Application of Theory and Research to Management of Warmwater Fish Populations[1]

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ABSTRACT

Balance in fish populations is an important concept in fisheries management. Research on the characteristics and dynamics of balanced and unbalanced bluegill (*Lepomis macrochirus*) populations suggests guidelines relative to growth rate, survivorship and recruitment which may be applied to other species such as gizzard shad (*Dorosoma cepedianum*). Regulations and stocking are important management techniques which may be applied to improve the state of balance and structure in fish populations.

INTRODUCTION

A primary objective of this paper is to discuss the concept of balance in fish populations. Balanced populations were defined by Swingle (1950) as populations that have the capacity to produce a satisfactory sustained yield of fish of suitable size in proportion to the productive capacity of the water. In this context balance may be taken to mean a satisfactory relationship between a fish population and its food supply. Satisfactory is judged according to the values of society and management objectives. If management objectives for a species or a lake include a reasonable sustained yield of fish of suitable size, and yield is dependent upon the productive capacity of the water rather than put and take stocking or artificial feeding, then the concept of balance must be part of the biological basis of management.

Data are presented below for bluegill (*Lepomis macrochirus*) populations in ponds in Missouri and lakes in Indiana. That information forms the basis for generalizations regarding the dynamics of balanced and unbalanced bluegill populations. Parallels are drawn between the characteristics of bluegill populations and gizzard shad (*Dorosoma cepedianum*) and some suggestions are made regarding management techniques to maintain or improve the state of balance within and between species.

Warmwater ponds, lakes, and reservoirs frequently have great potential for enhancement of sustained yield and therefore present an important management challenge. Many advancements and refinements have been made in the last 20 years in the management of coldwater fisheries. From a biologist's point of view, management of salmonids is relatively easy. Often food chains are short and species associations simple. Important physical and chemical requirements of habitat such as temperature and oxygen are well known and easily measured. Normally recruitment of fish to the populations can be regulated by stocking rates or enhanced with artificial spawning facilities.

Warmwater fisheries management has a long way to go to equal the predictability, efficiency, and success of trout programs, but warmwater management has not been without progress and success. The most successful program of which I am aware is the management of state-owned public fishing lakes in Alabama which contain primarily largemouth bass (*Micropterus salmoides*) and bluegill. A program that achieves an average sustained annual yield of more than 190 kg/ha (170 lb/acre), almost an average of 333 fishermen trips per hectare (135/acre) with an average success rate of more than 450 g (1 lb) of fish per trip, with a net income from daily fees of $12.35/ha ($5.00/acre) per year must be considered a biological, political and economic success (Byrd and Crance, 1965). This level of achievement was made possible largely by

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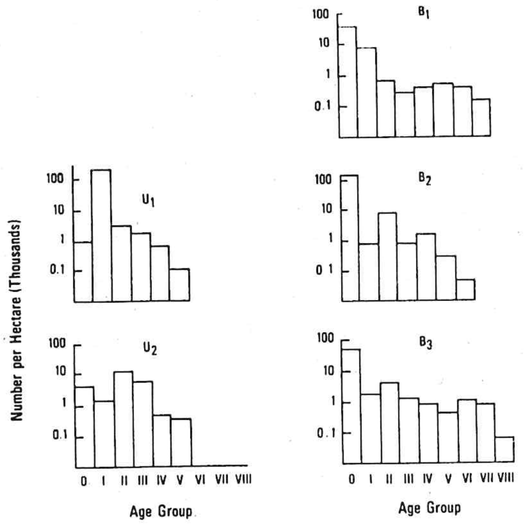

FIGURE 1.—Age-frequency distributions of bluegill in two unbalanced (U) and three balanced (B) ponds in Missouri. Data from Michaelson, 1970.

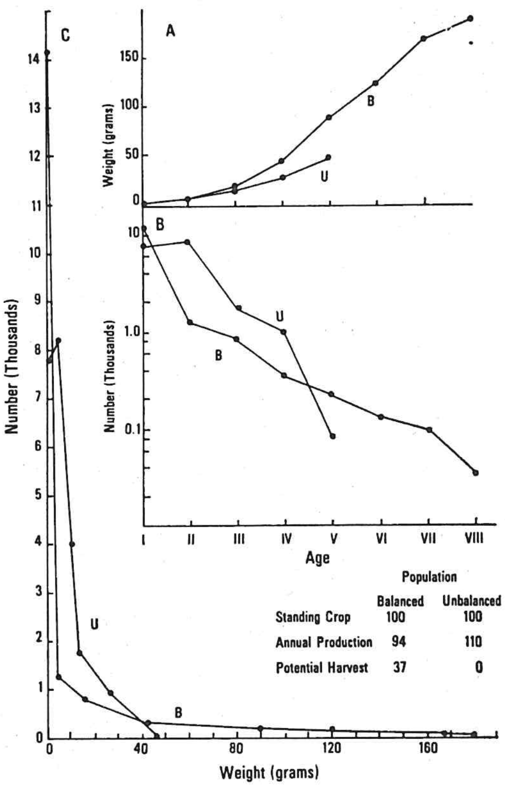

FIGURE 2.—Average growth and survivorship curves for three balanced (B) and two unbalanced (U) bluegill populations. Graphic estimate of production per 100 kg of biomass for bluegill populations with growth and survivorship curves as in A and B. Data calculated from Michaelson, 1970.

the extensive research of H. S. Swingle and associates. Biologically, two major concepts have made this program a success: (1) Productivity—an appreciation of the capacity of a body of water to produce fish flesh. The important principle applied in Alabama is that productivity is related to fertility. Efficient and economical fertilization programs have been developed. (2) Balance—the state of balance is identified as satisfactory or unsatisfactory by two methods: (1) Seining to ascertain the relative success of recruitment of young (Swingle, 1956). This technique is particularly important for identifying the state of balance of bluegill populations. (2) Biomass ratios between predator and prey (F/C, Y/C) and A_t, the percent by weight of harvestable sized fish (Swingle, 1950). The empirically determined biomass relationships for bass and bluegill for balanced systems describe a satisfactory structure for a steady state model of this predator-prey system in Alabama ponds. Ponds with values within the recommended ranges have the capacity to produce a satisfactory yield as defined for management goals in Alabama.

ANALYSIS OF POPULATIONS

Balanced and unbalanced bluegill populations have been an area of research at the Missouri Cooperative Fishery Unit. Michaelson (1970) described characteristics of three balanced and two unbalanced bluegill populations in five ponds of less than 0.5 hectare that had been stocked 8 to 15 years previously. Fish were collected in the fall with sodium cyanide. Important differences in year-class strength, growth, and survivorship patterns of bluegill were observed.

Year-class strength appeared to be more variable in the unbalanced populations (Fig. 1). Recruitment and mortality rates seemed to be quite consistent and stable in two of the balanced ponds, B_1 and B_3. The other balanced population, B_2, seemed to be in a marginal state of balance; only two of the previously mentioned biomass relationships were within the satisfactory range suggested

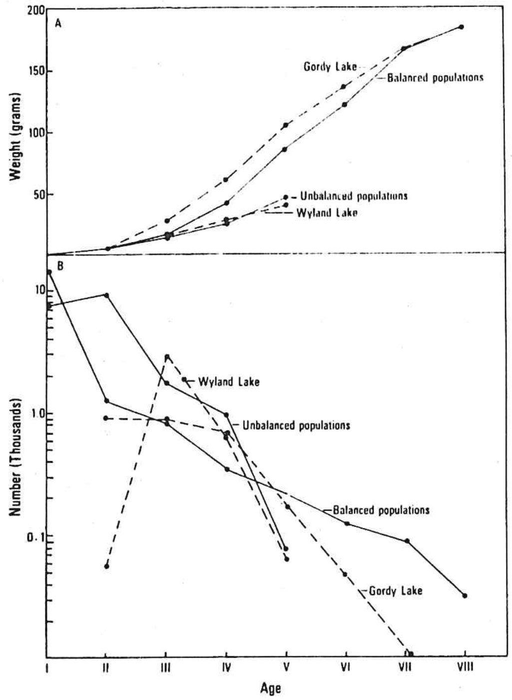

FIGURE 3.—Growth curves and number in each age group per 100 kg of biomass in Missouri and Indiana bluegill populations. Data from Michaelson, 1970 and Gerking, 1954, 1962.

by Swingle, and year-class strength was more variable than in the other two balanced ponds.

The average growth curves for the balanced and unbalanced populations are based on average back calculated annual length increments and an average length-weight relationship. Growth rate was higher for age-III and older bluegill in the balanced populations (Fig. 2A).

Survivorship curves (catch curves) were drawn after calculation of the number in each age group per 100 kg of bluegill in the standing crop (Fig. 2B). Since populations were recovered in the fall and year-class strength was variable, the number in each age group in the spring was calculated as a moving average of two. The survivorship curves suggest that in balanced populations there is a high rate of mortality in young fish; in unbalanced populations there is low mortality in young fish and high mortality for age group II and older. Longevity is longer in balanced populations.

Gerking (1953, 1954, 1962) obtained similar growth and survivorship curves for bluegill in two Indiana lakes. Growth of bluegill in Wyland Lake, which was the lowest recorded for any lake in northern Indiana, was similar to that for the unbalanced Missouri pond populations (Fig. 3A). Bluegill in Gordy Lake exhibited growth that was somewhat better than the average in the balanced populations. A dominant year-class of age-III bluegill was followed by a weak year-class in Wyland Lake, whereas no wide variation in year-class strength was apparent in Gordy Lake (Fig. 3B). No fish older than age-V were found in Wyland Lake and fish to age-VIII were found in Gordy Lake. These two bluegill populations undoubtedly are examples of unbalanced and balanced populations. It is not possible to estimate biomass ratios such as F/C since data on the largemouth bass populations were limited. Gerking mentions, however, that few bass were ever caught in Wyland Lake and that Gordy Lake had a good reputation for bass fishing.

The yields from Wyland and Gordy Lakes conform to the definition of unbalanced and balanced populations. Wyland Lake did not have a bluegill population structure that would provide a yield of satisfactory sized fish in proportion to the productive capacity. The annual catch rate of 9.5 kg/100 kg of estimated bluegill standing crop was only this large because a number of sublegal fish were removed for stomach contents samples. Gordy Lake, however, had an angler harvest that was 48% of the estimated bluegill standing crop.

These data suggest the following generalizations:

1. Balanced bluegill populations are characterized by good growth rates of intermediate and large fish; unbalanced bluegill populations exhibit poor growth of adults.

2. Balanced bluegill populations are characterized by a high, relatively stable recruitment of young bluegill; unbalanced bluegill populations are characterized by wide variation in year-class strength and recruitment of young fish, in other words, dominant year-classes.

3. Older fish are well represented in balanced populations; whereas, unbalanced populations are dominated by many fish of age-II or III and few fish survive beyond age-V.

The growth and survivorship curves for the pond populations were used to graphically estimate annual production per 100 kg of biomass at the time of annulus formation (Fig. 2C). Annual production was estimated to be slightly less than the standing crop in the balanced populations and exceeds the standing crop in the unbalanced population by 10%. The maximum potential sustained annual harvest, considered as the annual loss of fish more than 50 g (145 mm), is 37% of the standing crop in the balanced population. Few fish reach this weight in the unbalanced population since the average size of the oldest fish is 46 g. *This variation in potential quality and quantity of yield represents a major challenge in fisheries management.*

Characteristics of balanced and unbalanced bluegill populations may be reflected by other species of fish. Gizzard shad can exhibit wide fluctuations in year-class strength which may be indicative of imbalance for this species in reservoir populations. Variation in year-class strength of gizzard shad may result, at least partly, from an inverse relationship between adult stock and recruitment of young, i.e., a descending right arm in a stock-recruitment curve. Exceptionally strong year-classes have been observed following selective reduction of shad (Smith, 1959).

Also data on gizzard shad in Chautaugua Lake, Illinois, of Starrett and Fritz (1965) as analysed by Stock (1971) indicated an inverse stock-recruitment relationship in the species (Fig. 4). The strong 1954 year-class followed a fall when adult density was low, and subsequent larger stocks of adults produced smaller year-classes. Stock (1971) observed poor egg development in a slowly growing age-III year-class of gizzard shad in Thomas Hill Reservoir, Missouri. Those shad produced variable and generally poor crops of young when stocked in small ponds. Low recruitment at high adult density of gizzard shad may be related to poor maturation of eggs.

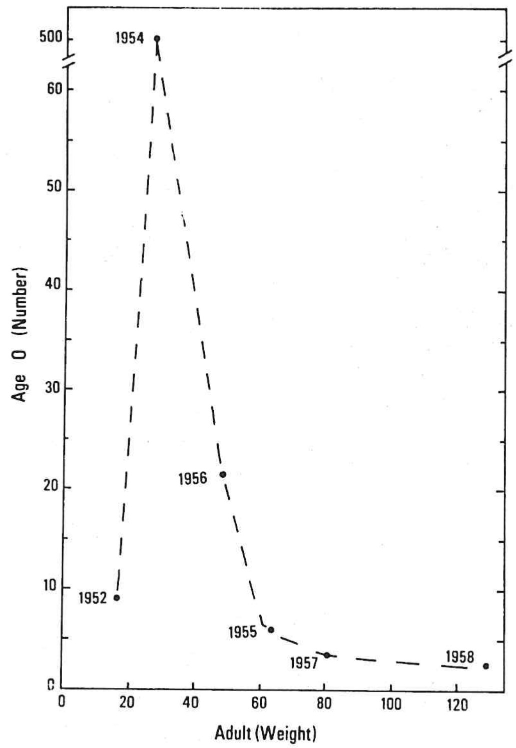

FIGURE 4.—Average number of young shad collected in summer (year indicated) plotted against weight of adults collected the previous fall in Chautaugua Lake. Data from Starrett and Fritz, 1965.

Bluegill may exhibit an inverse stock-recruitment relationship. In ponds studied by Swingle (1950), when number of young bluegill is plotted against weight of adults for ponds drained in the fall that contained at least 336 kg/ha (300 lb/acre) of primarily largemouth bass and bluegill, a negative relationship is apparent (Fig. 5).

The most effective management strategy of many reservoirs may be biological regulation of adult gizzard shad density. If an inverse relationship between adult stock and recruitment is the rule in gizzard shad population dynamics, a low to intermediate adult biomass should increase the average production of young and reduce the annual variability in recruitment.

An experiment to test this hypothesis was made by the Missouri Cooperative Fishery Unit with the cooperation of the Missouri Department of Conservation in 1967. Eight

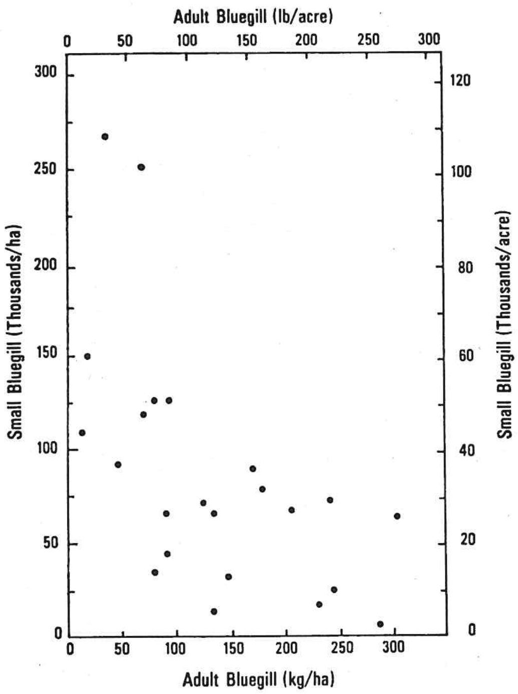

FIGURE 5.—Number of small bluegill plotted against weight of adult bluegill in Alabama ponds. Data from Swingle (1950).

0.2-ha (0.5-acre) drainable ponds were each stocked in the spring with 15 to 18 adult largemouth bass and 50 adult bluegill; six of the eight ponds were also stocked with large adult shad. Duplicate ponds were stocked at a high, medium, or low rate. The rates were 168, 90, and 27 kg/ha (150, 80, and 24 lb/acre). All ponds were drained in the fall. Maximum number and weight of young gizzard shad were recovered in the ponds stocked at the intermediate density of adults (Table 1). Only 18 young shad were found in the two ponds stocked at the low density although large schools of shad had been observed in these ponds during summer. The number and size of large young-of-the-year bass may explain the low number of shad in these ponds. The maximum number and weight of large young-of-the-year bass (10 to 24 cm; 4 to 9 in) were found in ponds stocked with the low density of adult gizzard shad. I believe that an initially large population of small shad grew at a low rate until they were consumed and almost eliminated by the fast growing members of the young bass populations. No young-of-the-year bass longer than 10 cm (4 in) were recovered in the ponds without gizzard shad which indicates the potential value of gizzard shad for bass production. The data support the concept that the best density of adult gizzard shad is an intermediate to low density.

BALANCE AND FISHERIES MANAGEMENT

There may be considerable enhancement possible in quality and quantity of sustained sport fishing yield of many ponds, lakes and reservoirs by one's altering the structure and improving the balance of populations. Two techniques, regulation and stocking, seem to hold promise.

The structure of populations, e.g. F/C ratios, may be improved in some waters by more restrictive regulation of the harvest of important predator species such as largemouth bass. Excessive bass harvest may be one of the major factors contributing to develop-

TABLE 1.—*Number and weight (kg) of young-of-the-year gizzard shad and largemouth bass recovered from 0.2-hectare ponds drained in the fall. Adult gizzard shad had been stocked in the spring at 168, 90 and 27 kg/hectare*

Adult shad stocked	Young shad		Young bass: Smaller than 10 cm		Young bass: Larger than 10 cm	
	Number	Weight	Number	Weight	Number	Weight
High	135	1.27	338	1.0	0	0
High	750	0.95	524	1.54	7	0.64
Medium	2300	4.77	440	0.86	16	1.27
Medium	950	1.86	415	1.0	22	1.0
Low	17	0.10	756	1.68	32	2.45
Low	1	—	443	1.0	34	2.18
Absent	0	0	247	0.82	0	0
Absent	0	0	923	1.68	0	0

TABLE 2.—*Recovery of tagged largemouth bass by anglers following the opening of new Missouri lakes*

Lake	Area (ha)	Fish tagged (No.)	Census period (days)	Tags recovered (%)	Bass catch (No./ha)	Angler effort (Trips/ha)
Jo Shelby[1]	12.6	156	4	69	116	91
Sterling Price[1]	14.2	174	4	50	44	30
Austin[1]	8.9	110	4	44	47	94
Sever[1]	64.0	100	8	42	77	30
Little Dixie[2]	83.0	250	4	46	44	54
Little Dixie[2]	83.0	250	141	72	77	279
Pony Express Silt Basin[3]	3.8	141	3	40	64	44

[1,2,3] Data collected by: 1. Gilbert Weiss; 2. Jerry Turner; 3. Lee Redmond.

ment of unbalanced populations of forage and panfish species. Excessive bass harvest has been observed when new lakes were opened to fishing in studies by personnel of the Missouri Department of Conservation. Largemouth bass were tagged prior to the opening of fishing in several lakes, and the number of tagged bass recovered was determined by creel census. The percentage of tags recovered in the first 3 to 8 days of angling was 40 to 69% (Table 2). In Little Dixie Lake the percentage of tags recovered for the first season was 72% (Turner, 1963).

These rates of harvest are too high to provide a satisfactory sustained yield of largemouth bass and probably bluegill as well. To correct this situation in Alabama, fishery managers selectively kill bluegill and stock fingerling largemouth bass. In small private ponds or intensively managed state-owned waters prevention of the problem of excessive bass harvest may be a better management strategy. Prevention of excess harvest may be best accomplished by an annual quota for the number of bass removed. Recommendations for optimum harvest rates of largemouth bass were suggested by Regier (1963) in his study of bass and bluegill populations in New York ponds. For some large public lakes and reservoirs the most practical regulation to apply and enforce may be a minimum length limit of 30 to 38 cm (12 to 15 inches). A high length limit may be necessary to maintain an adequate biomass of bass large enough to eat yearling or older gizzard shad and other large forage items. The result should be increased biomass and average size of bass and improved structure of the system such as F/C and Y/C ratios.

A second management technique which may be useful for improving the balance or structure of reservoir populations is the introduction and maintenance stocking of large piscivorous species. Bass alone may not be able to accomplish the function of density regulation of large forage species. Many reservoirs already have been stocked with large piscivorous game fishes. Recently a questionnaire distributed by the Reservoir Committee of the Southern Division of the American Fisheries Society indicated the following numbers of reservoirs have been stocked with large piscivorous species: striped bass (*Morone saxatilis*), 34; muskellunge (*Esox masquinongy*), 12; northern pike (*Esox lucius*), 12; walleye (*Stizostedion vitreum vitreum*), 51 (Jenkins, 1971). Introduction and maintenance of these large piscivorous species may not only add valuable sport fishing opportunities in themselves but if the generalizations regarding balance and stock and recruitment are correct, an adequate density of large piscivorous fish may also enhance the yield of other sport fishes such as crappies (*Pomoxis* spp.) and white bass (*Morone chrysops*). There are two possible objectives in a management program involving the stocking of large predators. The low point of aim would be to increase diversity by adding an additional species to the creel. The high point of aim would be to achieve a more favorable balance in the system and accomplish a more satisfactory sustained yield of other sport fish populations as well.

The technique of stocking raises the important questions of what species, what number, what size, where, and when (Anderson, 1971). The potential of hybrids as large predators in reservoir management programs needs to be evaluated. The striped bass–white bass hybrid shows promise in some situations (Bishop, 1968). The muskellunge–northern pike hybrid may have potential south of the normal range of the parent species; Scott (1964) found that the hybrid has a higher temperature tolerance than either parent. Moreover, hatchery personnel in Michigan believe that this hybrid fingerling is easier to produce than either parent species.

Characteristics of different geographic stocks of a species need to be considered in fisheries management. Important genetic differences in growth, survival, and vulnerability to angling have been observed in trout stocks as a result of natural and artificial selection (Calhoun, 1966; Flick and Webster, 1970). Differences in subspecies or geographic stocks also have been observed in warmwater species. Differences in growth, survival, and vulnerability to angling have been found in smallmouth bass originally described by Hubbs and Baily (1940) as northern and Neosho subspecies, *Micropterus dolomieui dolomieui* and *M. d. velox* (Anderson, Mohler and Divine, 1971). Observations by Bottroff in El Capitan Reservoir, San Diego County, California demonstrate that there are important differences in growth, survival, and angling vulnerability between Florida and northern largemouth bass (Graham, 1971).

I consider warmwater fisheries management to be on the threshold of major developments in the 1970's. Past and future research on population biomass and structure should pay great dividends in understanding important aspects of productivity and population dynamics. Much research remains to be done to understand population dynamics and production in various ecosystems. Two major areas where research is needed to help us to understand the dynamics of production in fish populations are illustrated by an Allen graph (Fig. 2C). On one axis is population number. We need to understand factors that influence recruitment of young fish and mortality, both angling and natural. On the other axis is average size which is determined by growth. We need to know more about the interrelations of food supply, which is influenced by production rate; vulnerability and competition; physical and chemical factors such as temperature, water transparency, and dissolved oxygen; and physiological, social, and genetic factors. More research needs to be accomplished in the laboratory and in controlled environments such as small ponds in order to increase our understanding of the production process and functioning of ecosystems.

There is a heavy responsibility ahead for management biologists in their recommendations for regulations and stocking. Guidelines need to be developed in order to establish sound programs. Much of their work will need careful evaluation in order to strengthen and improve their probability of success. The need for good communication and close working relationships between research and management is obvious. Hatcheries are involved as well since they will determine when and how they can produce their products which will be an important part of future management programs. With so much work to do, so many questions to answer and with such a great opportunity to improve the quality of the environment such as the state of balance in fish populations, thereby the lot of sport fishermen, I can not help but be excited about the future of the fisheries profession. Our constant challenge is the fact that the quality of sport fishing reflects the quality of living.

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