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RESPONSE OF THE BLUEGILL POPULATION AND FISHERY OF MILL LAKE TO INCREASED GROWTH: A SIMULATION MODEL[1]

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ABSTRACT

The growth rate of the bluegill in Mill Lake was increased hypothetically from slow to average to fast. New populations were generated with the assumptions that (1) natural mortality is age dependent (Model A) and (2) natural mortality is size dependent (Model B). The populations were then subjected to "fishing" and changes in the size and structure of the population were noted. Catch from the populations was predicted also.

Considering the large differences in growth, the differences in the populations and fisheries were small. According to the most realistic model (B), yield in kilograms and average size of bluegills creeled would increase with growth, and the numbers of large bluegills in the population would increase substantially if growth were increased from slow to fast. These benefits may be dampened considerably if the total standing crop of bluegills had to be reduced in order to improve growth. A similar model was constructed for the bluegill population and fishery of Sugarloaf Lake. The characteristics and predictions from that model agreed with empirical data from Sugarloaf Lake.

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Introduction

Mill Lake, like many other lakes in Michigan, contains a large, slow-growing population of bluegills (Lepomis macrochirus). In lakes of this type fisheries managers frequently attempt to improve bluegill growth and angling quality by thinning the population with toxicants. While it is well known that growth and, hence, the average size of the bluegills will improve for a short time (Hooper, et al., 1964), an analysis of other effects, such as changes in catch rates, has not been made. Such basic information would be of value in determining more fully the benefits of reclamation projects and in selecting goals for lake management.

The purpose of this report is to predict the changes in the size and structure of the bluegill population, and in the catch by anglers, if the growth of Mill Lake bluegills were increased. Although developed mostly from data collected at Mill Lake, the results appear to have wide-spread applicability.

This paper is the fourth in a series on Mill Lake fishes. The first paper (Schneider, 1971) described the vital statistics of the fish populations; the second (Schneider, 1973a) reported on the fishery which developed the first few days Mill Lake was re-opened to angling; in the third (Schneider, 1973b) the effects of exploitation rate and minimum size limit on the bluegill population and fishery were simulated. This fourth paper is an extension of the third in which growth is the major variable.

General methods

Most of the data and methodology used in this report may be found in the preceeding report (1973b). The same Ricker-type model was used here and, as before, the model "year" began in the spring. From instantaneous rate of growth (g), natural (q), and fishing (p) mortality, the numbers of bluegills in each age group of the population, and the corresponding catch by anglers, were computed on an annual basis. All results apply to the steady-state (equilibrium) condition.

Although growth was the major variable in the analysis, assumptions had to be made as to whether or not natural mortality would vary with growth and, if so, in what manner. Our knowledge of this interaction in fishes is very limited. It is usually assumed that natural mortality is age, rather than size, specific; on the other hand it is often suggested that fish which grow fast do not live as long as slow-growing fish. Consequently, I have developed one model (A) based on the assumption that the natural mortality rate of an age group of bluegills is independent of their growth, and a second model (B) based on the assumption that natural mortality claims a constant fraction (55%) of the 6.0-inch and larger bluegills irrespective of their age.

For these calculations I have used an exploitation rate of 30%, by weight, for those age groups containing bluegills of a size sought by anglers. This rate of exploitation is believed to be typical for lakes of this type. The models are based on the premise that the standing crop of age-II and older bluegills would remain at 49 kg per ha as growth was increased. This assumption will be discussed in greater detail later.

As a final step in the analysis, Model B was modified to fit specific data for the bluegill population and fishery of Sugarloaf Lake. Predictions from the model were then compared with empirical data.

Model A. In this model it was assumed that the natural mortality rate of each age group of Mill Lake bluegills would remain the same as growth increased from slow (the condition in which natural mortality was measured) to average (the Michigan average as determined by Laarman, 1963) to extremely fast (a hypothetical rate based on the growth of bluegills in Marble Lake as reported by Laarman and Schneider, 1972). Lengths of average- and fast-growing bluegills were converted to weights by means of an average length-weight relationship (Beckman, 1948) and instantaneous rates of growth (g) were computed. These growth rates plus the instantaneous natural mortality rates (q) observed in slow-growing bluegills may be found in Table 1.

From these data and a spring standing crop of 49 kg per ha of age-II and older bluegills, I computed the biomass and number of bluegills in each age group if fishing were not taking place. I then subjected these hypothetical populations to simulated fisheries in which 30% of the biomass (20-25% of the numbers) of each age group would be harvested. Harvesting began at age V for the slow-growing population, at age IV for the population growing at the average rate, and at age II for the fast-growing population. These ages of entry were roughly equivalent to a minimum size limit of 5.5-6.0 inches.

The age structures of the hypothetical populations were converted to size structures by means of the following size-age distributions:

Growth	Size group in inches		
	5.0+	6.0+	7.0+
Slow	V-IX	VI-IX	1/2 VII, VIII-IX
Average	1/2 III, IV-IX	1/2 IV, V-IX	VI-IX
Fast	II-IX	III-IX	1/2 III, IV-IX

The predictions from the model are summarized in Table 2. Looking first at the fisheries; the catch did not vary greatly when growth was altered. Between 6.0-7.6 kg and 75-90 fish would be caught per ha. The slightly smaller catches from the population growing at an average rate are due to a peculiarity in the growth pattern of Mill Lake bluegills which will be discussed later. The average size of bluegill in the creel would be 6.4 inches under conditions of slow growth and 6.9 inches under conditions of average or fast growth.

Looking now at the unexploited fish populations, in the second part of Table 2, the number of bluegills larger than 5.0

inches would be similar for populations with any of the three growth rates; however, the fast-growing population would have twice as many bluegills larger than 7.0 inches than the slow-growing population. A population growing at the average rate would have an intermediate number of larger bluegills.

The simulated fishery would have little effect on the numbers of 5.0-inch and larger bluegills in a slow-growing population (97% would remain), but an appreciable effect on this size group in average or fast-growing populations (residual populations of 81 and 76%, respectively). For any of the three populations the numbers of larger bluegills would be reduced to 40% of their maximum possible abundance.

Growth had an important effect on the critical size (i.e., the point in the life history of a cohort of fish when biomass is optimal) of the hypothetical populations. As growth increased from slow to average to extremely fast, the critical size increased from about 6.0 to 6.3 to 8.0 inches. Thus, if exploitation were to become extremely high (on the order of 80% or more), then minimum size limits approaching these critical sizes would be appropriate to optimize yields to the fisheries.

In summary, if natural mortality is age-specific and the total standing crop of bluegills remains constant, the major benefits of increasing the growth of Mill Lake bluegills would be an increase in the average size of the bluegill creeled and an increase in the numbers of larger bluegills in the population. Minimum size limits may be necessary to assure optimal yield from faster growing bluegill populations.

Model B. In this model it was assumed that the natural mortality rate of each age group would increase as growth increased with the net result that the natural mortality rate (n) of bluegills larger than 6.0 inches would remain at 55% per year. This assumption was based on the observation that n values on the order of 50% have been obtained for both slow- and fast-growing bluegill populations (see review by Schneider, 1969).

The natural mortality rates for each age group in the hypothetical average- and fast-growing populations were estimated by a trial-and-error process from the empirical q rates of the slow-growing bluegill population in Mill Lake. A graph of q against age and size served as a guide. The resulting estimates of q (the two right-hand columns in Table 1) preserved the tendency for q to increase with age, and resulted (when no fishing was taking place) in a natural mortality rate (n) equal to 55% of the 6.0-inch plus bluegills. Other assumptions and procedures were the same as in Model A.

The predictions from Model B have been included in Table 2 to facilitate comparison with those from Model A. For the same reason, the predictions for the slow-growing population have been entered in the Table under both models A and B.

In the B model, yield was increased from 6.7 to 7.6 to 9.8 kg per ha by increasing growth from slow to average to fast. The number of fish caught would be about the same (84-90) but the fast-growing bluegills would average 0.7 inches longer than the slow growers. In terms of the size of the unexploited populations, the number of 5.0-inch and larger bluegills would not differ appreciably, and the numbers of larger bluegills would be much greater in the fast-growing population than either the populations with slow or average growth. The effect of a typical fishery was similar to the effect observed in Model A except that a higher fraction of the larger bluegills (57% compared to 40-41%) would remain in the fast-growing population.

In summary, if natural mortality rate is a function of size rather than age, and total standing crop of bluegills remains constant, then according to Model B the major benefits of increasing the growth of bluegills in Mill Lake would be increases in yield, in average size of bluegills creeled, and in numbers of larger fish in the population.

The most prominent differences between models A and B are between the predicted yields and between the numbers of larger bluegills in the average- and fast-growing populations. Also, there is an important difference in the response of critical size to increased growth: the critical size did not vary with growth in Model B as it did in Model A but remained constant at about 6.0 inches.

Discussion

Considering the wide range of growth tested in the models, the differences between the predicted populations and fisheries were not very great. An extremely slow growth rate--so slow that no bluegills reached large size--could have been tested also but the results are obvious.

Actually the bluegills in Mill Lake grow slowly only for the first two years of life. The g values from age II on exceed those of average- and fast-growing populations. What appear to be irregularities in Table 2 were caused by certain peculiarities in the data, such as growth patterns and the slightly higher size of entry used in modeling the populations with average growth. Also, the high natural mortality rate during age II had a large effect on Model A. So high a rate seems inappropriate for the average- and fast-growing populations since their bluegills are much larger and, presumably, would be less vulnerable to predation than the smaller, slow-growing bluegills. For that reason, and because the literature on bluegill mortality suggests that n is size related, Model B is believed to be more realistic than Model A.

Either model shows that there would be some benefits if growth of Mill Lake bluegills could be improved without altering total standing crop. Thinning the population by means of toxicants could improve growth, but at the expense of standing crop, and, consequently, harvest. It has been estimated that the biomass of a slow-growing bluegill population must be reduced by one-third for a significant improvement in growth to occur for one year (Hooper, et al., 1964). If we assume that a management program of reducing the population by one-third every year would change growth of bluegills from slow to fast in the manner predicted by Model B, then (1) yield would remain at about 6.6 kg per ha (9.8 x 0.67); (2) catch in numbers would decrease from 90 to 59 (89 x 0.67); (3) the bluegills in the creel would average 7.1 inches instead of 6.4 inches; (4) the numbers of 5.0-inch and larger bluegills in the population (if fished at the typical rate) would decline from 470 (485 x 0.97) to 277 (525 x 0.79 x 0.67); but, (5) the numbers of large bluegills would increase from 33 (82 x 0.40) to 78 (206 x 0.57 x 0.67). In short, the "costs" of the management program--in addition to the cost of toxicant and manpower--would be decreases in numbers of bluegills harvested and the numbers of 5.0-inch plus bluegills available to fishermen; that is, a decline in bites per hour. The "benefits" would be more large fish in the creel and population; that is, an increase in quality. Obviously, if a one-third thinning program only improved growth to average, costs would clearly exceed benefits.

A test of the model: Sugarloaf Lake. Sufficient data on the bluegill population and fishery of Sugarloaf Lake were collected during 1952 so that a model could be constructed and its predictions tested. The model developed for Sugarloaf Lake was similar to Model B, average growth. Differences were that: (1) bluegills in Sugarloaf Lake grew slightly slower than the state average rate the first four years of life (Cooper, et al., ms); (2) exploitation rate was 21% by number (Cooper and Latta, 1954); (3) natural mortality (n) in the absence of fishing was 58% of the 6.0-inch and larger bluegills; (4) a reduced rate of exploitation (7%) was assigned to age III; (5) the computations were broken down into three seasons or periods--April 1 to June 24, June 25 to September 14, and September 15 to March 31--to more precisely simulate the dynamic nature of the system. In order to obtain seasonal growth rates, I assumed that growth in length was linear between April 1 and September 15, and that no growth took place September 15 - April 1. In order to obtain seasonal rates of natural mortality, I judged (based on the analysis of Patriarche, 1968, for another lake) that 28% of the annual n occurred in the first period, 62% in the second, and 10% in the third. Seasonal fishing rates were obtained by apportioning annual p on the basis of the unpublished catch estimates of K. E. Christensen for the 12 months prior to the fall of 1952: 26.6% of the annual catch was made in the first period, 34.9% in the second, and 38.5% in the third.

Table 3 is a simplified version of the Sugarloaf Lake model. Its format and computations were similar to those of models A and B except the latter were not broken down seasonally. For each time interval in the model, q + p was subtracted from g. Log_e of the result was the factor by which the weight of the population changed. The predicted catch, by weight, was the product of p and the average weight of the population. The numbers of fish in the population and catch were estimated by dividing kg per ha by the average weight of a bluegill. The total annual catch was the sum of the catches in each time interval.

The characteristics of the bluegill population generated by the model compare favorably with those estimated by Cooper and Latta (1954) in the fall of 1952. From the group of age-IV and older bluegills present each spring (equivalent to age-III and older in the fall) the model predicts that 22% would be caught, 42% would die from other causes, and 36% would survive the year. Cooper and Latta estimated that 21% were caught, 45% died naturally, and 34% survived. The model predicts a residual population of 153 6.0-inch and larger bluegills per ha; Cooper and Latta's estimate of the residual population was 157 bluegills per ha.

The fishery predicted by the model was similar to the fishery which existed in Sugarloaf Lake. The model predicted a catch of 109 bluegills per ha; the creel census estimate was 130 bluegills per ha. Additional data on the bluegill fishery of Sugarloaf Lake were obtained from 144 scale samples taken from the catch between 1949 and 1958--a period when the population and catch were stable. The average size of bluegills in the catch was 6.4 inches for both the scale samples and the model. Also, their age distributions were similar:

	Age						
	II + III	IV	V	VI	VII	VIII+	Total
Scale samples	22%	40%	28%	9%	1%	0%	100%
Model	22%	50%	21%	6%	1%	0%	100%

The empirical data and the predictions from the model are in remarkably good agreement considering all the potential sources of error in these data. This indicates that the age distributions of natural mortality and exploitation I assumed are realistic; namely (1) that natural mortality rate increases with age and is probably also a function of size and growth as assumed in Model B, and (2) that fishing rate (p) increases with size and age but exploitation (μ) tends to remain constant.

Closer agreement between the age distribution of the scale samples and the predicted catch could have been obtained if a lower rate of fishing had been assigned to age-group IV (many fish in this age were less than 6.0 inches and, probably were less desirable to anglers) and an even higher rate of fishing had been assigned to ages V and VI. This would have caused a reduction in the total catch, however, a prediction which is already on the low side but probably well within the statistical confidence limits of the creel census estimates. The catch prediction could be increased slightly by dividing the model year into even shorter time periods to obtain a better approximation of the dynamics of the system. For example, by dividing an annual model for Sugarloaf Lake into three periods, the predicted catch increased by 12%. This comparison likewise suggests that the annual models in Table 2 may underestimate the true catch by about 20% and may overestimate the residual population by a few percent. Nevertheless, these models--especially Model B--describe the complex relationship between growth, population size and structure, and the fishery with a useful degree of accuracy.

Table 1. Age-specific mean lengths and weights, and instantaneous growth (g) and natural mortality rates (q) for slow-, average-, and fast-growing bluegills.

Age	Length (inches)			Weight (grams)		
	Slow	Ave.	Fast	Slow	Ave.	Fast
II	2.5	3.8	5.4	3.4	16	48
III	3.6	5.0	6.9	11	36	102
IV	4.6	5.9	7.8	25	63	150
V	5.5	6.7	8.6	45	91	210
VI	6.4	7.3	9.1	72	119	246
VII	7.0	7.7	9.4	97	139	284
VIII	7.3	8.2	9.6	111	186	300
IX	8.0	8.7	9.8	150	214	315

Age	Growth (g)			Mortality (q) for growth:		
	Slow	Ave.	Fast	Slow	Ave.	Fast
II	1.174	0.811	0.753	1.52	0.26	0.42
III	0.820	0.560	0.385	0.26	0.28	0.53
IV	0.588	0.367	0.336	0.26	0.40	1.20
V	0.470	0.268	0.157	0.30	0.90	1.64
VI	0.298	0.155	0.143	0.53	1.60	2.40
VII	0.135	0.291	0.054	1.07	2.30	3.20
VIII	0.301	0.140	0.049	1.66	3.00	--
IX	--	--	--	--	--	--

Table 2. Predicted fisheries (with exploitation rate of 30%, by weight)* and populations with slow-, average-, or fast-growing bluegills under conditions of Model A (natural mortality is age-dependent) and Model B (natural mortality is size-dependent).

Model	Growth	Fishery				
		Time of entry		Catch per ha		Average length
		Age	Inches**	Kg	No.	(inches)
A	Slow	V	5.5	6.7	90	6.4
	Average	IV	5.9	6.0	76	6.9
	Fast	II	5.4	7.6	75	6.9
B	Slow	V	5.5	6.7	90	6.4
	Average	IV	5.9	7.6	84	6.7
	Fast	II	5.4	9.8	89	7.1

Model	Growth	Spring population by inch group					
		Number per ha without fishing			Relative number (%) with fishing		
		5+	6+	7+	5+	6+	7+
A	Slow	485	279	82	97	57	40
	Average	509	324	124	81	69	40
	Fast	488	200	169	76	42	38
B	Slow	485	279	82	97	57	40
	Average	545	307	68	86	74	41
	Fast	525	285	206	79	62	57

* An exploitation rate of 30% on a weight basis equals 20% by number for the fast-growing population, 25% by number for the population growing at an average rate and 23% by number for the slow-growing population.

** Approximate minimum size limit equivalent to that age of entry.

Table 3. A prediction of the bluegill population and catch (kilograms and numbers per hectare) of Sugarloaf Lake

Age	Date	$\overline{L}$ (in.)	$\overline{W}$ (g)	g	q	p	Factor[1]	Population Kg	Population No.	Catch Kg	Catch No.
III	4/1	4.6	29					10.4	358		
			35	0.32	0.08	0.02	1.25			0.2	7
	6/25	5.1	40					13.0			
			47	0.30	0.19	0.03	1.08			0.4	9
	9/15	5.6	54					14.0			
			54	0	0.03	0.04	0.94			0.5	9
IV	4/1	5.6	54					13.2	245		
			61	0.22	0.14	0.09	0.99			1.2	19
	6/25	6.0	67					13.1			
			75	0.23	0.33	0.12	0.80			1.4	19
	9/15	6.5	84					10.5			
			84	0	0.05	0.14	0.83			1.3	16
V	4/1	6.5	84					8.7	103		
			92	0.17	0.22	0.11	0.85			0.9	10
	6/25	6.9	100					7.4			
			116	0.27	0.58	0.15	0.63			0.9	8
	9/15	7.5	131					4.6			
			131	0	0.08	0.17	0.78			0.7	5
VI	4/1	7.5	131					3.6	28		
			139	0.12	0.27	0.13	0.76			0.4	3
	6/25	7.8	148					2.7			
			159	0.14	0.76	0.17	0.46			0.3	2
	9/15	8.1	170					1.2			
			170	0	0.09	0.18	0.76			0.2	1
VII	4/1	8.1	170					1.0	6		
			181	0.13	0.30	0.13	0.74			0.1	1
	6/25	8.3	193					0.7			
			198	0.05	0.86	0.17	0.38			0.1	0
	9/15	8.5	203					0.3			
			203	0	0.10	0.20	0.74			0.1	0
VIII	4/1	8.5	203					0.2	1		

[1] The factor by which the weight of the population changes.

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