COMBINED CULTURE OF CHANNEL CATFISH AND GOLDEN SHINERS IN WADING POOLS

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Fig. 1.—Ten-foot-diameter plastic pools with dividing screens of 3/16-inch-mesh nylon netting used to separate or to confine certain populations.

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The raising of golden shiners (*Notemigonus crysoleucas*) as a bait minnow, and of channel catfish (*Ictalurus punctatus*) as both a food and sport fish, has become an important industry throughout most of our southern states. It has been customary to raise the two species separately, but there is increasing interest in combining the cultures. Martin (1968) has listed various methods by which some growers have combined the two on a limited basis, but he points out that almost nothing exists in the literature about raising minnows and catfish in combination.

This study was undertaken to provide information not now available on the behavior, comparative efficiencies, and degrees of compatibility of channel catfish and golden shiners when in different combinations and under different spatial limitations. The Java tilapia (*Tilapia mossambica*) was also used in 1968 to measure the influence of such a third species upon its companion fishes; it was not used in the 1969 experiments.

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MATERIALS AND METHODS

All major experiments were conducted in 1968 and 1969 in plastic pools 10 feet in diameter and 30 inches deep. Limited observations were made in aquariums. Some pools were fitted with dividers (Fig. 1), which permitted the physical association or separation of the species, as desired, and also provided variations in spatial densities. Such dividers were constructed of 3/16-inch-mesh nylon netting on frames of galvanized tubing. The netting permitted a circulation of water and distribution of metabolites or other waterborne products throughout the pool area.

In all outdoor experiments in both years all pools were provided a substrate of light sandy soil. In all pools to be used in an individual experiment the soil substrates were meticulously standardized in two steps—pulverizing dried soil to the fineness of fine sand by passing it through a mill designed for grinding livestock feeds, and thorough mixing in a cement mixer. Each lot of mixed soil was evenly divided among all pools. Each received about 6.5 cubic feet of mixed soil, sufficient to cover the bottom to a depth of about 1 inch.

Water used in all experiments was pumped from a 3.5-acre pond. All fish populations were seined and weighed every 14 days and the weights were used to establish new feeding levels. Shiners received their food in the form of a meal; catfish were fed small pellets. Turbidities, dissolved oxygen, pH, free CO_2, alkalinities, and ammonia (NH_3) were monitored twice weekly, usually in the late morning. Outdoor pools were not shaded, and summer temperatures of surface waters were recorded as high as 96° F.

INDOOR EXPERIMENTS IN 1968

Culture in Plastic Pools

Methods.—Our initial experiment ran from January 11 to May 24, 1968, a period of 134 days. In partitioned 10-foot-diameter plastic pools we stocked channel catfish and golden shiners in two ways (Fig. 2). In one pool the two species were physically separated (two groups of each species, four partitioned areas) but shared the same water circulating through the separating nylon screen. In a second pool the species were physically associated (two mixed groups, two partitioned areas). Total areas and water volumes in the two pools were similar, and total numbers (100 catfish, 450 shiners) and initial weights of each species in each pool were equal. Also, over the course of the experiment each pool received the same total amount of food. Actually, original stock on January 11 included only 15 catfish in each group (30 in each pool), but on January 19 the numbers were increased to 50 in each group (100 in each pool). These final densities were equivalent to about 55,500 catfish and 250,000 shiners per acre. Individual

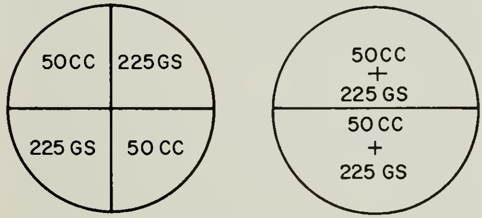

Fig. 2.—The partitioned circles illustrate the manner in which the pools used in the indoor experiments were divided by nylon screens to permit a mixing or separation of the groups of 50 channel catfish (CC) and 225 golden shiners (GS).

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weights when stocked averaged 1.68 grams for catfish and 1.31 grams for shiners.

Each pool was lighted by a 300-watt incandescent bulb from 6 a.m. to 5 p.m. Because the space available to these experiments was poorly heated, water temperatures could be maintained no higher than from 72 to 75° F. Both pools were continuously aerated and small submersible pumps assured a continuous, slow circulation of water throughout the pools.

Results.—After 134 days, standing crops in the two divided pools were equivalent to 2,709 pounds per acre (1,838 pounds of shiners, 871 of catfish) where the species were mixed, and 2,555 pounds per acre (1,942 pounds of shiners, 613 of catfish) where the species were separated, having increased from original stocks equivalent to about 920 pounds per acre (720 pounds of shiners, 200 of catfish). This was considered to be a good production rate for shiners, but catfish growth was limited by water temperatures that never exceeded 75° F.

Fish behavior was observed daily over about the first 30 days, after which visibility was limited by high turbidity. Normal shiner behavior appeared to be a slow, continuous, seemingly aimless movement in a loose school. When in the same water with catfish the two never mixed except when feeding; the catfish remained at the bottom, and the shiners were in the upper waters. However, when both fed on meal that had sunk to the bottom, they fed and intermixed in an apparent state of harmony.

Catfish behavior changed somewhat with time and increase in density, and was different when the catfish were and were not mixed with shiners. Initial populations of 15 channel catfish were exceedingly nervous, and when not darting wildly about or attempting to hide at the base of the divider screen they clustered in a corner, suspended vertically at mid-depths by slow, continuous tail movements, an activity which we called "tailwalking." Those catfish not associated with shiners tailwalked in the corner quite continuously during daylight hours and were not observed to feed. Those mixed with shiners appeared calmed by the association, tailwalked less, and fed readily. At the first feeding on January 12, the shiners fed vigorously as soon as the meal hit the surface of the water, and when the meal had sunk to the bottom and was being "picked" by the shiners, the catfish joined them, feeding slowly and steadily, freely intermixed with the shiners. The catfish reformed their school when the feeding period was ended. At such times there appeared to be no species discrimination and no antagonism whatsoever between species or individuals.

A significant change in the behavior of the catfish occurred after the numbers were increased from 15 to 50. The 50 catfish almost continuously maintained their school while feeding, sweeping quite rapidly about and appearing to "feed on the run." The school was never observed to disband and the individuals to feed leisurely while intermixed with the feeding shiners, as they had done when they formerly numbered only 15. The moving school occasionally caused minnows to scatter out of their path. These near-contacts, however, appeared to be inadvertent, and no overt antagonism or interference of the feeding of either species was observed. The calming influence of the shiners upon the catfish was apparent when the populations were sampled after the initial 2 weeks. The catfish not confined with shiners had lost weight to the extent of about 15 pounds per acre, while those with shiners had gained about 40 pounds per acre. At the termination of the experiment, final standing crops of catfish averaged 42 percent higher with shiners than when physically separated but sharing the same water.

Culture in Aquariums

Methods.—In a second indoor experiment we used plexiglass and screened containers of identical size (4.5 cubic feet) to confine channel catfish in equal portions of one of the 10-foot wading pools previously described. The plexiglass container, or aquarium, was submerged in the pool so that the confined fish were subjected to the same temperature, light, and water volume as those confined by the screened enclosure, the difference being that the 3/16-inch-mesh nylon netting permitted a circulation of water through the screened enclosure. We proposed to compare growth and behavior of fish in both containers with growth and behavior of an identical number of fish free to move about in the total area of the pool.

Concurrently we established similar experiments with smaller enclosures submerged in a 40-gallon aquarium to determine if the same response to crowding and the same interspecific relationships were apparent in the smaller water volumes. Unfortunately, the use of such small environments containing clear water proved unsatisfactory, and the series did not progress to the use of both catfish and shiners.

In the first set of experiments we used eight catfish in each of the three lots in the wading pool and four in each of the three lots in the 40-gallon aquarium. In all cases the fish ate little, if at all, and lost weight. This study was terminated after 29 days.

In a second run in these environments we increased the number of fish to 24 in each lot in the pool and to 12 in each lot in the aquarium.

Results.—In the aquarium trials all lots again lost weight, and that phase of the project was terminated. These and earlier tests in aquariums seemed to illustrate that catfish confined alone in small containers filled with clear water do not behave normally, remain nervous, and eat poorly. Tests under such conditions are impractical. In contrast, we have observed that upon transferring catfish from a clear aquarium containing only catfish to an adjacent aquarium, also clear but containing tilapia, or tilapia and carp, the catfish became calm and began to feed well and grow. The presence of another species of fish appeared to calm, and instill a sense of scurity in, the catfish.

The wading pool experiment involving three lots of 24 fish each was terminated on May 3, after 79 days, with the results shown in Table 1. The greater growth of the fish enclosed by glass, with no water circulation, was unexpected. A possible explanation was that the limited volume of water in the glass enclosure became quite turbid with food

TABLE 1.—Original and final weights and gains over a 79-day period for three lots of channel catfish under different conditions of confinement in a 10-foot-diameter plastic pool. The pool was maintained indoors.

Type of Population	Weight (grams)			
	When Stocked	At Final Census	Gain	Percent Gain
Free in pool	47.4	66.0	18.6	39.2
Confined by net	45.4	60.0	14.6	32.2
Confined by glass	41.0	70.0	29.0	70.7

and wastes, whereas the other waters remained clear. It is assumed that catfish obscured in the darker, turbid water were less nervous and were able to make more efficient use of available foods than their companion lots in the clear water. Concentrations of ammonia went to a maximum of 2.8 ppm in the glass enclosure and averaged 0.83 ppm for all readings over the experimental period; in the open pool the maximum was 0.34 ppm with an average of only 0.16. The greater concentration of ammonia in the glass enclosure occurred at relatively low pH values (mostly between 7.5 and 8.0) and apparently had no limiting effects.

OUTDOOR EXPERIMENTS IN 1968

First Series

Methods.—The first series of outdoor experiments involved 20 pools containing two replications of each of 10 experimental populations, as illustrated in Table 2. The pools were arranged in three rows, with a separation of about 2 feet between pools. The location of individual populations within the arrangement of pools was established by random selection. Water was maintained at a depth of about 21.6 inches, providing a volume of about 1,057 gallons. The pools were provided with soil substrates, as previously described.

Average total lengths and weights of the fishes when stocked were about 140 mm and 19 grams for catfish, 57 mm and 1.32 grams for the shiners, and 66.1 mm and 5.09 grams for the tilapia. A ration equal to 3 percent of the weight of the fish was fed once each day for 5 or 6 days each week. The pools were stocked over the 3-day period June 18–20, 1968 (catfish on June 18 and 19, and shiners and tilapia on June 20) and the study was terminated on September 11. Thus the growing period ranged from 83 days for shiners and tilapia to 85 for catfish, but for practical purposes it has been computed as 84 days for all species.

Results.—Catfish mortalities were either catastrophic, as when oxygen was depleted, or insignificant. In both populations in which 16 catfish were intermixed with shiners, and in one where 16 catfish were separated from the shiners by a screen, total mortalities were suffered too late in the experiment for the fish to be replaced, and no final census data could be recorded (Table 2). Among the 13 populations that provided usable data, only 10 catfish were observed dead and replaced during the experiment. All 13 of these populations were intact, containing either 8 or 16 individuals, at the termination of the study.

Shiner mortalities were high following initial stocking, gradually lessened over the first 30 days, and were quite insignificant thereafter. Rates of mortality were similar in all populations. Dead shiners floated and were replaced daily where separated from the catfish, but were not missed or replaced until the time of the biweekly sampling period when they were mixed with the catfish. If the shiners were eaten by the catfish, it probably occurred after the shiners had died, because mortalities were again approximately equal in all populations during the later period when very few deaths occurred in any pools. It seems unlikely that the catfish would have preyed upon living shiners during the first month but not in the last two. Growth curves do not indicate that the catfish mixed with shiners had a greater advantage during than after the period of high shiner mortality.

Our production data gain some perspective in Table 2, which presents final standing crops of all populations in terms of pounds per acre, together with the ranges and seasonal averages of pH, turbidity, ammonia, carbon dioxide, and total alkalinity. These data show that (1) standing crops of catfish were highest in weight when they were maintained alone in an entire pool, but only about 10 percent higher than when the same numbers of catfish were confined to one-half of a pool or when mixed with shiners and tilapia in an entire pool, (2) standing crops of shiners were consistently and significantly (.05 level) higher in weight when in direct association with catfish, or with catfish and tilapia, than when maintained alone, as emphasized by the fact that 45 shiners mixed with catfish made a greater gain than 90 shiners maintained alone, (3) shiners and tilapia increased total fish production while scarcely affecting catfish production, and (4) when all three species were combined at the lower stocking rate of 8 catfish and 45 shiners, mean production of catfish was about 14 percent higher and total production was 42 percent higher than in mixtures containing only catfish and shiners.

In Table 2 we may also observe that in general the highest production by both catfish and shiners occurred in those pools having the highest levels of turbidity, ammonia, and carbon dioxide. We suspect that the higher levels of ammonia and carbon dioxide were the result, rather than the cause, of higher fish production. It seemed clear, however, that both fish density and turbidity influenced production and that the two were inseparably related. Catfish production appeared to be most strongly influenced by density or availability of space, while shiners appeared to be more strongly influenced by turbidity or density of phytoplankton. For example, gains by catfish having access to entire pools were always higher than gains by similar numbers confined to halves of pools; these differences were significant at the .05 level. On the other hand, gains by shiners were greatest where turbidities were greatest, regardless of whether they had access to all or only one-half of a pool, and this correlation (r = .901) between high shiner production and high turbidity was significant at the .01 level.

It was additionally clear that high turbidity occurred only in the presence of catfish. The level of turbidity was related more to the area of bottom available to the catfish than to the number of catfish, the presence or absence of

Table 2.—Means of final standing crops for channel catfish (CC), golden shiners (GS), tilapia (T), and all species combined (All), in 10-foot-diameter plastic pools, compared with ranges and seasonal averages of pH, and of parts per million of turbidity, ammonia, carbon dioxide, and total alkalinity. The pools were maintained outdoors over an 84-day growing period, with two replications for each type of population.

Type of Population [a]	Final Weight (lbs/A) CC	GS	T	All	Range (in parens) and Seasonal Average pH	Turbidity (ppm)	NH_3 (ppm)	CO_2 (ppm)	Alkalinity (ppm)
16 90 [b]	..	438[d]	..	438	(7.2–10.0) 8.1	(8–220) 76	(0.04–.97) 0.41	(0–18.1) 5.2	(56–123) 80.0
$\underline{16}$ 90 [c]	884 [d]	381[d]	..	1,265	(7.5–10.0) 8.3	(7–106) 46	(0.01–.72) 0.31	(0–9.5) 2.7	(57–100) 70.5
16 90 10	1,012	447	588	2,047	(7.4–10.0) 8.2	(3–295) 85	(0.04–1.61) 0.44	(0–13.3) 3.9	(52–113) 75.1
16	1,111	..	..	1,111	(7.4–10.1) 8.2	(5–210) 60	(0.00–.96) 0.33	(0–9.3) 3.4	(57–99) 71.4
$\underline{16}$	1,011	..	..	1,011	(7.5–10.1) 8.3	(2–92) 34	(0.00–.60) 0.27	(0–10.4) 3.3	(59–98) 72.9
90	..	258	..	258	(7.8–9.9) 8.3	(0–32) 16	(0.00–.46) 0.19	(0–12.4) 3.1	(55–85) 67.7
$\underline{90}$		226	..	226	(7.3–9.4) 8.3	(0–19) 8	(0.00–.47) 0.17	(0–6.9) 2.5	(57–84) 66.8
8 45	560	294	..	854	(7.4–10.0) 8.2	(7–150) 55	(0.00–.83) 0.34	(0–10.8) 3.8	(57–115) 74.8
$\underline{8}$ 45	460	171	..	631	(5.7–9.5) 8.4	(4–60) 27	(0.04–.60) 0.23	(0–6.9) 2.2	(57–97) 67.0
8 45 5	637	237	338	1,212	(7.4–9.9) 7.8	(1–196) 65	(0.00–.80) 0.50	(0–13.3) 3.5	(57–110) 72.0

[a] Populations contain shiners in lots of 45 or 90, catfish in lots of 8 or 16, and tilapia in lots of 5 or 10.

[b] Designates pool containing 16 catfish and 90 shiners intermixed

[c] Designates pool containing 16 catfish separated from 90 shiners by a net.

[d] Data from one pool only due to excessive mortalities in its replicate.

shiners, or the amount of food received by the pool. For example, turbidities were consistently higher in those pools having only catfish, but where the catfish had access to all of the pool bottom, than in a) the pools where the same numbers of fish received the same amount of food but were restricted to one-half the pool, or in b) those pools where the same number of catfish were restricted to one-half the pool but where food received was greater due to the presence of 90 shiners in the other half. In these instances, turbidities were due primarily to densities of phytoplankton, and these greater densities were believed related to the interaction of the catfish with the bottom mud. Stirring of the bottom by catfish did not muddy the water but it was probably sufficient to increase the release of soil nutrients into the water for use by phytoplankton. The shiners therefore appeared to gain an indirect benefit from their association with catfish due to the greater production of phytoplankton associated with the catfish.

Also of interest were the differences in food conversion ratios and their relationship to turbidity. Conversions were computed on the somewhat vulnerable assumption that each species ate only its assigned ration—pellets for the catfish and tilapia, and meal for the shiners. While the assumption cannot be completely true, the data are nonetheless informative.

Table 3 presents all conversion statistics for which data are available. At the higher density levels the most efficient conversion ratios by catfish occurred in those pools containing only catfish and having intermediate (34–60 ppm) turbidities (Table 2), whereas the least efficient conversions by shiners were in those pools containing only shiners and having very light turbidities (8–16 ppm).

In those pools containing both catfish and shiners, conversions by catfish were slightly, but not significantly, lower when mixed with shiners than when separated from them by a net, whereas conversions by shiners *were* significantly lower (1) when mixed with catfish than when separated from them by a net, (2) when separated by a net but

Table 3.—Mean conversion ratios of artificial feeds by catfish, shiners, and tilapia, each species individually and the species combined, over two time intervals and under different types of association and confinement for two replications of each type population. Species are designated as: CC = channel catfish, GS = golden shiners, T = tilapia. All indicates a combination of all species. The populations were maintained outdoors in 10-foot diameter plastic pools.

Type of Population[a]	7/16/68–8/13/68			7/16/68–9/11/68			
	CC	GS	All	CC	GS	T	All
16, 90 [b]	1.55	0.88	1.31	..	..	..	..
16/90 [c]	1.73	1.85	1.76	..	..	..	..
16, 90, 10	..	..	..	1.98	1.03	0.65	1.22
16	1.44	..	..	1.78	..	..	..
16 (divided)	1.51	..	..	1.65	..	..	..
90	..	..	..	..	2.52	..	..
90 (divided)	..	..	..	..	3.02	..	..
8, 45	1.09[d]	0.62[d]	0.91[d]	..	..	..	..
8/45	2.09	2.37	2.14	..	..	..	..
8, 45, 5	..	..	..	1.50	1.05	0.53	1.07

[a] Populations contain shiners in lots of 45 or 90, catfish in lots of 8 or 16, and tilapia in lots of 5 or 10.

[b] Designates pool containing 16 catfish and 90 shiners intermixed.

[c] Designates pool containing 16 catfish separated from 90 shiners by a net.

[d] Data from one pool only due to excessive mortalities in its replicate.

sharing the same water than when in a pool alone, and (3) when mixed with catfish than when in a pool alone.

It should be noted, however, that turbidities due to phytoplankton were also consistently highest where the two species were in direct association and where the catfish had access to the entire bottoms of the pools. This suggests that the higher turbidities favored both species and that the shiners probably gained a part of their sustenance from the phytoplankton which caused the higher turbidities.

Second Series

Methods.—A second series of outdoor experiments was designed as a homogeneity study to measure the variations of catfish production within and between pools and to determine if the presence of the divider screen and the consequent confinement of the fish to a smaller area (while maintaining the same density) had in itself any measurable influence upon production. It involved only fed catfish in eight pools. Each pool was stocked with 16 catfish (8,880 per acre), but four pools were divided into equal halves by nylon netting, and equal numbers (8) were placed on each side of the dividing screen. The catfish were from the same lot and of the same size as those stocked in the outdoor pools previously discussed and were fed at the same rate. However, only three divided and three undivided pools produced useful data because of excessive mortalities in one population and the intermixing of the divided populations in a second pool.

Results.—There was no mortality in the six pools which provided usable data, and the final standing crops ranged from 927 to 1,110 pounds per acre, with a mean of 1,026. There was no significant difference (.05 level) in the pounds of catfish produced in the six pools, indicating that the existence of the dividers and the confinement of the catfish to half the pool area had no influence on catfish production.

The average final standing crop in these six pools, 1,026 pounds per acre, was very similar to that of 1,061 obtained concurrently in the four pools in our other series which contained catfish only.

DISCUSSION OF 1968 EXPERIMENTS

Results from the indoor experiments differed from those obtained in outdoor pools because of the great differences in the experimental environments. The indoor pools contained no soil substrates, foods eaten were entirely artificial, and the water was maintained at a constant temperature of 72–75° F., which is below that considered optimum for growth of either catfish or shiners. The outdoor pools contained a soil substrate which, when "worked" by catfish, contributed to the dense blooms of phytoplankton, which in turn contributed to the diet of both shiners and tilapia. Additional foods for the outdoor fishes included terrestrial insects which at times entered the pools in substantial numbers, as well as a large complement of aquatic insects, including mayflies, dragonflies, and a variety of midges, which very quickly colonized the outdoor pools and began reproducing. There were also substantial differences in fish densities in the indoor and outdoor populations.

Final standing crops of shiners in the indoor pools greatly exceeded those produced outdoors, while the outdoor production of channel catfish greatly exceeded that produced indoors. Greater production of shiners indoors was due in part to the greater density per pool (400 vs. 90) and to the longer growing period; but greater weights of channel catfish were produced outdoors in spite of a much lesser density (16 vs. 100) and a shorter growing period. Factors contributing to the greater production by catfish outdoors probably included higher water temperatures and the availability of natural foods.

The presence of shiners and tilapia caused little or no loss of catfish production in the outdoor pools. Poor production by catfish indoors suggests that growth may have been inhibited by the high density of shiners, although low water temperatures were also important.

The much greater production of shiners indoors indicated that growth was inhibited very little by the combination with a dense population of catfish, by the relatively low water temperatures, or by the higher levels of ammonia and carbon dioxide in the indoor pools.

The degree of behavioral and physiological compatibility of the catfish and shiners in the densities here employed may be inferred partly by direct, but largely by indirect, evidence. We pointed out earlier that no antagonistic behavior was ever observed in the mixed populations in the indoor pools. A high degree of compatibility among the outdoor populations was indicated by the fact that (1) shiner production was greater in mixed populations than when shiners were alone and (2) the presence of tilapia and/or shiners did not limit catfish production.

Direct observations of the species when mixed in the outdoor pools were limited by the tendency of the catfish to hide when the water was clear enough for good visibility, and by phytoplankton blooms. All species normally fed at the surface, but catfish maintained alone were sometimes slow to rise to the food. When mixed with tilapia, however, they commonly rose immediately and competed vigorously with the tilapia for the food. Coexisting shiners stimulated the same response but to a lesser degree. All three species were stimulated to a faster and more vigorous feeding response when associated than when alone and able to feed at their leisure, and such stimulation led to a more efficient use of food.

EXPERIMENTS IN 1969*

First Series

Methods.—Our first series in 1969 involved 21 pools having three replications of each of seven types of populations. The catfish were stocked on May 29 and the shiners on June 4, 1969. We used two levels of densities which doubled those used in 1968. The maximum populations of 32 catfish and 180 shiners were equivalent to 17,760 catfish and 99,900 shiners per acre. The two species were again separated in some pools and mixed in others, as illustrated in Table 4.

*All 1969 experiments were conducted in outdoor pools.

Mean weights of fish in the original stocks were about 2.73 grams (173 per pound) for shiners and about 13.0 grams (35 per pound) for catfish. Final censuses were made on September 10, 1969, providing growth periods of 104 days for catfish and 98 days for the shiners. Tilapia were not used in 1969 because they were not essential to the study. Again, the catfish received pellets and the shiners received meal. All fish were fed twice a day for either 5 or 6 days each week at a total daily ration approximating 3 percent of their weight. The populations were sampled by seine, and fish weights were measured every 14 days. All pools received nearly continuous aeration.

Results.—Table 4 presents the average final standing crops in replicated pools for the two species, both individually and combined, along with seasonal ranges and means of various environmental parameters. Data for some populations were unusable because of excessive mortalities, due principally to failures in aeration, but usable data were obtained from at least two replications of each of the seven experimental populations. We had believed that in doubling the densities we would assure that carrying capacities would be attained prior to our termination of the experiments in September, but an inspection of the growth curves in Fig. 3 shows that rates of growth had not declined by

TABLE 4.—Means of final standing crops, in pounds per acre, for various mixed and unmixed populations of channel catfish (CC) and golden shiners (GS) when maintained outdoors for about 100 days in 10-foot diameter plastic pools, together with ranges and means of pH and parts per million of turbidity, ammonia, and free carbon dioxide based on determinations made twice weekly over the same period.

Type of Population [a]	Usable Replications [b]	Final Weight (lbs/A)			Range (in parens) and Mean			
		CC	GS	Both	pH	Turbidity (ppm)	NH_3 (ppm)	CO_2 (ppm)
32 180 [c]	2	1,629	1,344	2,973	(7.20–9.00) 7.89	(48–340) 151	(0–1.90) 0.728	(0–17.62) 3.44
32 / 180 [d]	2	1,918	1,136	3,054	(7.49–9.01) 7.92	(18–410) 179	(0.17–1.31) 0.660	(0–12.86) 2.67
16 + 90 | 16 + 90	2	2,154	1,022	3,176	(7.31–8.80) 7.77	(34–600) 207	(0.30–1.97) 0.671	(0–12.38) 3.61
16 + 90 |	3	1,049	709	1,758	(7.42–8.30) 7.78	(2–57) 29	(0.05–.85) 0.413	(0–13.33) 3.37
16 90	2	1,238	687	1,925	(7.37–8.5) 7.84	(17–150) 89	(0.10–1.09) 0.523	(0–9.52) 2.22
32	2	2141	. .	. .	(7.40–8.84) 7.81	(8–211) 75	(0.13–1.26) 0.588	(0–9.52) 2.63
180	3	. .	1,260	. .	(7.35–8.88) 7.85	(14–260) 105	(0.04–1.47) 0.649	(0–11.43) 1.78

[a] Populations contain shiners in lots of 90 or 180 and catfish in lots of 16 or 32.
[b] Indicates whether usable data were available from two or three replicates.
[c] Designates pool containing 32 catfish and 180 shiners intermixed.
[d] Designates pool containing 32 catfish separated from 180 shiners by a net.

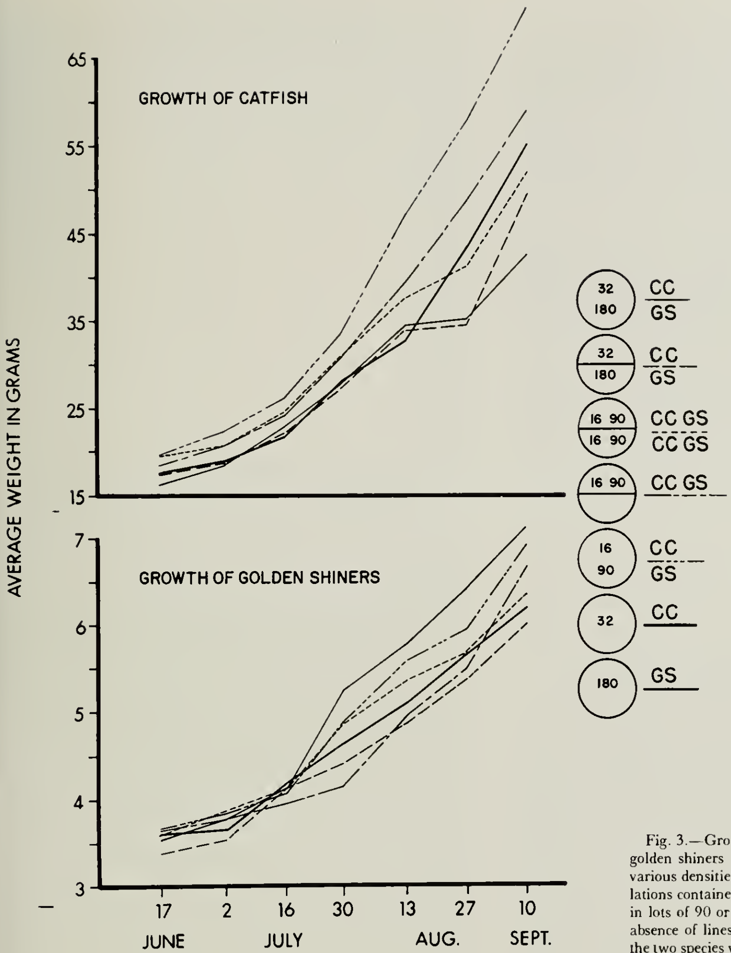

Fig. 3.—Growth curves for channel catfish (CC) and golden shiners (GS) held in 10-foot-diameter pools at various densities and degrees of association. The populations contained catfish in lots of 16 or 32, and shiners in lots of 90 or 180, as diagrammed. The presence or absence of lines bisecting the circles indicates whether the two species were mixed or separated.

September 10, even though standing crops were large. Maximum crops exceeded 2,000 and 1,000 pounds per acre for catfish and shiners, respectively, providing a weight of over 3,000 pounds per acre where the species were combined. In these tests the highest standing crop of catfish occurred when each half of a pool contained 16 catfish mixed with 90 shiners but was less than 1 percent greater than the final weight of 32 catfish alone in an entire pool. No significant differences existed in production by 32 catfish alone or when mixed with shiners.

As in our 1968 tests, the greatest production of shiners occurred when the shiners were directly associated with catfish, but production was not significantly greater than that by an equal number of shiners maintained alone in an equal volume of water. Perhaps the most impressive result of these experiments was that the total combined production by 32 catfish and 180 shiners when each was maintained alone in separate pools was not significantly larger than that made by the two species when combined in one pool.

In the 1968 tests high production by shiners was associated with high plankton turbidity, and high turbidity appeared to be related to the amount of pool bottom available to foraging catfish. In the more dense populations of 1969, turbidity was related more to numbers of fish than to the existence or activities of one or the other species. The factors which probably contributed most to the high turbidities in 1969 were the greater levels of feeding and of organic wastes in those pools containing the higher densities of both species.

Second Series

Methods.—In a series of eight pools we established two replications of each of four different populations that all contained the same total numbers of both species, but in four different degrees of association (Table 5). The objective was to gain additional information on species relationships and the influence of density. The pools received their initial stock on May 29, 1969, and were drained and censused on July 23, 1969, providing a growing period of 55 days.

TABLE 5.—Means of final standing crops, in pounds per acre, for two replications of each of four different combinations of channel catfish (CC) and golden shiners (GS) when maintained outdoors in 10-foot-diameter plastic pools over a 55-day growing period. Underlined quantities designate weights of those fishes mixed in the same half pool.

Type of Population [a]	Final Weight (lbs/A)				
	GS	GS	CC	CC	Total
32/180 [b]	734	..	1,000	..	1,734
32/180 [c]	754	..	864	..	1,618
90/90 + 32	379	363	1,003	..	1,745
16/16 + 180	..	700	537	391	1,628

[a] Populations contain shiners in lots of 90 or 180 and catfish in lots of 16 or 32.
[b] Designates pool containing 32 catfish and 180 shiners intermixed
[c] Designates pool containing 32 catfish separated from 180 shiners by a net.

Results.—Among the eight shiner populations, differences in production were not significant between those confined in one-half of a pool and those occupying all of a pool, or between those directly associated with catfish and those sharing the same water with catfish but being physically separated from them by a screen. Differences in production between catfish populations were larger than those for shiners, but still not significant. The differences appeared related to predation of shiners by catfish, and this was the only experiment in which such predation was evident. Gains by catfish were consistently largest when the catfish were mixed with shiners, and the data in Table 6 show that numbers of unaccounted-for shiners were consistently larger where mixed with catfish. The differences were statistically significant.

Some calculations were made to provide a basis for evaluating the degree to which predation of shiners by catfish might have influenced production of the catfish. Using the mean final weight of shiners of 4.28 grams (which would be excessive for this computation), assuming that all unaccounted-for shiners were eaten by the catfish, and assuming a conversion ratio of 1 pound of catfish gain for 2 pounds of shiners eaten, predation of shiners would have accounted for about 67 percent of the difference in the final standing crops of catfish when mixed and when not mixed with shiners. We believe, however, that the actual contribution of the shiners was much less.

TABLE 6.—Numbers of golden shiners that could not be accounted for at time of final censuses after being mixed or not mixed with channel catfish over a 55-day period in 10-foot-diameter pools.

Type of Population [a]	Pool Number [b]	Number Unaccounted for	Mixed with Catfish
32/180 [c]	22	29	yes
	27	32	yes
32/180 [d]	23	5	no
	24	8	no
16/16 + 180	28	39	yes
	29	41	yes
90/90 + 32	25 E	5	no
	25 W	13	yes
90/90 + 32	26 E	11	no
	26 W	19	yes

[a] Populations contain shiners in lots of 90 or 180 and catfish in lots of 16 or 32.
[b] "E" beside number indicates east half of pool, "W" indicates west half
[c] Designates two pools, each containing 32 catfish and 180 shiners intermixed.
[d] Designates two pools, each containing 32 catfish separated from 180 shiners by a net.

Third Series

Methods.—In this series we again used eight pools which had standardized bottom soils and were filled simultaneously with water from a common source. We attempted to minimize all environmental differences with the purpose of measuring those differences in production attributable purely to the physical association or separation of the two species. This was accomplished by the common mixing of water between a pool containing only one of the two species and a second pool containing both species freely mixed. Mixing was accomplished by a slow pumping of the water from one pool to another and returning the same volume by siphon. The small submersible pumps used transferred water at a rate of about 48 gallons per hour and were operated 9 hours each day for 5 days each week. The principal environmental difference between the paired pools was the greater depth of about 1 inch in the pool receiving the pumped water, which was necessary to keep the siphon in operation. Such mixing was intended to minimize the differences of such factors as turbidity, pH, temperature, ammonia, and dissolved oxygen between paired pools.

The pools received their initial stock on July 24, 1969, and were drained and censused on September 16, 1969, providing a growing period of about 54 days. Among the eight pools we had two replications of each of two pairs as follows:

1. A pool containing 180 shiners alone sharing circulated water with a pool containing 180 shiners mixed with 32 catfish.
2. A pool containing 180 shiners alone sharing circulated water with a pool containing 32 catfish alone.

Results.—The results of these experiments are presented in Table 7 and may be summarized as follows:

1. The greatest productions by shiners (1,163 and 1,132

TABLE 7.—Numbers recovered and final standing crops, in pounds per acre, for populations of channel catfish (32) and golden shiners (180) when mixed or separated but sharing water circulated between populations. Pools having a common water circulation are paired in the column at left. The populations were maintained outdoors in 10-foot-diameter plastic pools for 54 days.

Paired Populations and Numbers in Original Stock	Final Standing Crop			
	Golden Shiners		Channel Catfish	
	Number	Pounds	Number	Pounds
180 ┐	162	1,066	..	..
180/32 ┘	170	1,127	31	1,521
180 ┐	173	1,124	..	..
180/32 ┘	174	1,027	33	1,674
180 ┐	176	1,163	..	..
32 ┘	..	..	32	1,637
180 ┐	171	1,132	..	..
32 ┘	..	..	32	1,447

pounds per acre) were in those populations maintained alone in pools sharing circulated water with pools containing catfish only; these averaged less than 10 percent greater than their companion populations and were not significantly different from them.

2. Greatest production by catfish occurred in those pools also containing shiners, but there was less than 5 percent improvement and this was not significantly greater than when catfish were separated but shared circulated water.

3. Near-equal survivals by shiners when mixed and not mixed with catfish showed that predation was not a factor in this experiment.

The pump and siphon arrangement was not completely efficient in equalizing measured parameters in the paired pools, but the similarities in standing crops among both mixed and unmixed populations rendered the failure unimportant. These results completely substantiated those obtained in tests previously described, namely, that at the densities used neither species limited production of the other when mixed, and as many total pounds could be produced by a mixed population in a single pool as by the same total numbers separated by species in two pools and fed similar rations.

OVERALL DISCUSSION

Our findings resembled those of Yashouv (1969), who found that growth increments of carp (*Cyprinus carpio*) and tilapia (*Tilapia aurea*) in mixed culture sometimes exceeded those exhibited by either in monoculture.

Our studies demonstrated that, within the range of sizes and densities used, the channel catfish, golden shiner, and tilapia (*T. mossambica*) were extremely compatible. When combined, each stimulated the other to a faster and stronger feeding response, which resulted in a more efficient conversion of food. No antagonistic behavior was observed, and evidence of significant predation of shiners by catfish occurred in only one of the six test series studied during the 2-year period. While predation of shiners might become important if larger sizes of catfish were used, in certain types of operations the predation might be minimal or otherwise unimportant. If shiners were the primary crop, the "bonus" production of catfish could more than compensate for such limited predation as might occur, and if marketable-sized catfish were the principal crop, it would be of small consequence if some of the supplementary crop of shiners were eaten.

There are two basic fish farming operations in which the two species could be combined:

(1) Mix shiner fry with catfish fry, with the purpose of producing salable minnows and fingerling catfish. The shiners could be spawned in the pond or introduced as matted eggs or fry. The channel catfish could be added as fry, and Martin (1968) has recommended that such fry be at least 1 inch long. It would be advantageous to introduce catfish and shiners in approximate known numbers so as to control the size of the minnows and catfish fingerlings grown in this operation.

(2) Mix shiner fry with catfish fingerlings, with the purpose of producing salable bait minnows and channel catfish large enough for the food or "fish-out" market. In such an operation Martin suggests that the catfish not be placed in the pond until the shiners have become advanced fry.

Our results in the wading pools suggest that each species could be treated as if it were being cultured alone, insofar as densities, feeding rations, and final standing crops are concerned. It should be remembered, however, that at the higher densities used in 1969, aeration was required to prevent oxygen depletion in the pools. The potential for such depletion was undoubtedly enhanced by the small size and shallowness of the pools which caused abnormally high water temperatures and unusually high densities of phytoplankton. Such a tendency might be less in ponds, but it still could be a problem if high densities of both species received normal rations in ponds having no water exchange. The problem could be eliminated by water exchange, and could be greatly lessened by taking extreme care not to overfeed the catfish and by feeding the shiners a reduced ration.

The unusual efficiency with which our shiners that were mixed with catfish appeared to be converting supplied fish meal into fish flesh suggested that they were gaining important and unmeasured nutrients from the abundant phytoplankton. If rich plankton blooms could be produced in the absence of full rations for shiners, production of shiners might be reasonably high with a minimum shiner ration while maintaining a normal production of catfish on normal catfish rations.

Two principal problems in such a combined culture would be the danger of oxygen depletion because of the increased organic load, as already discussed, and the difficulties in harvesting the shiners without mechanical injury from the catfish. It seems reasonable to expect that a technique could be developed whereby the shiners could be trapped, baited, or otherwise removed with a minimum of contact with the companion species. If not, it would be important to assure that the catfish be enough larger than the shiners to permit their separation by mechanical grading. Martin (1968) has suggested that the crop of fingerling catfish not exceed 10,000 per acre to assure that they will grow large enough to be easily separated from the shiners.

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