more than once per summer and since more than one female may contribute to the nest of a single male (Hasler et al., 1946), recommendations of two or three females per male have been made by Martin (1954) and by Bell (1960).

With little information on which to base experimental brood-fish population densities, I chose four densities ranging from the suggested 25,000 fpsa (Dobie et al., 1956) to 325,000 fpsa (slightly above projected carrying capacity of the pond). Likewise three sex ratios were chosen starting with Bell's (1960) suggestion of three females to one male and ranging up to nine females to one male. The twelve combinations were as follows:

Brood-fish density (fpsa)	Sex ratio (femlae to male)		
1968	3:1	6:1	9:1
25,000	x	x	x
125,000	x	x	x
225,000	x	x	x
325,000	x	o	x

where x = combination used, and o = combination not used. Because the results were skewed to the left (Figure 1), additional combinations were tried in 1969 to determine more precisely the optimum combination of population density and sex ratio. Six ponds were stocked with the following population structures:

Brood-fish density (fpsa)	Sex ratio (female to male)		
1969	3:1	6:1	9:1
15,000	o	x	x
25,000	x	x	x
50,000	o	x	o

where x = combination used, and o = combination not used.

Sexes were differentiated by the presence or absence of an ovipositor as described by Flickinger (1969).

Spawning cubicles were constructed to reduce territorial conflict between male fathead minnows by providing visual isolation and territorial markings. Cubicles (Figure 2), 4 inches x 6 inches x 2-½ inches, were constructed by stapling aluminum strips to boards. The boards were nailed to stakes driven into the pond bank. The aluminum dividers pointed downward, and fish eggs adhered to the underside of the board. One cubicle was provided for each male fish.

To reduce the biomass of fish in the ponds, young-of-the-year fish were removed three times the first summer and twice the second summer. Because the quantity of spawning boards in ponds with high brood-fish densities made seining impractical, fingerlings were removed with a small seine manipulated from the bow of a motor boat. Adults and remaining progeny were harvested early in the fall by draining the pond.

A commercially prepared fish food containing 33% protein was given to the brood fish at a rate of 3% body weight per day; a small additional quantity of food was provided for the progeny. Equal portions of the total daily ration were distributed three times a day.

Results of the brood-fish density and sex ratio experiment (Figures 1 and 3, and Table 1) show that greater production of fingerlings was attained at low population densities. Assuming a carrying capacity of approximately 300,000 salable sized fish or 1,000 lb. of fpsa (based on an actual production of 255,600 salable sized fpsa weighing 1,010 lb.), the more successful brood-fish densities were far below carrying capacity of the pond. Densities of 15,000 and 25,000 fpsa generally produced many more fingerlings than did higher densities. I had hypothesized that territorial conflict might limit spawning success, but since each male fish was furnished a spawning cubicle, territorial conflict should not have been limiting. Hence, carrying capacity of the pond should have become the upper limit on brood-fish density. On the contrary, fingerling production declined at brood-fish densities well below carrying capacity. The combined weight of 225,000 adults and 1 million fingerlings per surface acre would total approximately 1,000 lb. (assumed carrying capacity), but only half that many fingerlings were produced in my experiment (Table 1). Furthermore, only a portion of the 528,000 fingerlings was present simultaneously with the brood fish. Perhaps carrying capacity for fry is lower than for salable sized fish due to excessive reduction of plankters by fingerling and adult fish resulting in starvation of the fry before they can learn to accept commercially prepared food. Chemical or behavioral factors associated with high brood-fish densities might also inhibit spawning. However, research is needed on these hypotheses.

Sex ratios were altered from the normally expected equality because the fathead minnow is polygynous. Also, total number of available eggs increases with number of female fish, making the potential yield of fingerlings from a spawning pond higher. The results (Figures 1 and 3, and Table 1) indicate that a sex ratio of six females to one male was most productive. Apparently three females to one male had too few available eggs to attain maximum fingerling production. Nine females to one male resulted in lower fingerling production, though not as low as occurred at a sex ratio of three females per male. Lower production at nine females per male might have been caused either by not enough males to fertilize all the available eggs or by production of so many fry that survival to fingerlings was repressed.

Clouding data analysis are: (1) two spawning failures (25,000 fpsa at 6 females to 1 male, 1968; and 25,000 fpsa at 9 females to 1 male, 1969), and (2) generally lower production in 1969 than in 1968. Cause of the spawning failures is unknown. Several inspections of the spawning boards showed that some eggs had been deposited, but few fry were produced. Predacious insects had been killed prior to the spawning period, and the few predacious insects seen all summer could not have exerted much influence on fingerling production. Lower production of fingerlings in 1969 probably is due in part to weather conditions and to low (less than 1.5 ppm) dissolved oxygen levels. The fathead minnows in my ponds commenced spawning April 30, 1969, as compared to June 2, 1968. However, in 1969 there was little spawning activity from mid-May to mid-June due to cool rainy weather. Also, in 1969 chemical treatment of *Chara* sp. produced high biological oxygen demands, and subsequent low dissolved oxygen levels reduced spawning activity for almost a week during the middle of July. By August, 1969, little spawning activity was evident. In 1968 the brood fish spawned from June until September with no interference from cool weather or from low levels of dissolved oxygen.

Although the three combinations at 25,000 fpsa were repeated in 1969 to compare results to 1968, the combination of 25,000 fpsa at a sex ratio of 3 females to 1 male provides the only comparison because the other two combinations each failed during one of the summers. If this single comparison is used as a basis for adjusting lower production in 1969 to a level with 1968, then production in 1969 would be multiplied by a factor of 3.869. However, this adjustment causes several distortions of the data (Table 2). First, an exceptionally high production of fingerlings is predicted. Second, for unknown reasons, a sex ratio of 3 females to 1 male is favored instead of the 6:1 ratio illustrated as optimum in Figures 1 and 2. Although an unadjusted predicted fingerling production of 1.5 million seems a little low, the predicted optimum brood-fish combination of 19,200 fpsa and 5 females to 1 male fits the data (Figures 1, 3, and 4, and Table 1). Since the fathead minnow is a periodic spawner, it is difficult to determine the number of eggs deposited per female per spawning season. Estimates of the number of mature eggs present in a female at any one time range from 186 to 1,000 eggs per female (Bell, 1960; Hasler et al., 1946; Isaak, 1961; and Wascko and Clark, 1948). Isaak (1961) estimated the total number of eggs (mature and immature) per female fathead minnow to be from 636 to 1,338 with an average of 950. Using Isaak's average number of eggs per female fathead minnow per year, the optimum brood-fish density and sex ratio predicted above could produce a maximum of 15.2 million fingerlings if means to realize 100% survival from eggs to harvested fingerlings were devised.

It is difficult to compare the results of my research on production of fathead minnow fingerlings with the research of others. Not only are there great differences in brood-fish population densities, but also none of the earlier researchers, with the exception of Hedges and Ball (1953), removed portions of the fingerlings prior to harvest at the end of the summer. The average number of fingerlings per female at brood-fish densities of 15,000 and 25,000 fpsa (Table 1) was considerably less than the average number of fingerlings per female at brood-fish densities below 2,000 fpsa (Table 3). However, fingerling production at 15,000 and 25,000 fpsa was generally much greater than at 10,000 fpsa (Table 3). The reason I had greater production at 15,000 and 25,000 fpsa than Prather et al. (1953) had at 10,000 fpsa is most certainly partial removal of the fingerlings during the spawning period. Saylor (1971) increased yield of fingerling gathead minnows as much as 41% by periodic complete removal by draining.

FLEXIBILITY OF SPAWNING BEHAVIOR

Much has been written on spawning requirements of the fathead minnow, but these references have reported only what the fish prefer. However, a commercial operation cannot cater to preferences unless the cost-benefit warrants such. Therefore, this portion of my study was designed to determine acceptability of some possible intensive spawning techniques. Three areas of emphasis were: (1) location of spawning structures, (2) size of nest site, and (3) reduction of territorial conflict.

To avoid ambiguity, I view a spawning board as containing several potential nest sites, be they marked or unmarked. A nest is the area delineated by eggs deposited on the board.

To investigate spawning behavior of the fathead minnow, four ponds, 0.005 acre in size (15 ft x 15 ft) and 5 ft deep, were initially stocked with 75 female and 25 male fathead minnows.

Location of Spawning Structures

If methods are developed for using high brood-fish densities, considerable space will be required for positioning spawning structures. According to Hedges and Ball (1953), Hasler et al, (1946), and Isaak (1961), the fathead minnow usually spawns at depths of 3 ft. or less. Hasler et al. (1946) also stated that eggs are usually deposited in the angle between spawning structure and substrate. Therefore, I investigated whether or not the fathead minnow will spawn at depths up to 5 ft(typical maximum depth of fish culture ponds),and whether or not spawning devices need to touch the pond bottom.

To determine depth limitation on spawning, one board containing 12 cubicles as described earlier was anchored to the pond bank at a depth of 4 ft. and another similar board was anchored 5 ft deep. The results were as follows:

Depth of board	Number of nests at weekly intervals		
(ft)	(week 1)	(week 2)	(week 3)
4	1	5	(removed)
5	0	1	8

The number of nests located at depths of 4 ft and 5 ft indicate that fathead minnows will readily spawn at these depths.

The relation of spawning boards to substrate was evaluated so that available space for positioning spawning boards might be further increased. One spawning board with 12 cubicles was suspended at mid-depth in the water column with little reference to the pond bottom, and one similar board was floated in the middle of the pond with no reference to the pond bottom. Inspection one week later revealed three nests on the board at mid-depth and two nests on the floating board. These results show that spawning boards need not be near the pond bottom or sides to be acceptable to the fish. Many nests located on floating boards used in another portion of the research substantiated to a greater degree the use of floating boards for fathead minnow propagation.

Results from the above two experiments demonstrate that virtually the entire pond may be used for positioning spawning boards. Not only the sides and the bottom, but also the open water are acceptable from the surface down to 5 ft in depth.

Size of Nest Site

Again looking toward highly intensive fish culture techniques, this portion of my study sought the minimum size nest site that the fathead minnow will use, and whether or not size of the site influences size of the nest. Isaak (1961) determined the average number of eggs per nest according to the size of the nesting object. His results were:

No. eggs per nest	Least dimension of the nesting object (inches)
338	< 0.75
544	> 0.75 but < 1.25
806	> 1.25 but < 2.00
1,038	> 2.00

To investigate cubicle size, two boards containing 10 cubicles 4 inches wide with lengths ranging from 2 inches to 12 inches (at 1-inch increments with the 6-inch length omitted) were anchored in one pond. These boards were removed one week later to record location of nests. The boards were replaced for three additional week-long trials. Although the data on nest size (Table 4) are limited, there is an indication that larger nest sites resulted in larger deposits of eggs as found by Isaak (1961). Also, the fathead minnow preferred larger nest sites - at least up to 10 inches x 4 inches (Table 4). Further research into relation of cubicle size to size of egg mass deposited was not conducted because cubicles were found to be of little value in developing intensive culture techniques.

Reduction of Territorial Conflict

Since territorial conflict may limit spawning success, another objective was to explore the possibility of obtaining more nests per spawning board by reducing territorial conflict through the use of visual isolation, territorial markings, or both.

Attempts to reduce territorial conflict were aimed initially at the use of cubicles, which provided visual isolation as well as territorial markings. Because providing the minimum amount of visual isolation would be least expensive, determining the necessary degree of visual isolation was the goal of the first series of trials. One board with 12 cubicles 4 inches x 6 inches x ½ inch and another board with 12 cubicles 4 inches x 6 inches x 1½ inches were anchored in one pond. When the boards were removed one week later, four nests were located on the board with ½-inch deep cubicles, but for unknown reasons no eggs were deposited on the board with 1½-inch deep cubicles. Since the shallower cubicles would be less expensive, no investigation was made to discover the reason for the rejection of the deeper cubicles. In the next trial, the ½-inch deep cubicles were paired with a plain board of the same length (3 ft). One week later the board with cubicles contained five nests, and the plain board contained only two nests. As a final trial in this series, only one plain board was offered for one week. When the plain board was removed, it contained six nests with five of them located within a distance of 20 inches. A board with every cubicle filled could have had just six nests in a span of 18 inches. The results of this series of trials show that the fathead minnow prefers cubicles but will also spawn on a plain board when no choice is offered. Therefore, further investigation into the value of fisual isolation was undertaken.

The fish populations in all four ponds were increased to 150 females and 50 males so that a greater nesting potential existed.

An experiment was conducted to evaluate acceptance when no choice was offered. Three ponds were used with four boards, 3 ft long, in each pond. The control pond had plain boards; another pond had 48 cubicles, 4 inches x 6 inches x ½ inch, to provide territorial markings and minimum visual isolation; and the third pond had 48 marked areas, 4 inches x 6 inches, formed by shallow saw cuts to provide territorial markings but no visual isolation. All boards were removed after one week with the following results:

	Number of nests		
	cubicles	saw cuts	plain boards
	3	3	2
	3	3	1
	2	3	3
	0	5	2
Average	2.0	3.5	2.0

No significant difference (Chi-square) was found in utilization of the three types of spawning boards.

The next objective on reduction of territorial conflict was to determine whether or not visual isolation or territorial markings would allow placement of more nests per spawning board than would be deposited on plain boards when available spawning sites were limited.

To investigate this proposition, the four ponds were stocked with 150 female and 25 male fathead minnows.

Because this next series of trials was conducted the following summer, the first trial was a repeat of the one just described with the only difference being each pond had two boards instead of four. After a one week trial the results were:

	Number of nests		
	cubicles	saw cuts	plain boards
	3	3	4
	2	3	6
Average	2.5	3.0	5.0

Statistical analysis (Chi-square) showed that again all three types of spawning boards were used equally.

In the next trial each pond received only one spawning board instead of two as before so that there was not an available nest site for each male fish. In the final trial each pond received only one-half of each board so that there were even fewer nest sites available to the male fish. The number of nests established after one week for each trial were:

	Number of Nests		
	cubicles	saw cuts	plain boards
One board	6	6	3
One-half board	5	6	6

Although sample size was small, providing visual isolation or territorial markings did not significantly increase the number of nests per spawning board even under conditions of limited available spawning sites. Apparently not only was just a small portion (25 to 30%) of the male fathead minnows guarding territories at any one time, but also the territory was easily compressed to 24 square inches or less. Therefore, plain boards should be used as spawning structures, for they are accepted by the fish and are less expensive than boards with either cubicles or saw cuts.

POST-SPAWNING MORTALITY

Some authors have stated that large numbers of adult fathead minnows, predominantly males, die after spawning (Lord, 1927; Markus, 1934b; Surber, 1940; Hasler et al, 1946; Hutchens, 1946; Branch of Game-Fish and Hatcheries, 1950; Prather et al, 1953; Dobie et al, 1956; and Isaak, 1961. However, Forney (1957b) stated that large mortalities of adult fathead minnows do not constitute a problem in New York.

To investigate survival of adult male and female fathead minnows, brood fish that had been stocked at lower densities were sexed and counted at the end of summer as well as at the start. Higher densities were not sexed again because of insufficient manpower to sort such large numbers of fish. Also, lack of spawning activity at higher densities generally resulted in excellent adult survival (Table 1). The survival of male and female fathead minnows in the lower brood-fish densities(Table 5) was generally low, but survival of female fish was always greater than survival of male fish. With development of extensive secondary sex characteristics, the male fathead minnow undergoes a greater physiological change than the female. Also, while caring for the nest, the male must expend considerable energy with little opportunity to feed. Nikolsky (1963) stated that "the natural life span of a fish is closely connected with the course of its metabolism. In very many species a complete mortality as a result of exhaustion occurs after the first spawning." In the Atlantic salmon (*Salmo salar*), more males die than females. Nikolsky stated that such occurrence has adaptive significance because large females are more important for the reproduction of the species than are large males. Since the fathead minnow is polygynous, this mechanism may be the reason for differential mortality of the sexes in this species.

Forney's (1957b) observation that post-spawning mortality does not constitute a problem in New York ponds was based on inspection of the shoreline for dead fish. Since the ponds could not be drained, he was unable to determine actual survival. I never observed mass mortality of brood fish, but fall harvests revealed that a large percentage of the brood fish had died sometime between stocking in the spring and harvesting in the fall. Predators and scavengers would reduce the number of dead fish seen along the shoreline.

SUMMARY

This research project has investigated intensive culture of the fathead minnow for sale as a bait fish. Optimum brood-fish density and sex ratio were 19,200 fpsa and 5 females to 1 male. Predicted fingerling production from this combination was 1.5 million fish, which is more than 5 times the production reported in the literature. Based on the spawning success of altering brood-fish sex ratios and on the observation of greater mortality of male fathead minnows, alteration of brood-fish sex ratios is desirable for a commercial operation. Not only would greater fingerling production result, but also the discarded males could be sold before death. Spawning requirements were so flexible that the entire pond bank and water column may be used for positioning spawning boards. Larger nest sites encouraged larger egg deposits. Nests could be crowded together as effectively by restricting available nest sites as by providing visual isolation or territorial markings. Post-spawning mortality of both sexes ran as high as 91%.

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Table 1. Stocking and harvest data for fathead minnows in spawning ponds.

Initial brood-fish density (fpsa)	Sex ratio (female to male)	Total fingerlings removed (fpsa)	Adult survival (percentage)	Number of fingerlings per initial female
15,000*	6:1	1,576,113	10.2	122.6
15,000*	9:1	868,028	14.8	64.3
25,000+	3:1	2,401,627	80.4	128.1
25,000*	3:1	620,781	10.6	33.1
25,000+	6:1	26,940	51.0	1.3
25,000*	6:1	792,652	57.4	37.0
25,000+	9:1	3,097,261	73.3	137.7
25,000*	9:1	10,573	9.6	0.5
50,000*	6:1	365,075	9.0	8.5
125,000+	3:1	339,793	96.5	3.6
125,000+	6:1	865,604	47.8	8.1
125,000+	9:1	552,232	90.8	4.9
225,000+	3:1	77,798	93.1	0.5
225,000+	6:1	528,603	96.2	2.7
225,000+	9:1	460,650	86.3	2.3
325,000+	3:1	44,903	71.2	0.2
325,000+	9:1	29,843	103.2	0.1

*Stocked in 1969
+Stocked in 1968

Table 2. Comparison of predicted[1] brood-fish density and sex ratio optima and resulting fingerling production using adjusted and unadjusted production data.

	Coded x 3.869	Uncoded
	1969	
Brood-fish density (fpsa)	6,304	6,304
Brood-fish sex ratio (female to male)	3:1	3:1
Fingerling production (fpsa)	13,803,388	3,569,408
	1968 & 1969 combined	
Brood-fish density (fpsa)	7,398	19,171
Brood-fish sex ratio (female to male)	4:1	5:1
Fingerling production (fpsa)	9,007,812	1,524,499

[1]The prediction equation from the multiple regression analysis was $y = bx_1 x_2 e^{-a_1 x_1 - a_2 x_2}$, where x_1 = brood-fish density and x_2 = sex ratio.

Table 3. Comparison of the number of fingerlings produced per female fathead minnow stocked at various population densities and sex ratios.

Brood-fish density (fpsa)	Sex ratio (female to male)	Number of fingerlings per female	Source
1 pair	1:1	4,144	Markus, 1934b
300	1:1	567	Bauman, 1946
500	1:1	560	Prather *et al.*, 1953
1,000	2:1	503	Hedges and Ball, 1953
1,000	1:1	400	Hasler *et al.*, 1946
1,000	1:1	336	Prather *et al.*, 1953
2,000	1:1	283	Prather *et al.*, 1953
10,000	1:1	19	Prather *et al.*, 1953

Table 4. Number and size of fathead minnow nests located in cubicles of various sizes.

Cubicle size (inches)	Total no. nests[1]	Nest size[2] (sq inches)
2 x 4 x 2½	1	
3 x 4 x 2½	1	
4 x 4 x 2½	2	1.0
5 x 4 x 2½	2	4.0
7 x 4 x 2½	2	10.0
8 x 4 x 2½	5	18.0
9 x 4 x 2½	7	24.0 and 17.5
10 x 4 x 2½	7	17.5 and 1.5
11 x 4 x 2½	4	21.0
12 x 4 x 2½	3	19.5

[1]Number of nests located in each cubicle size during a four-week period. Each cubicle size was available eight times during the period.
[2]Nest size was recorded only on nests found at the end of the fourth week.

Table 5. Survival of adult fathead minnows in spawning ponds.

Fish population density (fpsa)	Sex ratio (Female to Male)	Male survival (percentage)	Female survival (percentage)
15,000	6:1	3.0	11.4
15,000	9:1	9.4	15.4
25,000	3:1	26.0	73.1
25,000	3:1	2.8	13.2
25,000	6:1	10.9	57.7
25,000	6:1	14.4	64.5
25,000	9:1	65.8	85.3
25,000	9:1	2.3	10.5
50,000	6:1	0.1	10.5

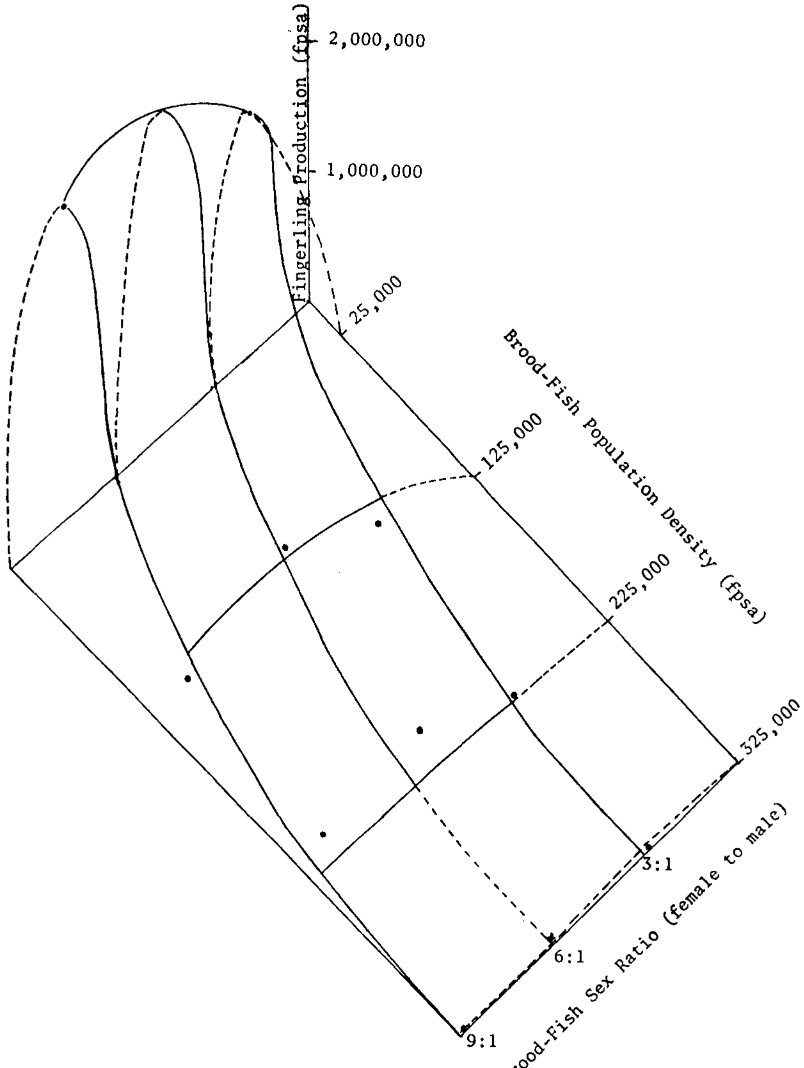

Figure 1. Relationship between production of young fathead minnows and density and sex ratio of brood fish (1968).

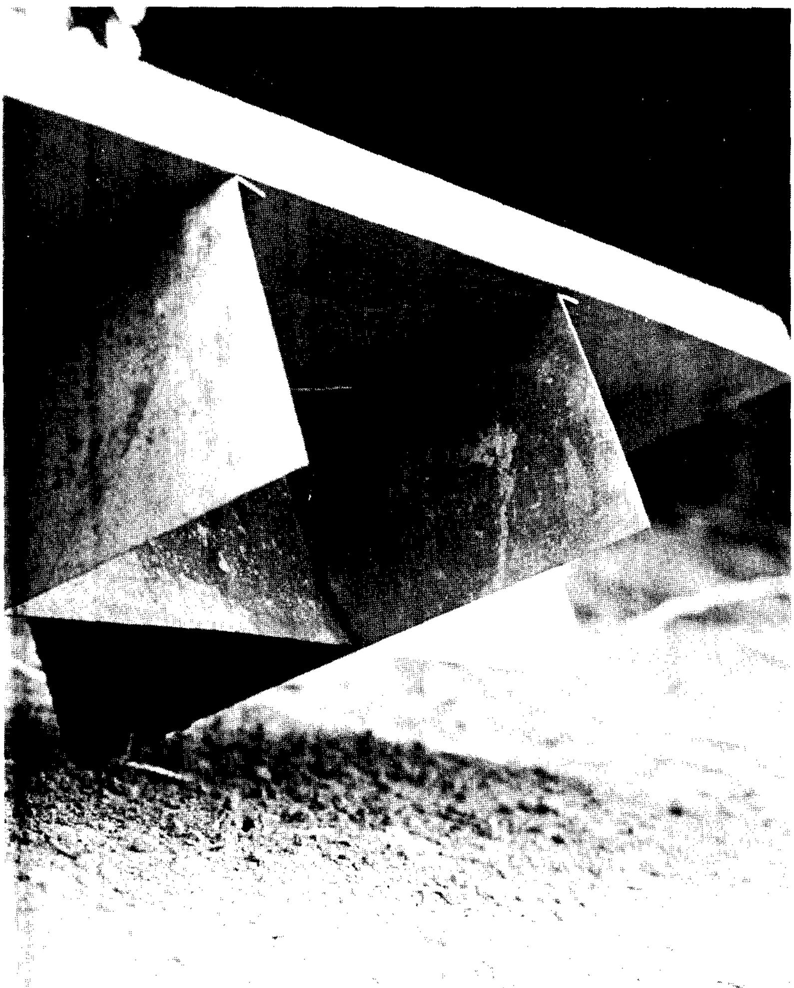

Figure 2. Spawning cubicles constructed to provide visual isolation and territorial markings for each male fathead minnow.

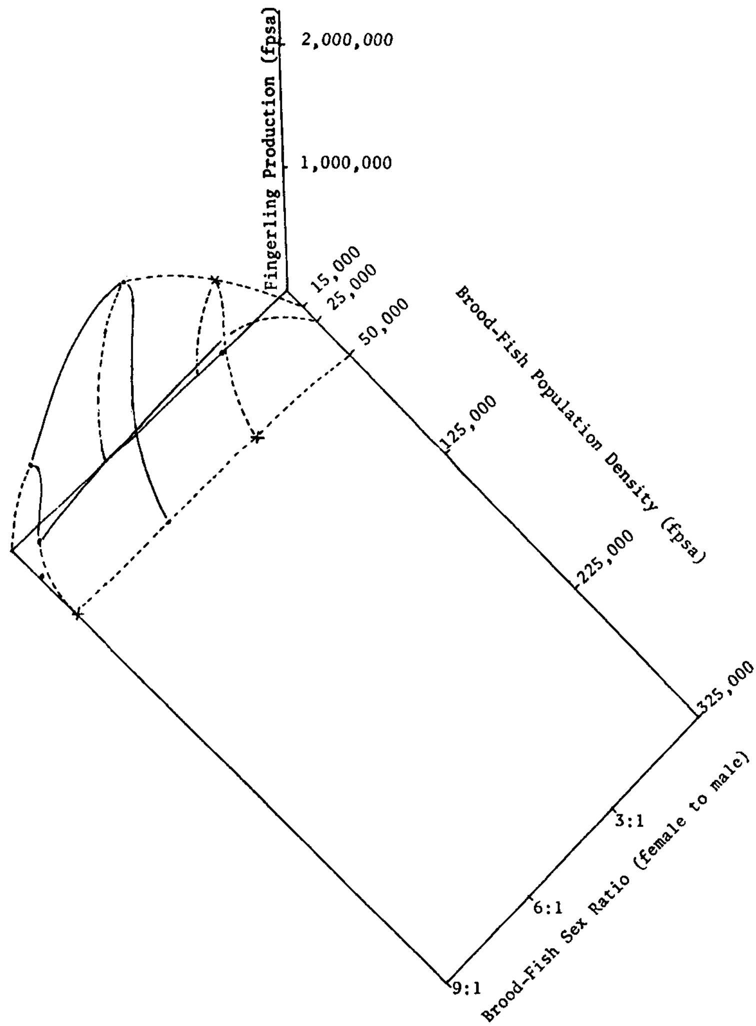

Figure 3. Relationship between production of young fathead minnows and density and sex ratio of brood fish (1969).

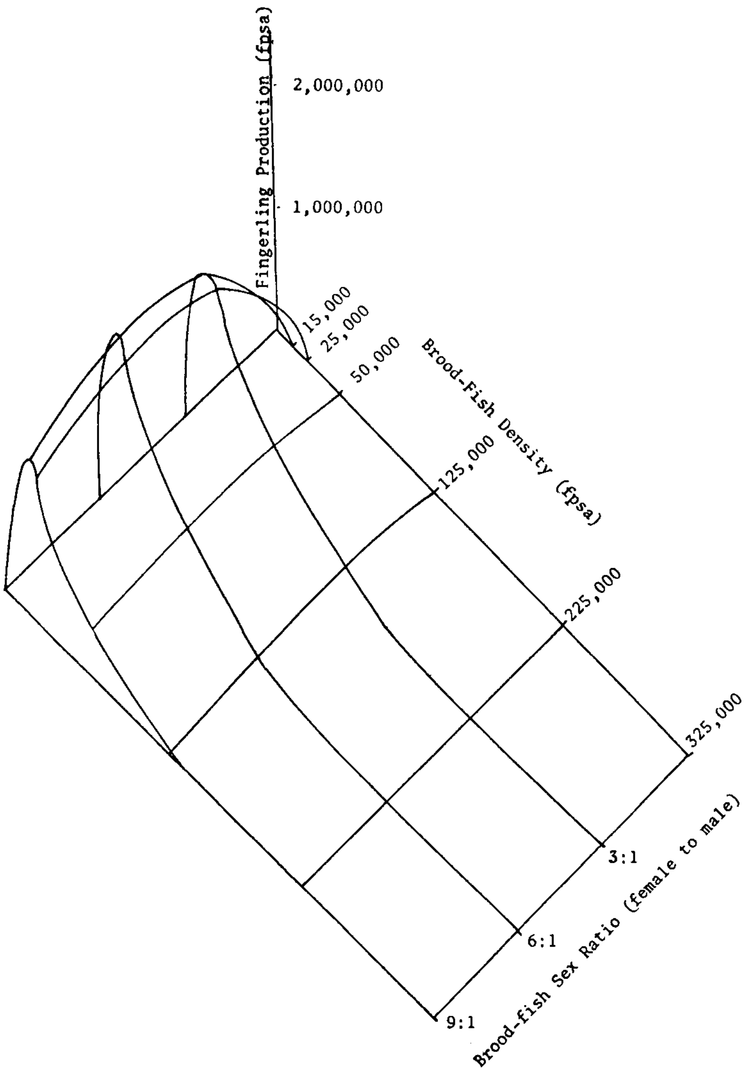

Figure 4. Relationship between production of young fathead minnows and density and sex ratio of brood fish (composite of 1968 and 1969).