SPAWNING REQUIREMENTS AND CHARACTERISTICS OF THE FATHEAD MINNOW[1]

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ABSTRACT

New information concerning spawning and reproduction of the fathead minnow (*Pimephales promelas* Rafinesque) from observations in Colorado, and a review of important findings of previous works is presented in this paper. Potential for egg production by mature, Age I females is between 1,000 and 10,000 eggs per breeding season. On the basis of this information and the known polygynous mating behavior, we estimate that 19,200 adult fathead minnows in a ratio of five females per male should be stocked per surface acre to yield a theoretical maximum production of 1.5 million fingerlings per surface acre under intensive-culture conditions. Spawning usually starts in May with exact timing of initial spawning apparently controlled by day length but influenced by many factors. In one fathead minnow population in Colorado water temperature at the time of the first observed spawns was 1.6 C lower than had been reported by previous investigators.

INTRODUCTION

The fathead minnow (*Pimephales promelas* Raginesque) probably exhibits the highest ecological valence of all cyprinids occurring in North America. Present geographical range includes southern Canada, the United States and northern Mexico with viable populations from sea level to an elevation of 3034 m above sea level (Andrews 1971). Because of a favorable reputation among fishermen, availability over a wide range, small maximum size, and ease of culture and maintenance, this species is widely cultured for bait, forage, and use in toxicity studies.

Since detailed information about specific aspects of spawning requirements of the fathead minnow is available only for limited, scattered portions of the U. S. geographic range, we shall present new information concerning spawning and reproduction resulting from our work[3] as well as a systematic review of important findings of previous studies.

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[3]Complete results of work upon which this paper is based are contained in the following theses prepared in partial fulfillment of the requirements for the degree of Doctor of Philosophy, Colorado State University:

Andrews, A. K. 1970. The distribution and life history of the fathead minnow (*Pimephales promelas* Raginesque) in Colorado. Ph.D. Thesis, Colo. State Univ., Ft. Collins. 131 p.

Flickinger, S. A. 1969. Increasing fathead mknnow production through population manipulation. Ph.D. Thesis, Colo. State Univ., Ft. Collins. 66 p.

SEXUAL DIMORPHISM

Just prior to spawning male fathead minnows develop a generally darkened color (often nearly black) with vertical bands of golden brown, a swollen blunt head with breeding tubercules, and a thickened rugose nape pad. Ripe females are silvery to olivaceous in color, have a more pointed head, and exhibit the generally swollen ventral contour associated with the presence of mature eggs. An ovipositor becomes evident about one month before spawning, but it may be detected in mature females throughout the year even though it is reduced during non-spawning seasons (Fickinger 1969).

FECUNDITY

The fathead minnow is reported to be an intermittent, multiple-spawning species. Hasler et al. (1946) and Radcliff (1931) stated that this species has a long breeding season, possibly spawning intermittently all summer. One pair of fathead minnows produced 4,144 fingerlings from 12 spawnings over a period of two months (Markus 1934).

Fecundity has been estimated by various authors to be : 1) approximately 4,000 eggs/female (Markus 1934); 2) 800-1,000 eggs/female, including only macroscopic eggs (Bauman 1946; Hasler et al. 1946); 3) 255-2,400 eggs/female based on eggs counted in nests (Isaak 1961); and 4) 802 eggs in a 47 mm female, 2,328 eggs in a 52 mm female, 2,622 eggs in a 54 mm female, and 1,800 eggs in a 55 mm female, of which approximately one-third of the eggs were ripe (Carlson 1967).

Isaak (1961) observed up to 6,000 eggs in a single nest and Markus (1934) found 12,000 eggs in one nest. These numbers far exceed the number of mature eggs observed in any ripe female and indicate that several females contribute to the egg mass. Hasler et al. (1946) also concluded that more than one female spawns in a single nest.

Egg production was determined for two Colorado populations of fathead minnows by direct counts of all eggs, all stages of development visible at 30X. One population was from a typical high-plains, irrigation reservoir with monthly mean water temperatures during the breeding season of 14-22 C, and one population was from a montane lake with monthly, mean, spawning-period water temperatures of 10-20 C. Mature females from the warmer water ranged in size from 40 to 70 mm total length. Range in ovary volume per female was 0.20-0.80 ml (mean = 0.37 ml, N = 200), and range in total egg count per female was 2,010-9,768 (mean = 4,743, N = 200). The regression of total number of eggs on ovary volume was: $y = 227 + 12{,}081\,X$ ($R^2xy=0.52$); y = total eggs/female and X = ovary volume in ml. Mean number of mature eggs per female was 831 (range = 441-1,242, N = 200). Given total length between 40 and 70 mm (L), the regression $y = -451 + 20\,L$ ($R^2ly=0.22$) estimates total number of mature eggs (y) for a female of a given length at any time.

Mature females from the colder water had a size range of 45 to 70 mm total length. Range in ovary volume was 0.10 to 0.40 ml (mean = 0.26 ml, N = 200) and range in total egg count was 1,253 to 9,268 (mean = 4,867, N = 200). Regression of total eggs on ovary volume was: $y = 1{,}182 + 13{,}943\,X$ ($R^2xy=0.48$); where y = total eggs/female and X = ovary volume in ml. Number of mature eggs per female ranged between 33 and 936 (mean = 388, N = 200). Given length between 45 and 70 mm, the regression $y = -372 + 14\,L$ ($R^2ly=0.10$) estimates total number of mature eggs (y) for a female of a given length (L) at any time. Fecundity estimates for fathead minnows, as for other multiple-spawning species, are susceptible to errors depending on length of time from the last egg release.

Based on growth of fathead minnows reported by Waskco (1939), females in

Ohio populations do not reach the minimum size that we observed was required to attain maturity until early to mid-September of the year in which the fish were hatched. Since spawning has usually terminated by September, one would not expect to have Age 0 fish spawning in more northern latitudes as has been observed in more southern climates.

STOCKING BROOD FISH

Brood fish densities ranging from 500 to 25,000 fish per surface acre have been recommended (Forney 1957b, Dobie et al. 1956, Altman and Irwin 1954, Martin 1954, Hedges and Ball 1953, Prather et al. 1953). Since female fathead minnows spawn more than once per summer and since more than one female may contribute to the nest of a single male, recommendations of two or three females per male have been made by Martin (1954) and Bell (1960). Based on our experiments with brood fish densities ranging from 15,000 to 325,000 fish per surface acre and sex ratios ranging from 3 to 9 females per male, we estimated an optimum brood fish density to be 19,200 fish per surface acre and an optimum sex ratio of 5 females per male. Projected fingerling ($\simeq$15 mm total length) production from this combination would be 1.5 million fish per surface acre.

INITIATION AND DURATION OF SPAWNING ACTIVITY

It is not clear whether temperature, photoperiod, or both trigger spawning in fathead minnows. A variety of minimum temperatures and dates of first spawning have been observed by various investigators (Table 1) and although some minimum temperature requirement is indicated, the large number of first spawnings in May strongly support day length as the major influence initiating spawning activity. However, temperature may be more important than photoperiod once the reproductive cycle has been started. For example, we observed initial spawning in intensive-culture ponds on June 2, 1968 and April 30, 1969; in both years the temperature reached 18 C for the first time when spawning commenced.

Actual first date of spawning is probably determined by complex interrelationships involving temperative, light and relative severity of the preceding winter with its effects on the general condition of the fish as spawning approaches and sex products mature.

Table 1. Minimum mean water temperature and month at initiation of spawning by fathead minnows.

Temp °C	Date	Location	Source
12.8	June 19, 1969	Colorado	Wild population at 2464 m elevation (present study)
13.9	May 25, 1969	Colorado	Wild population at 1502 m elevation (present study)
15.3	June 16, 1967	Colorado	Wild population at 2464 m elevation (present study)
15.3	--	Wisconsin	Williamson (1939)
14.4	June 18, 1968	Colorado	Wild population at 2464 m elevation (present study)
14.4-16.7	--	Alabama	Prather et al. (1953)
16.7-17.8	--	Iowa	Markus (1934)
16.7-17.8	--	Kentucky	Martin (1954)
17.8	March-May	California	Bell (1960)

Temp °C	Date	Location	Source
17.8	--	Missouri	Dobie et al. (1956)
17.8	--	Minnesota and Wisconsin	Dobie et al. (1948)
17.8	May	Ohio	Langlois (1937)
17.8	May 30, 1968	Colorado	Wild population at 1502 m elevation (present study)
17.8-21.1	--	Oklahoma	Altman and Irwin (1954)
18.0	April 30, 1969	Colorado	Intensive-culture population (present study)
18.0	June 2, 1968	Colorado	Intensive-culture population (present study)
18.3	May 25, 1960	Minnesota	Isaak (1961)
18.3-21.1	May-August	Ohio	Waskco and Clark (1948)
20.0	May	Iowa	Lord (1927)
21.1	May	Illinois	Hutchens (1946)
22.2	May 27, 1959	Minnesota	Isaak (1961)
-	May 12	New York	Forney (1957a)
-	Mid-May	Wisconsin	Hasler et al. (1946)
-	Late May to early June	Wisconsin	Thomsen and Hasler (1944)
-	June	Michigan	Hedges and Ball (1953)

Dobie et al. (1956) reported that a water temperature of 29.5 C caused spawning activity to cease. Isaak (1961) found that water temperature had no apparent effect on the cessation of spawning which occurred in early August. Thomsen and Hasler (1944) noted spawning abatement by mid-August. No spawns or spawning activities were observed under intensive culture conditions after 9 September by Saylor (1971).

PRE-SPAWNING BEHAVIOR

Male fathead minnows select, prepare and defend the nest site (Isaak 1961). Intense intraspecific competition occurs at this time with some instability of the integrity of established territories if potential nest sites are limited. However, in most cases, once a male has established a territory, he is able to successfully defend it against larger males. Little agonistic behavior is exhibited between males as long as both fish are guarding established territories, even when territory centers are separated by as little as 7 cm.

Fathead minnows usually spawn beneath objects (Lord 1927, Markus 1934, and many others), even under such transient objects as old maple and oak leaves (Isaak 1961). In the absence of substrate materials under which nests may be established fathead minnows will utilize any available nest site substrate, e.g., rooted aquatic vegetation, vertical surfaces of pier supports or large rocks. Anchored, floating boards have been offered as nest sites and, with the exception of Forney's (1957a) findings, have been reported to be heavily utilized by Waskco and Clark (1948) and in our intensive-culture ponds. Preferred nest site materials are old, water-soaked boards and sticks at a depth of approximately 1 m (Flickinger 1971, Isaak 1961, Forney 1957a, Hedges and Ball 1953, Waskco and Clark 1948, Thomsen and Hasler 1944).

The depth at which nests are located has been correlated with temperature (Dobie et al. 1948) and with water clarity (Waskco and Clark 1948). We found that fathead minnows will readily spawn at depths up to 1.5 m when no other choice is offered.

Fathead minnows have also exhibited preferences for the substrate upon which nest site materials are located. Isaak (1961) found that all nests were located over a sandy substrate and no nests were located over soft mud. Sand, marl and gravel, by order of preference, were reported by Thomsen and Hasler (1944) with gravel being used only when no other sites were available. However, these preferences are not obligatory, for in lakes that lack preferred substrates, fatheads readily spawn over whatever is available, e.g., mud or gravel.

SPAWNING BEHAVIOR

Isaak (1961) and McMillan (1972) described spawning behavior as follows:

(1) Males cleaned the underside of the object selected for the nest site, using the head tubercules in a scraping action and pulling pieces of algae and associated debris off the nest surface with the mouth. Clearance beneath objects located on the substrate was achieved by creating a depression beneath the object by a sweeping action of the caudal fin.

(2) Males with prepared nest sites would allow some gravid females to approach the site while driving off males that approached within a distance of 50 cm. McMillan (1972) notes that males would also drive ripe-looking females from the nest and a great amount of persistence was required by the female before the male would accept her in the nest vicinity.

Territory size was very compressible. When a number of males selected nest sites under some large object (e.g., a large board), the egg masses would often touch at their peripheries and defense of the areas containing all adjacent nests became a communal effort.

(3) Eggs were usually deposited at night.

(4) The male and female swam back and forth beneath the prepared overhead site and rolled on their sides to emit the sex products. Close lateral contact and body vibration preceded emmission of sex products (McMillan 1972).

(5) The buoyant, adhesive eggs stuck to each other and to the undersurface of the nesting object.

(6) After egg deposition was complete, the male drove the female from the nest.

Although most of the observations made by McMillan (1972) agreed with those of Isaak (1961), McMillan described the spawning act in more detail:

"Finally, when a sufficient degree of vibratory stimulation has been reached, the male lifts and presses the female's ventral surface against the object's underside. In doing so, he turns so that he is beneath the female and can use the posterior part of his body to manipulate her upward. The tubercles on his large pectoral fins also help him to grip the female tightly. As the fishes' bodies are taut and strained in this position, the female emits one or perhaps several eggs, and the male probably releases sperm at this instant. Then they abruptly separate, although a new bout of vibrating may begin only seconds later."

POST-SPAWNING BEHAVIOR

The male remains at the nest site tending and defending the eggs until hatching occurs. If it is early in the spawning season, the male usually accepts other ripe females and begins accumulating another egg mass at the same nest site location. Consequently, eggs of several different ages may be found in a single egg mass. When the breeding season is drawing to a close, males abandon nest sites and move to deeper water, seldom rejoining the large schools of mature females. Whether one male remains at a nest site for the duration of the spawning season or whether there is a succession of males at that site is unknown, and further research is needed to determine number of "broods" for which one male is responsible.

Early researchers (Markus 1934, Hubbs 1933, Wynne-Edwards 1933, Radcliff 1931, Lord 1927) noted the activity of the male during the intensive care of the eggs. Although no one has specifically studied the role males perform in care of eggs, males have been observed bumping the egg mass with the rugose nape pad and nipping at the egg mass. These actions may serve to clean the egg mass or to turn the eggs to insure adequate aeration (Markus 1939, 1934, Wynne-Edwards 1933). Isaak (1961) speculated that bumping of freshly deposited eggs with the rugose pad spread the eggs into even layers.

We removed a number of egg masses from males and incubated these egg masses at different temperatures to determine procedures required to artificially incubate eggs, and rate of development and time required to hatch eggs at the temperatures at which egg masses are found. Untended egg masses were highly susceptible to fungus and had very low hatching success unless they received artificial aeration and regular prophylactic treatments. Incubation time in days (y) is dependent on temperature (°C=X) according to the linear regression: $y=26.04 - 0.88 X$ ($R^2xy=0.71$).

BROOD FISH MORTALITY

Timing and magnitude of mortality of post-spawning fish under various environmental regimes is not clearly documented. Most authors agree with Markus (1934) that approximately 80% of the spent adults die. Forney (1957a) reported that only 7% of the spawning adults died. We found that lack of spawning at high adult population densities ($\geqslant$125,000 fish per surface acre) generally resulted in high adult survival (up to 96%). In addition, Prather et al. (1953) stated that mortality was higher for males than for females, and sterile adults had a longer life span and grew larger than did fertile fish. According to Dobie et al. (1956), males die 30 days after spawning and females die 60 days after spawning. We concur with Isaak (1961) who found few fish reached three years of age in wild populations. In our intensive-culture ponds survival varied from 0.1% to 65.8% (mean = 15.0%) for males and from 10.5% to 85.3% (mean = 38.0%) for females and at no time was any mass dieoff observed.

Saylor (1973) had a unique opportunity to record brood fish mortality in a pond that was drained twice during one spawning season and restocked with the surviving adult fathead minnows. Female survival, based on original number stocked, was 45.8% and 29.3%, respectively for the time intervals preceding the two drainings, and male survival was 80.3% and 12.0%, respectively for the same time intervals.

SUMMARY

The following generalizations may serve as an aid in predicting the response of fathead minnows either to intensive culture, or to introduction into new environments:

1. *Fecundity.* A mature, Age I female may be expected to produce between 1,000 and 10,000 eggs from several spawnings over the course of the breeding season with the exact number depending primarily on female size and on relative environmental resistance.

2. *Brood Fish stocking rates.* Due to polygynous spawning behavior, approximately five females should be stocked for every male. For maximum production, stocking densities should approximate 19,000 adults per surface acre of suitable habitat for fathead minnows.

3. *Pre-spawning behavior.* If suitable spawning sites are available, males will establish territories and prepare the nest site just prior to spawning. The spawning territory is highly compressible (down to the size of the actual egg mass) and cannot be considered a limiting factor in production.

4. *Initiation and duration of spawning.* Although time of initial spawning is controlled by many factors, light is apparently one of the major controlling factors (given minimum temperature of approximately 13 C) and initial spawning should occur during May. Spawning will cease between early August and early September unless mean water temperatures rise above 30 C at an earlier date.

5. *Spawning behavior.* The most significant behavioral trait is contribution to the egg mass by several females.

6. *Post-spawning behavior.* Males guard and tend eggs until they hatch.

7. *Brood fish mortality.* Essentially, all male and up to 90% of the female brood fish may be lost after spawning under intensive culture conditions. In wild populations, essentially no fish survive the third year of life.

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