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GROWTH AND PRODUCTION CONTROL OF GOLDEN SHINER *NOTEMIGONUS CRYSOLEUCAS* (MITCHILL) BY MANIPULATING TEMPERATURE AND DENSITY

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Sha Miao (1990) Growth and production control of golden shiner *Notemigonus crysoleucas* (Mitchill) by manipulating temperature and density. *Bull. Inst. Zool., Academia Sinica* **29**(4): 223-232. Better control of the golden shiner to meet market demand is needed. An experimental study evaluated the simultaneous effects of two factors (temperature and stocking density) with three treatment levels each. Three thermal regimes consisted of one constant temperature (24°C) and two daily thermocycles. The temperatures of the two thermocycles increased respectively from 22.7 to 26.8°C and from 24.6 to 28.8°C in a 12-hour-cycle, and then declined to their respective orgins on the following 12-hour-cycle. Three fish densities were created by stocking five fishes per 10-, 15- and 30-gallon aquaria.

Data indicated that density was not a dominant factor during the 80-day experiment. However, the results suggested that the temperature of the dynamic system should be constant at 24°C or cyclic between 24.6 and 28.8°C for the first 20-day period but cyclic between 22.7 and 26.8°C for the second to control golden shiner production for market needs. As for the last two 20-day periods, among the three studied temperatures, no significant differences in terms of growth showed up.

Key words: Golden shiner, Constant temperature, Thermocycle, Stocking density, Stochastic modeling.

The minnows (Cyprinidae) are one of the characteristic families of North American fishes and are of economic importance since they constitute the major portion of the food for game and commercial fishes (Markus, 1934). The advent of minnow farming was preceded by many years of harvesting of wild minnow stocks (Brown and Gratzek, 1979). A major problem of the bait industry has been that it can not catch enough minnows during the summer when the sport fishery reaches its peak (Gordon, 1968). As wild stocks became more difficult to find and to harvest, as a result of overharvesting, pollution and other factors, interest grew in raising bait fish (Brown and Gratzek, 1979).

In aquaculture, two variables that may influence recruitment to fish stocks are temperature and population density, both of which could influence growth and fecundity. Everhart and Youngs (1981) reported that the growth rate of fish depends to a large extent on temperature and most species of fishes do not spawn unless the water temperature is within certain limits. A temperature fluctuating between 10 and 20°C and averaging 15°C does not necessarily have the same effect on organisms as a constant temperature of 15°C (Odum, 1959).

Le Cren (1965) stated that population density and growth rate are inversely related. As population density increases, competition for nutrients, food and living space usually intensifies, providing one of the most effective controls on both plant and animal populations (Odum, 1959). Meanwhile, metabolic wastes, which are directly proportional to population density, have been implicated as inhibitory to growth and toxic to fishes (Yu and Perlmutter, 1970). Smith *et al.* (1978) reported that high population density appeared to limit growth and gamete development regardless of food abundance.

The golden shiner is an excellent bait minnow (Cooper, 1937; Pflieger, 1975; Prather, 1957; Scott and Crossman, 1973) and is well suited for pond culture (Forney, 1957; Pflieger, 1975; Scott and Crossman, 1973). Miao (unpublished report) indicated that there is a high demand for golden shiner in the Michigan minnow market. The objective of this research is, therefore, to control the growth and production of golden shiner by manipulating temperature and stocking density.

MATERIALS AND METHODS

A linear stochastic model based on a split-plot design (Cochran and Cox, 1957; Gill, 1978a, 1978b, 1986; Myers, 1979; Petersen, 1985; Winer, 1971) was designed to investigate the effect of interaction between temperature and stocking density on the growth of golden shiner. The model is

$$\begin{aligned} Y_{tdap} = \mu + T_t + D_d + (TD)_{td} \\ + A_{(td)a} + P_p + (TP)_{tp} \\ + (DP)_{dp} + (TDP)_{tdp} \\ + (AP)_{(td)ap} + E_{(tdap)} \end{aligned}$$

where $t=1, 2, 3$; $d=1, 2, 3$; $a=1, 2$; and $p=1, 2, 3, 4$.

The right hand side of the above equation is composed of varieties of a system's inputs. These inputs represent average effects resulting from a particular factor or a combination of factors at a certain quantitative level. The μ is described as the true mean of the distribution of Y for a population defined by the experimental conditions as a whole. The capital letters T and D represent temperature and density, respectively. The three treatment levels (t) in temperature were: (1) constant temperature of 24°C; this was determined by averaging the temperatures of spawning initiation (21°C or 70°F) and spawning cessation (27°C or 80°F) for golden shiner (Brown and Gratzek, 1979; Pflieger, 1975; Scott and Crossman, 1973), (2) low cyclic temperature from 22.7 to 26.8°C, and (3) high cyclic temperature from 24.6 to 28.8°C. Three density levels (d) were created by randomly distributing groups of five fishes into aquaria of 10-, 15- and 30-gallon. Stocking rate of golden shiner at 5 fishes per 15-gallon-water was reported to produce the best growth (Hickman and Kilambi, 1974; Roseberg and Kilambi, 1975). The $(TD)_{td}$ indicates the average effects of the interaction of temperature at level t and density at level d. The t levels of temperature and d levels of density are combined in all possible ways to make $t \times d = 3 \times 3 = 9$ treatment combinations. And for each treatment combination, there were two aquaria, or two replicates (a). The $A_{(td)a}$ denotes random effects of aquaria nested within a treatment combination. Also known as "Error one", the $A_{(td)a}$ correspond to the $E_{(td)a}$ of the model for a completely randomized design without the repeated measurement.

This study lasted eighty days. The weights of individual fish were taken at the beginning of the study and at intervals of twenty days. The growth rate was estimated at the end of each twenty-day interval. As a result of the fish weight samplings repeatedly being taken at intervals of twenty days, the P_p are effects of time at the various sampling points in the process of repeated measurement, where the sampling intervals are $p=1, 2, 3, 4$. The $(TP)_{tp}$ and $(DP)_{dp}$ are the effects of the interactions of time with temperature and time with density, respectively. The $(TDP)_{tdp}$ are the effects of the interaction of three factors; temperature, density and time at the combined levels tdp. The interaction of an aquarium with time; $(AP)_{(td)ap}$ is not separable from the residual error within an aquarium, $E_{(tdap)}$. The $E_{(tdap)}$ is the residual error or net effect on Y of all unspecified factors of influence peculiar to aquarium a at interval p under the treatment combination td. The left hand side of the equation is the system's output symbolized by Y. Variable Y represents the weight ratio of the 5 fishes which is the final weight divided by the initial weight over the study time periods (i. e., 20, 40, 60, 80 days). Therefore, the sampled variable Y_{tdap} is the measurement being taken from aquarium a at interval p under the $(td)^{th}$ treatment combination. The total number of observations, or sample size, is $N=t\times d\times a\times p=3\times 3\times 2\times 4=72$.

In order to prevent a possible influence on the experimental estimates, a few nuisance factors had to be eliminated or systematically controlled. The system's illumination included nine fluorescent light fixtures with four 34-watt bulbs each regulated to a light period from 0800 hours to 2000 hours each day. The aquaria were filled with cold tap water one week prior to the addition of the fish to allow for aeration, iron precipitation and chlorine removal. The water came from the Michigan State University water supply system originating in deep groundwater sources. The experimental fishes were shipped by air from Finley Company Farms in Arkansas (P. O. Box 317, Lonoke, AR. 72086). On arrival, five fishes were randomly chosen and distributed into each aquarium and acclimatization began. The system's conditions of acclimatization were identical to those of the experiment. The research began after twenty days of acclimatization. The fishes received a daily diet of 3% of their body weights. This ration was divided into two equal parts given at 1000 hours and 1600 hours each. A commercial diet (Purina Trout Chow, Diet CR 6-30 #4 GRAN, manufactured by Glencoe Mills INC., Glencoe, Minnesota 55336) was the food source utilized for this feeding scheme and was kept refrigerated. The feeding activities were periodically terminated one day before to one day after the sampling date when the measurements of the fish weights and lengths were taken. Meanwhile the aquaria's clean-ups were repeatedly performed during the weighing periods. This cleaning scheme consisted of (1) scrubbing walls of the heaters and aquaria, and (2) syphoning the metabolic wastes and feed residuals. After syphoning, each aquarium was refilled (about one-third of its volume) with conditioned water previously stored in a reservoir.

RESULTS

The mean weight and mean weight ratio per treatment combination at four periods of 20-day each are contained in Tables 1 and 2 respectively. The assumptions underlying this statistical modeling, $E_{tdap}\sim NID(0, \sigma^2)$, were fully examined before entering the stage of analysis of variance.

Table 1

The mean weight per treatment combination at 4 periods (P) of 20-days each

Thermal treatment	Density treatment														
	10-gallon					15-gallon					30-gallon				
		P 1	P 2	P 3	P 4		P 1	P 2	P 3	P 4		P 1	P 2	P 3	P 4
24°C	Mean	11.85	11.60	12.30	13.35	Mean	11.70	10.45	10,65	11.45	Mean	12.60	11.20	11.70	13.55
	S^2	5.44	2.88	4.50	2.64	S^2	0.32	3.64	6.12	3.64	S^2	3.38	2.00	2.88	3.64
22.7 to 26.8°C	Mean	9.10	10.30	11.75	12.40	Mean	9.70	10.10	10.60	11.20	Mean	12.05	13.35	14.25	15.35
	S^2	0.32	0.32	1.81	2.00	S^2	0.08	2.00	3.38	5.78	S^2	0.41	0.24	0.12	2.64
24.6 to 28.8°C	Mean	10.25	10.30	10.80	12.15	Mean	12.80	12.25	12.65	14.05	Mean	11.60	11.75	12.70	13,25
	S^2	0.84	1.28	0.50	0.60	S^2	1.28	1.12	0.84	3.12	S^2	2.88	6.12	5.78	6.12

Table 2

The mean weight ratio per treatment combination at periods (P) of 20-days each

Thermal treatment	Density treatment														
	10-gallon					15-gallon					30-gallon				
		P 1	P 2	P 3	P 4		P 1	P 2	P 3	P 4		P 1	P 2	P 3	P 4
24°C	Mean	1.136	0.984	1.058	1.090	Mean	1.352	0.890	1.014	1.084	Mean	1.278	0.890	1.043	1.158
	S^2	0.117	0.002	0.0008	0.003	S^2	0.048	0.014	0.003	0.005	S^2	0.001	0.0003	0.0004	2×10^{-5}
22.7 to 26.8°C	Mean	1.048	1.132	1.139	1.056	Mean	0.976	1.044	1.047	1.053	Mean	1.095	1.108	1.068	1.079
	S^2	0.019	7×10^{-5}	0.005	5×10^{-7}	S^2	0.006	0.031	0.001	0.002	S^2	2×10^{-6}	0.0003	0.0002	0.02
24.6 to 28.8°C	Mean	1.094	1.004	1.051	1.125	Mean	1.236	0.964	1.034	1.108	Mean	1.188	1.008	1.084	1.044
	S^2	0.029	0.0004	0.002	2×10^{-6}	S^2	0.004	0.028	0.0002	0.003	S^2	0.002	0.004	0.0005	4×10^{-6}

Table 3
Bartlett's test on homogeneity of variances regarding the weight ratio

Time period	S_p^2	B	C	Test statistic B_C	Critical value $X^2_{\alpha,td-1}$	Is the assumption of equal variances respectively associated with 9 treatment combinations met?
Period 1 Day 1~Day 20	0.025	16.181	1.370	11.808	$X^2_{02.,8}=11.03$ $X^2_{0.1,8}=13.36$	Fair
Period 2 Day 21~Day 40	0.009	13.874	1.370	10.124	$X^2_{0.2,8}=11.03$ $X^2_{0.1,8}=13.36$	Yes
Period 3 Day 41~Day 60	0.001	4.680	1.370	3.415	$X^2_{0.2,8}=11.03$ $X^2_{0.1,8}=13.36$	Yes
Period 4 Day 61~Day 80	0.004	17.941	1.370	13.092	$X^2_{0.2,8}=11.03$ $X^2_{0.1,8}=13.36$	Fair

The result of the Shapiro-Wilk test against normality shows that the random errors of the observations are normally distributed ($w=1.14$, $p \gg 0.9$).

The homogeneity of variances associated with the nine treatment combinations were examined within each time period. Table 3 indicates that the assumption of equal variances is met.

Table 4 reveals that the time factor (period) has a significant effect on the growth of fish. However, a multiple comparison among the three thermal treatments must be done for the same period of time because of the significant interaction effect between period and temperature (Table 4).

Since density is not an effective factor from the ANOVA, the aquaria with various volumes at every time interval may be treated as a set of replicates as long as they receive the same thermal treatment. By applying Tukey's test, the means of thermal

Table 4
ANOVA of the weight ratio

Source of variation	Degrees of freedom (D.F.)	Sum of squares	Mean square	F ratio	Probability
Total (Y)	71	0.955525	0.013458		
Temperature (T)	2	0.001596	0.000798	0.0898	
Density (D)	2	0.004842	0.002421	0.272	
Interaction (TD)	4	0.018771	0.0046927	0.528	
Error I (A/TD)	9	0.079995	0.0088883		
Period (P)	3	0.218839	0.0729463	7.154[a]	$0.001<p<0.0025$
Interaction (TP)	6	0.245025	0.0408375	4.005[a]	$0.005<p<0.01$
Interaction (DR)	6	0.056241	0.0093735	0.919	
Interaction (TDP)	12	0.054905	0.0045754	0.449	
Residuals (E)	27	0.275311	0.0101967		

a. The effect of treatment or treatment combination is significant.

Table 5
Turkey's test on thermal treatments of the weight ratio within each time period

Time period	Thermal treatment	Treatment mean	Difference between means	Determination according to HSD[a]=0.0975
Period 1 Day 1 to Day 20	24°C 24.6~28.8°C 22.7~26.8°C	1.255 1.173 1.040	0.082 0.133	Treatments 24°C and 24.6 to 28.8°C are effective
Period 2 Day 21 to Day 40	22.7~26.8°C 24.6~28.8°C 24°C	1.095 0.992 0.922	0.103 0.070	Treatment 22.7 to 26.8°C is effective
Period 3 Day 41 to Day 60	22.7~26.8°C 24.6~28.8°C 24°C	1.084 1.056 1.038	0.028 0.018	There is no significant difference
Period 4 Day 61 to Day 80	24°C 24.6~28.8°C 22.7~26.8°C	1.111 1.092 1.062	0.019 0.030	There is no significant difference

a. Referring to Tukey's test modified by Gill (1986):
$HSD=(q_{\alpha,t,\hat{r}_E})\sqrt{({}_p{}^2/r)/2}$, where $\alpha=0.05$, $t=3$, $r=6$,
$S_p{}^2=[MS_{A/TD}+(p-1)\,MS_E]/p$,
$\hat{\gamma}_E=(S_p{}^2)^2/\{[MS_{A/TD}{}^2+(p-1)\,MS_E{}^2]/[tp^2(r-1)]\}$,
$MS_{A/TD}$=Error I=0.0088883 (Table 4),
MS_E=Residuals=0.0101967 (Table 4), $p=4$.

Table 6
Daily growth rate of a single fish associated with producing thermal treatment at 4 periods of 20-days each

Time period	Thermal treatment	Treatment mean (W_t/W_0)[a]	Daily growth rate (G)[b]	Remark
Period 1	24°C	1.255	0.0113568	Optimum
(Day 1 to	24.6~28.8°C	1.173	0.0079782	Optimum
Day 20)	22.7~26.8°C	1.040	0.0019610	
Period 2	22.7~26.8°C	1.059	0.0045377	Optimum
(Day 21 to	24.6~28.8°C	0.992	−0.0004016	
Day 40)	24°C	0.922	−0.0040605	
Period 3	22.7~26.8°C	1.084	0.0040329	Statistical
(Day 41 to	24.6~28.8°C	1.056	0.0027244	tie
Day 60)	24°C	1.038	0.0018648	
Period 4	24°C	1.111	0.0052630	Statistical
(Day 61 to	24.6~28.8°C	1.092	0.0044005	tie
Day 80)	22.7~26.8°C	1.062	0.0030077	

a. W_0 is the fish weight of an aquarium at time zero or the former time; W_t is the fish weight of an aquarium at time t or the latter time.
b. G is the daily growth rate of fish, that is,
$G=\ln(W_t/W_0)/t$, where $t=20$ days.

treatments were compared at every time interval. Table 5 presents the effective-thermal treatment(s) in terms of weight ratio on the basis of the 20-day-cycle.

Table 6 summarizes the optimum thermal treatment(s) regarding daily growth rate for a single fish in a time sequence.

DISCUSSION

While the density factor with designed ranges was shown to be insignificant, the thermal factor throughout the first two studying periods did have a significant effect on the growth and production of fish. The constant temperature (24°C) and the temperature cyclic between 24.6 and 28.8°C were both shown effective for the first 20-day period. The cyclic temperature, fluctuating between 22.7 and 26.8°C, appeared to be the best treatment from day 21 through day 40. As for the last forth days, among the three studied temperatures, no significant differences in terms of growth were shown. These results suggested that the three thermal treatments should be interchanged with one another over the first two consecutive intervals to achieve the management goals.

Biette and Geen (1980) demonstrated that the growth of young sockeye is greater under cyclic than constant temperatures. For brown trout, a fluctuating temperature could significantly increase their feeding, growth and lipid deposition compared with constant temperatures at the mean of the fluctuations (Spigarelli *et al.*, 1982). Odum (1959) stated that the growth of organisms normally subjected to variable temperatures in nature (as in most temperate regions) tends to be depressed, inhibited or slowed down by constant temperature. However, depending on the time of day the thermocycle was initiated, weight gain and testicular growth could be either stimulated, inhibited or equal to that in fish subjected to constant heat or constant cold (Spieler *et al.*, 1977).

The two studied cyclic temperatures as a secondary design utilized in this study differed from the primary desires. The primary desires intended to be 24±2 and 24±4°C with daily fluctuations of 4 and 8°C, respectively. However, budgetary constraints did not allow using the desired temperature cycles, forcing the use of a secondary design. In addition, the electrical supply to the laboratory only allowed each treatment combination to be replicated 2.5 times in terms of the needed heating and aeration. Constrained to two replicates per treatment combination, this experiment ran the risk of low statistical power. The replication used was the maximum attainable with the facilities available.

The results indicate an application in utilizing the heated effluent waters of power plants as a substitute water source. Aquaculture industries in some countries today face an increasing problem of water supply. More and more farming systems are getting less and less water out of deep wells because of lowered water tables. Such declines expose the serious fact of overpumping resulting from the high water demand by industrial plants and a vast increase in farming activities.

Unfortunately, Taiwan's aquaculture also suffers from a land shortage. As a result of this limitation, the competition for land utilization among varied systems including industry and farming has intensified. Consequently, sea ranching is able to exploit an extra dimension to continuously develop local aquaculture.

Sea ranching in Taiwan may be localized within the coastal areas where heated effluent waters are released from nuclear power plants. By mixing waters properly, several desired temperatures (constant or cyclic) could be generated to enhance fish production and to meet market demands. The application of "waste-heat" aquaculture, in fact, has proven to be economically feasible in some developed countries.

However, the results (Table 6) indicate that the two sets of thermal treatments in the four consecutive intervals are both optimum, namely, in a statistical tie. Additionally, the growth rate and carrying capacity are a pair of parameters in the Logistic Equation (Ricker, 1975; Spain, 1982; Wilson and Bossert, 1971). Their magnitudes are affected with the intensity of the treatment combination. In turn, the biomass production of the Logistic Equation is positively related to the two parameters. A better growth rate or carrying capacity reveals that a given treatment combination is more effective. There is no causal correlation between the paired parameters. This implies that a better growth rate is not necessarily accompanied by a better carrying capacity, or vice versa. Consequently, several sets of treatment combinations in a time sequence were statistically determined as optimum considering only growth rate. Likewise, other sets of treatment combinations might be accepted as optimum considering only carrying capacity.

Therefore, to clarify the obscurity and controversy of the experimental results, some further studies, for instance, a computer simulation, should be conducted in the future.

Nevertheless, a less effective treatment combination does not always indicate a nuisance input. Such inputs, especially from the management point of view, may act as control valves to reduce an unwanted growth and production at different rates, and therefore to provide positive effects for the system. For example, sport fishermen may require various sizes of bait minnow in fishing. Our objectives are to provide neither a shortage nor an oversupply, but rather a supply that meets the demand of the market place.

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藉溫度和放養密度控制小金鯉的成長速率和生產量

繆 峽

為求市場供需平衡，小金鯉的成長速率和生產量勢必得有效控制。藉溫度和放養密度之搭配，本實驗探討該兩個因子對小金鯉的成長和產量之影響。

溫度因子包括了三種層次不等之強度，它們分別為攝氏 24 度之恆溫以及攝氏 22.7～26.8 度和 24.6～28.8 度之兩種變溫。兩種變溫之週期都是 24 小時。也就是在第一個 12 小時內，各自由低溫點升至高溫點，再在第二個 12 小時內由高溫點同降至低溫點。三種放養密度則是每 10, 15, 30 加侖之魚缸各放養 5 尾魚。

雖然結果顯示在該實驗狀況下的放養密度不是重要因子，但在為期 80 天（每 20 天為一成長週期）的成長過程中，不同之溫控應當隨成長週期變遷而交替運作，以達到平衡市場供需之目的。因此，在第一個 20 天內，溫控應當維持在攝氏 24 度或採用攝氏 24.6～28.8 度之變溫。在第二個 20 天的成長週期中，攝氏 22.7～26.8 度之變溫控制最為有效。至於最後的 40 天內，三種實驗溫控對成長之影響並無顯著差異。