EXPERIMENTAL MASS-REARING OF THE MOSQUITOFISH, *GAMBUSIA AFFINIS*

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ABSTRACT. A solar heated, closed-system, intensive culture facility for mass-rearing of *Gambusia affinis* is described. The results of fry production experiments and short-term growth rate experiments are presented and interpreted to indicate that operational fish production at or below the goal of $16.50/kg will not be easily reached.

INTRODUCTION

The use of *Gambusia affinis* (Baird and Girard) for mosquito control is limited by the supply of fish. Mosquito sources need to be stocked with fish early enough in the season to capitalize on reproduction in the field. Natural sources of fish are unreliable and slow to develop. Those California mosquito abatement districts with large numbers of rice fields could use several metric tons of fish between April and July. Additional needs for fish arise from wastewater impoundments, marshes and restocking where agricultural practices have caused fish kills.

The expectation that mosquitofish can be reared in large quantities is based on diverse sources of information. Spotte (1970) has provided practical and theoretical insight into the design of closed-system fish culture systems that take into consideration the size of the fish and physical factors such as filter particle size, volume of filter and flow rate. The mosquitofish can reach sexual maturity in the field in 42 days (Krumholz 1948). That translates into a growth rate of about 11%/day. Silliman and Gutsell (1958) and Wurtsbaugh and Cech (1983) have found that under favorable conditions poecillid fishes grow very rapidly, and the mosquitofish in particular, can grow at rates over 20% of body weight per day in captivity. Wurtsbaugh and Cech found growth fastest at 30°C in comparison with 25 and 35°C. A mosquitofish temperature preference study by Winkler (1979) gives evidence that 31°C may be optimum for growth. However, to date there is no mosquitofish production adequate for stocking on a large operational basis.

The study reported here proceeded with the underlying goal of developing a rearing facility that could yield approximately 1.4 metric tons of fish yearly at a cost of $16.50/kg, which would allow stocking of fish for mosquito control in rice fields at 0.6 kg/ha at a cost competitive with chemical control methods (Hoy and Reed 1970). A four part strategy was used: 1) fry production and growth to maturity throughout the year, 2) a high density of fish in water recirculated through biological filters, 3) minimization of the load on the filters by careful control of the feeding rate, 4) solar heating and auxiliary heating.

The ultimate use of an intensive culture system and method for mass rearing by agencies with limited budgets militates for use of common and inexpensive materials. Furthermore, simplicity of design was given precedence, perhaps at the expense of maximum carrying capacity.

MATERIALS AND METHODS

A post and truss fiberglass greenhouse (5.49 × 15.24 m) with a macadam pavement floor housed 12 rearing tanks arranged six each along a central aisle. The primary source of heat was solar, but supplemental heat was provided by an 80,000 BTU propane heater. The tanks were constructed with 12.5 mm plywood, 2.44 × 2.44 × 0.41 m deep, and without bottoms. Each corner was reinforced with a wooden block and the top edges of the sidewalls were reinforced with routed beams.

Each tank was lined, first with 20 mil vinyl sheet, then with a 6 mil polyethylene sheet. The liners were held in place by the reinforcing beams, the sheets having been fitted prior to installation of the beams. The polyethylene sheet served as a barrier to fungicidal chemicals in the vinyl as well as protection against abrasion by filter materials.

The water recirculation system utilized the "air-lift" principle (Spotte 1970), whereby air was released at the bottom of a column of water in a lift pipe. The light (air-water) mixture moved upward and spilled from the lift pipe as water constantly replaced the aerated water at the bottom. The entire system was plumbed with polyvinylchloride (PCV) pipe. Each tank had 16 lift pipes 76 mm diam with outfall 33 cm from the bottom, each activated by 12.5 mm air lines. A grid of 8 equally spaced horizontal slotted 37 mm manifolds parallel to the aisle delivered water from the bottom of the tank into the lift pipes.

Air, recirculated through the greenhouse, was provided to each tank through a horizontal

76 mm manifold. Two horizontal 37 mm manifolds perpendicular to the aisle received air from the 76 mm manifold for the vertical air lines that were inserted into the lift pipes (Fig. 1).

A high volume, low pressure supply of air was generated by a blower powered by a 1.5 hp electric motor and capable of delivering ca 900 ft^3/min at a head of 25 cm of water. Air flow was controlled either by valves at the connection to

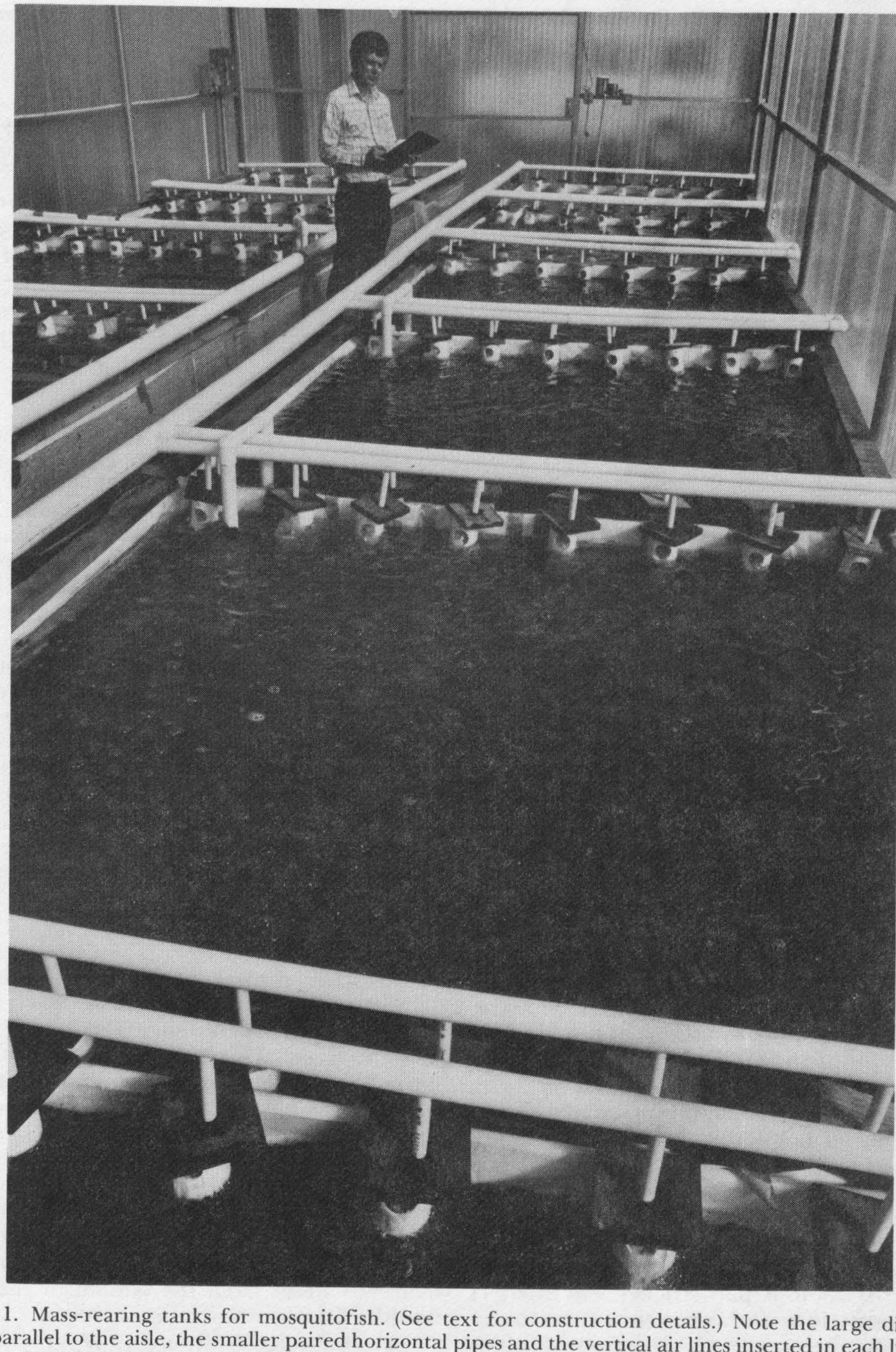

Fig. 1. Mass-rearing tanks for mosquitofish. (See text for construction details.) Note the large diameter pipes parallel to the aisle, the smaller paired horizontal pipes and the vertical air lines inserted in each lift pipe. The wooden blocks on top of the lift pipes reduced splashing.

the 76 mm manifold or by changing the submergence of the air line. The rate of water circulation with 12 tanks receiving air was a maximum of 32 liters/min per tank and up to 160 liters/min when only one tank received air. Thirty-two liters/min provides a vertical flow of 0.54 cm/min. Therefore, experimental comparisons of fish growth rates were made at 0.5 versus 2.0 cm/min.

The greenhouse enclosure was used on the assumptions that sunlight would simultaneously reduce heating costs and encourage maturation and growth of the fish. Supplemental fluorescent lighting was provided on a 16/hr/day regime. No quantitative data are available to establish the ratio of solar to auxiliary heat in the system.

The biological filter in each tank consisted of a 50 mm layer of crushed rock (6 × 12 mm) covered by a 128 mm layer of Lapis Luster #3 aquarium sand. The crushed rock provided little surface area but served to keep the slots on the undersides of the grid of delivery pipes free of sand. Three major factors contribute to the carrying capacity of a biological filter: a) particle size, b) depth of filter, c) flow rate through the filter. The theoretical capacity of these filters will be discussed following presentation of the results.

Experiments on fish growth were conducted during the spring of 1984 either with fish free-swimming over the filter or with the fish in suspended cages. The suspended cages were 16-mesh fiberglass attached to 37 mm PVC pipe frames. Spawning experiments were conducted using either gravid females in individual cages following Downs and Beesley (1983) or using 90 females in 0.6 × 0.6 m wooden frames with 6-mesh net bottoms. Fry production utilized both the hatchery system (Downs and Beesley 1983) and the tanks in the greenhouse. All experiments used stock or its offspring from southern Yuba County, CA, supplied by Sutter-Yuba Mosquito Abatement District.

Two experiments compared methods of fry production. Both compared the number of fry produced by 90 females in individual cages versus those from 90 in a cage 0.6 × 0.6 m^2. The first experiment was for 6 days and the second was for 2 days. Both comparisons were replicated 4 times. In the first experiment the mass cages were in the greenhouse and the individually caged fish were in the hatchery building, whereas in the second both treatments were in the hatchery building. The second experiment addressed the possibility that site differences rather than caging method was important.

Following the cage comparisons a series of fry production trials on a 2–2–3 day cycle were carried out to determine the practicality of fry production from individual cages as a routine source of fry. For each 2 or 3 day period 6 replicates of 90 females were set up.

Finally, two series of paired comparisons of rates of growth in tanks with flow rates of either 2.0 or 0.5 cm/min were made. The first was with fish in suspended cages over the filter, the second was with the fish free-swimming. The fish used as stock for the comparisons of growth in different filter flow rates were graded through a screen that selected fish no smaller than 1100/kg, and that averaged about 770/kg.

Throughout these experiments the fish were fed a mixture of equal parts of Purina Trout Chow No. 3 and Sutter-Yuba Mix, with a supplemental ration of about 5% Tetramin® flakes. The basic ration was dispensed automatically at 2 hr intervals at approximately 30 g/day per 0.45 kg of fish (wet weight). The automatic feeding system is described by Hoy (1984).

RESULTS AND DISCUSSION

The two experiments that compared fry production methods showed that many more fry were produced by individually caged fish than by an equal number of fish in a single cage (Table 1). The first experiment compared individually caged fish in a conventional building (hatchery) and in a very gentle current of water vs. group caged fish in a greenhouse in a more rapid current. In that experiment there was a very highly significant difference ($p < 0.001$) in the numbers of fry produced. To determine if there was a site effect, a second experiment in the hatchery compared the cage methods and found again that production by individually caged fish was far greater ($p < 0.001$). Note that on a per day basis, the yield was only about 1.1 or 1.2 fry/female.

A series of 9 fry production trials, each using 90 individually caged fish replicated 6 times, confirmed the results of the first two experiments. The mean production per trial ranged from 0.73 to 2.16 fry/female (Table 2). No time

Table 1. Paired comparisons of fry production from 90 gravid mosquitofish in individual cages vs group-caged fish (n = 4).

	Experiment 1 (6 days)		Experiment 2 (2 days)	
Replicate	Individual	Group	Individual	Group
1	562	39	57	12
2	412	68	202	43
3	923	93	309	31
4	568	75	303	43
Mean***	616.25	68.75	217.75	32.25

*** Means significantly different by ANOVA at $p < 0.001$ for both experiments.

trend was evident, although the trials were conducted in April when increasing yields might have been expected (Reynolds 1977).

These experiments indicate that for a rearing facility to be self-sufficient and produce hundreds of kilograms of fish, a more efficient fry production method is required. Another consideration is that a lower rate of fry production may prevail during the winter months (Reynolds 1977).

Experiments to determine the effect of the rate of water movement through the filter on the growth rate of the fish supported by the biological filter were initially conducted with 0.91 kg of fish in 0.7 × 1.4 m suspended cages. However, high mortality and only moderate growth of the survivors caused rejection of that method after two pairs had been compared.

Finally, a series of paired comparisons of flow rates of 0.5 cm/min vs. 2.0 cm/min were made with the fish swimming free over the filter. Seven pairs were set up. A significant number of fish were lost from one tank from an overflow and one tank had very high mortality. In 10 days the 6 tanks at the lower flow rate had an average increase in weight of 0.31 kg (S.D. = 0.34) while the 6 at the higher rate had an average increase of only 0.18 kg (S.D. = 0.07). The theoretical maximum load of fish per tank, using Spotte's (1970) formula at flow rates of 0.5 and 2.0 cm/min are 2.67 and 4.567 kg respectively. Note that quadrupling the flow rate provides for only a 71% increase in load. Also, the beginning experimental load was 0.91 kg, only 34% of the maximum at the slower flow rate. Clearly, nothing was gained by using the faster flow rate, perhaps because the load was well below the maximum.

These experiments give some encouragement to those who are interested in large-scale rearing of mosquitofish. Growth rates for the 10-day periods averaged 24.1%, at 24 4° C. Increasing the temperature to 30° C might have increased growth to as much as 36%. However, a 12-tank system such as described here could not be expected to yield 1.4 metric tons of fish per year without either exceeding the theoretical maximum load or significantly improving on the observed growth rate.

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Table 2. Fry production by 90 individually caged gravid females, by periods, replicated 6 times/period.

	Period								
	1	2	3	4	5	6	7	8	9
Days/period	2	2	3	2	2	3	2	2	3
Mean/replicate	132.0	214.5*	189.7	326.5	389.0	359.0	218.8	196.2	260.2
S.D.	67.4	61.3	79.1	93.3	93.0	127.4	99.5	25.8	57.8
Mean/day/♀	0.73	1.19	1.05	1.81	2.16	1.33	1.22	1.09	0.96

* Mean based on 4 replications rather than 6.