SPORT FISH PRODUCTION AND PRODUCTIVITY RELATIONSHIPS IN RECLAIMED DOMESTIC WASTEWATER

by

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STATEMENT BY AUTHOR

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ABSTRACT

The purpose of this study was to evaluate the suitability of reclaimed domestic wastewater for a sport fishery. The water was reclaimed by a tertiary treatment of sand filtration. The fish tested were Channel catfish, *Ictalurus punctatus*, Rainbow trout, *Salmo gairdneri*, and Malacca *Tilapia* hybrids. The major objectives were to establish survival rates, growth rates, stocking schedules, and maximum stocking densities for these fish in an unusual and highly productive environment. Less than 1% survival occurred in five trout experiments and in one catfish experiment. An important cause of mortality was low sunrise oxygen tensions resulting from respiration of dense phytoplankton blooms which were stimulated in part by high (14 mg/l) average inflow orthophosphate concentrations. When fish survived, production was high. The total yields of acceptable Channel catfish and *Tilapia* were 383 and 397 Kg per hectare, respectively. *Chironomus* larvae, the predominant food organism, comprised 90% of the estimated annual benthic production of 14,180 Kg per hectare. Zooplankters, although abundant, were not an important source of fish food because of their small size. Phytoplankton productivity averaged 10.2 gm O_2 per m^3 per day. The present waters, although highly productive, cannot be expected to support a dependable fishery because occasional unfavorable oxygen conditions are likely to reoccur.

INTRODUCTION

The goal of this study was to evaluate the reuse, for a recreational fishery, of domestic wastewater reclaimed through a tertiary treatment of horizontal and vertical flow sand filtration. Tucson, Arizona supports a metropolitan area of about 350,000 people solely on ground water. Aquifer recharge is insufficient to meet existing water demands; consequently, the water table has been steadily lowered. In addition to projected domestic and industrial uses, there is an increasing demand for aquatically oriented recreation facilities in the Tucson area. Pena Blanca Lake, 65 miles away, is the nearest publicly accessible recreational impoundment. This lake does not fulfill present needs. Obviously, to provide recreational waters, some new source of water must be found. In response to a recognition of future problems, the Tucson Wastewater Reclaimation Project was initiated in 1965 by the City of Tucson with the support of the Federal Water Pollution Control Administration.

Although the use of tertiary treated domestic wastewater for recreational purposes is relatively rare, there is an increasing awareness of the importance of wastewater reclaimation, particularly in the Southwest. Only the Santee Recreational Project (Merrell et al., 1967), also based on sand filtration can be directly compared with this project. Findings from another study with similar objectives, the Antelope Valley Project at Lancaster, California, supplied additional insight into the problem (Stern and Dryden, 1968).

To develop an intensive fishery, it is necessary to have complete control over population densities, and this can only be realized when fish do not reproduce. Fish with exceptional growth rates must be selected for such a fishery, and they should be easily raised in numbers or readily available from commercial sources. The wide range of water temperatures in a desert environment limits the number of acceptable fish species, and dictates their management. Based on the above considerations, three fish species, Channel catfish, *Ictalurus punctatus*, Rainbow trout, *Salmo gairdneri*, and Malacca *Tilapia* hybrids (Hickling, 1962), were evaluated for suitability in this unique situation. Traditionally, warm water ponds in this area have been stocked with Largemouth bass, *Micropterus salmoides*, and one or more sunfish as a forage fish. Centrarchid fishes have been avoided in this study because they tend to overpopulate and become stunted. Although the total productivity potential can be very high with stunted fish populations, a great number of small fish are of little value in a sport fishery.

The following major objectives were considered:

1. To develop an intensive fishery in a habitat enriched to a degree that approaches pollution, a reasonable percentage of the fish must survive. Therefore, the survival rates were determined.

2. In addition to simply surviving, fish must feed and grow well. Growth rates were determined by periodic sampling and measuring.

3. Based on the above considerations, guidelines for stocking schedules were established that would produce maximum yield in a desert temperature regime.

4. Since an intensive fishery was planned, the maximum stocking densities suitable to produce acceptable fish in a reasonable time were determined.

To further evaluate the quality of the water, primary, benthic, and fishery productivity potentials were evaluated, and the zooplankton standing crop was measured. Inflow concentrations of nitrate and ammonia nitrogen, and orthophosphate were considered. These waters were then compared with other reclaimed wastewaters and with natural waters.

Ultimately, it is anticipated that the results of this study will serve as guidelines for establishing a recreational fishery on a realistic scale in the Tucson area, possibly in other communities, as well.

PHYSICAL CHARACTERISTICS OF THE STUDY AREA

The study area is located near the Tucson Municipal Sewage Treatment Plant, Tucson, Arizona, northwest of the city at an elevation of about 690 meters (Figure 1).

The area is characterized by mild winters and hot summers with air temperatures frequently in excess of 38° C. The U. S. Department of Commerce (1967b) reports that solar radiation in this area averages 475 gm cal. per cm^2 and that about half of the average total rainfall of 27 cm falls during summer convectional storms (1967a).

Effluent from an activated sludge system flowed over a sand and gravel filter. Horizontal filtration distances varied between 16 and 60 meters, while vertical filtration distances varied from about 1 to 6.5 meters. On the average, about 135 m^3 (35,000 gallons) per day of filter effluent was collected in the filter sump.

The ponds were approximately 33 meters on a side (about 0.25 acre each), with a slope of about 3 : 1, and an average depth of about 1.5 meters. The ponds were lined with bentonite and silt.

Filter effluent was pumped from the sump into ponds B and C simultaneously, and upon overflowing, filled ponds A and D, respectively. Thus, using the same effluent two separate pond series were established.

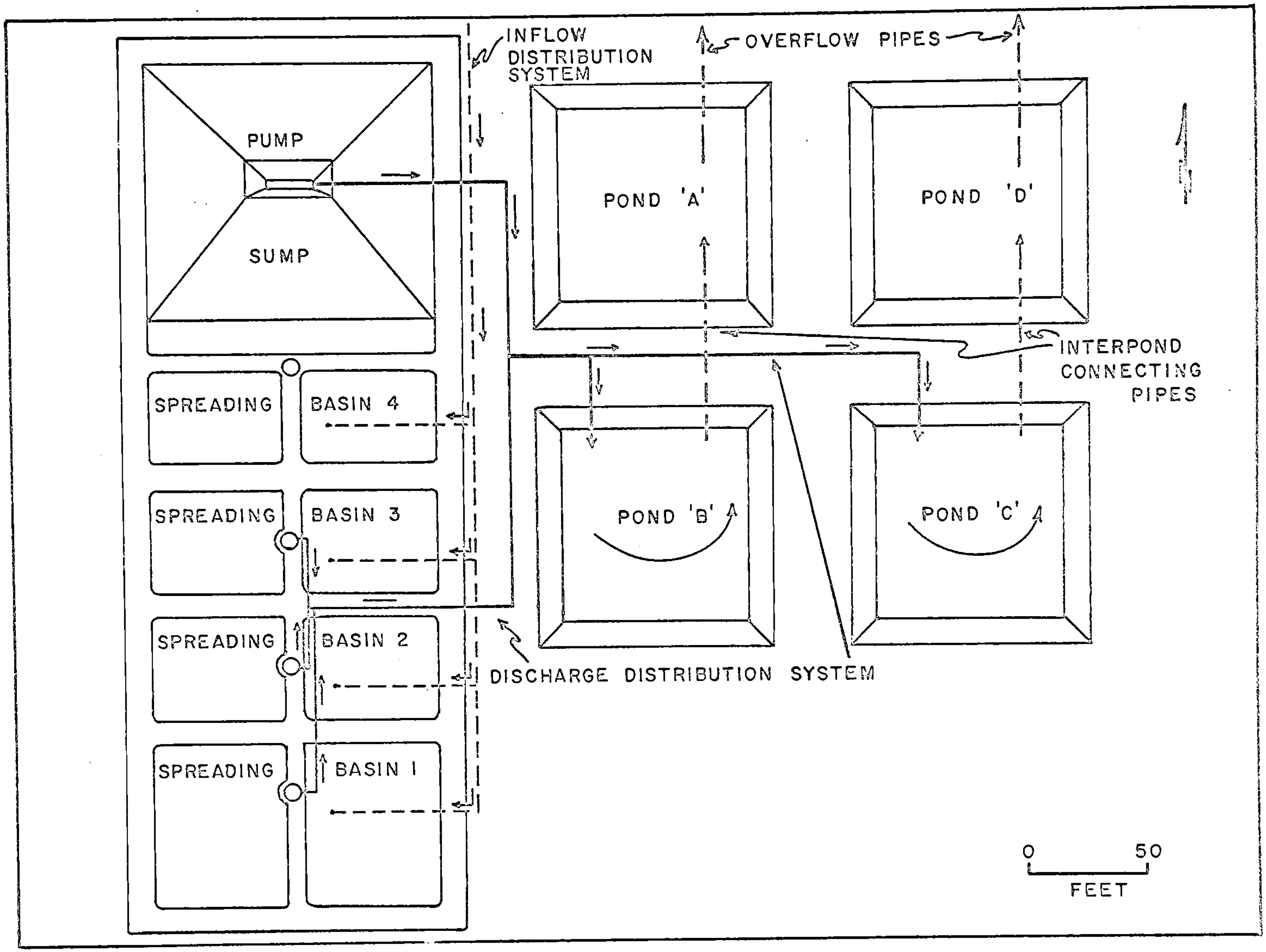

Figure 1. Filtration System and Pond Arrangement.

PROCEDURES

Channel catfish were used to provide fishing throughout the year, Rainbow trout as a supplement during winter months, and *Tilapia* hybrids were introduced in May to provide additional summer fishing. All fish were stocked at subcatchable sizes. Both trout and *Tilapia* were stocked at sizes and numbers that presumably would allow them to enter the fishery within three months. No artificial fish food was used, thus the cost of producing catchable fish was reduced. Fish were stocked in monocultures and in various combinations throughout the study (Table 1).

Channel catfish averaging approximately 12 cm total length were supplied by the U. S. Fish and Wildlife Service hatchery at Austin, Texas. Rainbow trout averaging about 11 cm total length were transported on two occasions from Page Springs Hatchery, operated by the Arizona Department of Game and Fish. *Tilapia* hybrids were reared at the off campus research facility of the Arizona Cooperative Fishery Unit. The procedure used was modified from McConnell (1962). These hybrids averaged 4 cm total length when released.

Tilapia hybrids were introduced into ponds B, C, and D on three dates. A total of 250 fish were eventually planted in each pond. On May 3, 1968, 169 fingerlings averaging 3.9 cm were introduced into each pond. On June 3, another 60 of similar size were added to each pond, and on June 20, the final 21 fingerlings were

Table 1

Stocking Schedule and Numbers.

Pond	Channel catfish	*Tilapia* hybrids	Rainbow trout
A	Oct. 1, 1967 750		
	Oct. 19, 1967 200		Oct. 22, 1967 125
B			Oct. 16, 1967 250
		May-June 1968 250	
	Oct. 19, 1968 200		Oct. 22, 1968 50
C	Oct. 1, 1967 250	May-June 1968 250	
			Oct. 22, 1968 50
D	Oct. 1, 1967 500	May-June 1968 250	
			Oct. 22, 1967 125

added. In August about 100 Tilapia were removed from each pond to simulate fishing pressure.

Representative fish samples (approximately 10% of fish stocked) were taken by seining at two to three month intervals. M.S.222, Tricaine methane sulfonate, was used as a sedative in the holding cans to reduce handling injuries. Fish were measured and weighed, and means were calculated from these measurements. Three to five fish were always retained for stomach analysis. The rest were returned to their respective ponds.

Tilapia and Channel catfish experiments were terminated on October 12, 1968, when all fish in ponds B and C were removed by seining followed by rotenoning. All fish were weighed in groups of 10, and total lengths of a representative sample (50) were measured.

Benthic biomass (standing crop) samples were taken with a "dip stick," a suction device which operated on water displacement (Figure 2). The bottom composition prohibited more conventional techniques. A thin layer of ooze, seldom exceeding 2 cm, covered the firm bentonite and silt bottom. The device was operated by placing the thumb over the small vent tube and forcing the wide end to the bottom of the pond. When the thumb was released, air was displaced by water rushing in past the flap valve at the bottom. The dip stick was rotated gently in one spot while it filled. Only when the dip stick filled smoothly was the sample accepted. Acceptable samples were poured through a wash bucket with a 30 mesh brass screen at the bottom. The device was then refilled with water and rinsed into the bucket.

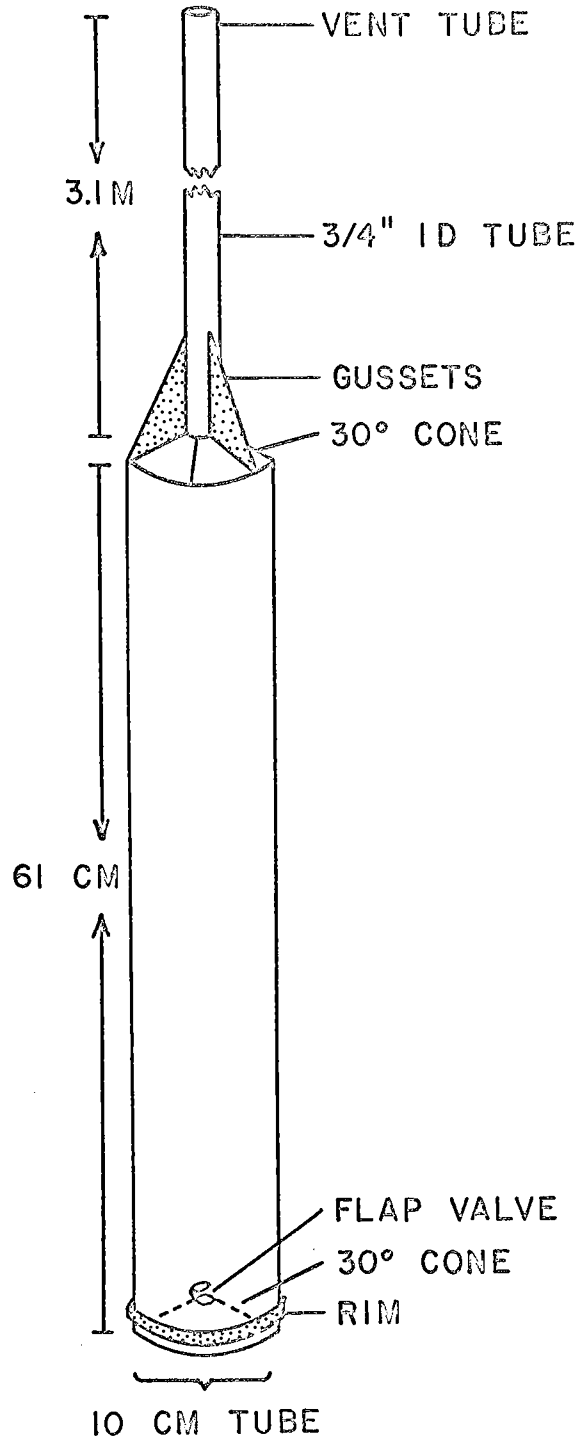

Figure 2. The "Dip Stick," a Water Displacement Sampling Device for Benthic Organisms.

This sampling technique was somewhat biased in favor of coarse bottom materials. Portions of the bottom of pond C were sandy, and samples taken in these areas generally filled at an acceptable rate on the first try.

Four samples were taken from different sections of each pond monthly. These samples were immediately fixed in 10% formalin in most instances, but when time permitted, small samples were sorted alive with forceps. Fixed samples were sorted in one of three ways, depending on their size and the amount of accompanying detritus. When detritus was a problem, invertebrates were floated with a 30% (by volume) sucrose mixture. When detritus was not a problem, a suction device using an aspirator and a screened collection bottle (Scarola and Giberson, 1967) was used to sort invertebrates. Some small samples were picked directly with forceps. Samples were then oven dried at 50° C for 24 hours and weighed on a Mettler balance to the nearest 10 mg.

Zooplankton biomass (standing crop) samples were taken with a 23 cm, 55 mesh per cm, nylon plankton net mounted at the end of an aluminum pole. The net was swung on a 3.5 meter radius through approximately 160° arc. Four such samples were collected from all ponds monthly. For comparison with other studies, it was necessary to know approximately how much water was sampled from each pond in a sampling period. To quantify the technique described above, a Schueler metering tow net was used once for calibration. By comparison, the net used was found to be 38% efficient. On this basis, approximately 0.62 m^3 were sampled from each pond monthly.

Zooplankton samples were preserved in a 10% formalin solution. Dry weight was determined by oven drying the samples at 50° C for 24 hours and weighing on a Mettler balance to the nearest 10 mg.

Gross primary productivity measurements were based on the rate of evolution of oxygen by phytoplankton. Water samples were taken in 130 ml stoppered bottles. The sampling device used consisted of a 6 meter aluminum tube with a hand operated bilge pump and counterweight at one end. At the other end of the tube, a bracket held the bottle in place. A modified rubber stopper, a clamp to hold the stopper, and a length of plastic tubing from the bottle to the pump completed the apparatus. When sampling, the device was held at the desired level and pumped until the bottle had been flushed five or six times. Winkler (azide modification) reagents were added directly to the 130 ml stoppered bottle in the field. Phenylarsene oxide (PAO) supplied by Hach Chemical Company was used as a titrant.

Samples were taken about 15 cm below the surface and 15 cm above the bottom. Two samples from each level were taken from opposite sides of all ponds at sunrise and the two bracketing sunsets. Gross productivity was then calculated graphically (McConnell, 1962). The elapsed time between sampling periods averaged twelve days.

Additional water samples were taken to determine chlorophyll concentrations during periods of low oxygen tensions and fish kills. The sampling device described above was used to take vertical samples which were placed in one liter brown glass bottles. The samples were filtered, with vacuum, using an AA "Millipore" membrane filter. The quantity of water passing through the filter varied with seston concentration, since the membrane tended to clog easily. The filter and the filtered material were dissolved in 95% acetone, agitated, and allowed to stand for 24 hours. Optical density was read on a Bausch and Lomb "Spectronic 20" at 665 $m\mu$. The results, reported as mg per m^3 chlorophyll, were calculated from optical density readings as described by Odum, McConnell, and Abbott (1958).

Water temperatures were determined by two methods throughout the study. Taylor maximum-minimum thermometers were mounted at three levels on a welded pipe frame. These thermometers were used continuously throughout the study. Reading these thermometers was difficult because they accumulated algae, slime, and insect eggs, and because the prevailing low humidity of the area caused rapid evaporation which depressed the minimum readings when the thermometers were removed from the water for reading. Maximum and minimum temperatures were sufficiently accurate to establish temperature trends, however. A Yellow Springs "Tele-Thermometer" was used for vertical samples during most of the study.

La Motte color standards were used to measure the pH of samples from each pond at each oxygen sampling. Data on nitrate, ammonia nitrogen, and orthophosphate were supplied, when possible, by the Tucson Wastewater Reclaimation Project chemist.

RESULTS

The final survival percentages varied greatly from pond to pond, even for the same species and stocking rates (Table 2). Survival did not exceed 1.0% in any of five trout experiments. In two of the three initial Channel catfish experiments and in all *Tilapia* experiments, survival exceeded 70%. There appears to be an inverse relationship between the density of Channel catfish and the percentage of surviving *Tilapia*.

As might be expected, the growth rate of Channel catfish decreased with increasing stocking densities (Tables 1 and 3). The highest catfish growth rates occurred during spring and summer months with warmer water temperatures. In pond C, acceptable fish (greater than 25 cm) were available by July 1968, or about 260 days. In pond D, where fish were stocked at twice the density, a greater total yield was recorded but a full year elapsed before many of the fish reached an acceptable size.

Tilapia grew rapidly in all ponds and reached an acceptable size (17 cm) within 80 days. The greatest yield occurred in pond B, where 42.4 Kg were produced (Table 4). This was not substantially higher than in ponds C and D, in which Channel catfish were present.

Benthic invertebrate standing crop data from 13 monthly samples are presented in Table 5 and in Figure 3.

Table 2

Duration of Experiments and Percent Survival of Fish.

Pond	Channel catfish	*Tilapia* hybrids	Rainbow trout
A	Oct. 1, 1967- May 1968 <1.0%		
	Oct. 19, 1968- April 1969 unknown[a]		Oct. 22, 1968- Jan. 1969 <1.0%
B			Oct. 16, 1967- April 16, 1968 <1.0%
		May-June 1968- Oct. 12, 1968 94%	
	Oct. 19, 1968- April 1969 unknown[a]		Oct. 22, 1968- Jan. 1969 <1.0%
C	Oct. 1, 1967- Oct. 12, 1968 82%	May-June 1968- Oct. 12, 1968 86%	
			Oct. 22, 1968- Jan. 1969 <1.0%
D	Oct. 1, 1967- Oct. 12, 1968 92%	May-June 1968- Oct. 12, 1968 71%	
			Oct. 22, 1968- Jan. 1969 <1.0%

a. Fish were restocked as competition for Rainbow trout, and were not recovered.

Table 3

Mean Weight and Length, and Net Production of Channel catfish by Pond.

Date Sampled	A grams (centimeters)	C grams (centimeters)	D grams (centimeters)
Oct. 1, 1967[a]	12.32 (11.48)	11.68 (11.48)	12.62 (11.48)
Jan. 12, 1968	21.87 (13.67)	22.06 (13.73)	24.07 (13.67)
Apr. 26, 1968	41.43[b] (15.70)	39.06 (15.60)	33.95 (15.10)
June 11, 1968		80.66 (20.45)	60.60 (19.84)
Aug. 21, 1968			118.50 (24.90)
Sept. 4, 1968		175.00 (28.70)	
Oct. 12, 1968[c]		203.52 (30.10)	130.15 (25.59)
Total weight produced		38.80 Kg	54.08 Kg

a. Average length and weight at initial stocking.

b. Nearly complete mortality on May 3.

c. Experiment terminated. Mean weight of all fish recovered.

Table 4

Mean Weight and Length, and Net Production of *Tilapia* hybrids by Pond.

Date Sampled	B grams (centimeters)	C grams (centimeters)	D grams (centimeters)
May-June 1968[a]	1.61 (4.10)	1.65 (4.10)	1.85 (4.10)
June 11, 1968		19.87[b] (9.87)	
July 22, 1968	114.30 (17.10)		
Aug. 21 & 28[b] 1968	190.00 (21.28)		224.20 (21.87)
Aug. 28, 1968[b] Sept. 4, 1968		212.44 (21.24)	
Oct. 12, 1968[c]	173.40 (21.28)	173.84 (20.03)	188.30 (21.66)
Net Production	42.43 Kg	40.26 Kg	37.03 Kg

a. Average length and weight at initial stocking.

b. Samples composed almost entirely of fish from the May 3, 1968 introduction.

c. Experiment terminated. Almost all fish recovered.

Table 5

Benthic Invertebrate Biomass (Standing Crop) gm / m^2.

Month	Pond A	Pond B	Pond C	Pond D
Oct. 1967	17.92	13.39	12.86	1.26
Nov. 1967	17.79	8.54	12.21	3.52
Dec. 1967	7.96	15.35	32.18	6.14
Jan. 1968	14.09	12.42	9.07	6.94
Feb. 1968	14.86	13.02	34.25	12.12
Mar. 1968	11.78	9.84	14.21	8.94
Apr. 1968	16.80	13.35	8.39	4.16
May 1968	11.54	20.88	6.91	1.21
June 1968	6.63	12.74	2.04	0.86
July 1968	16.84	0.00	3.27	0.00
Aug. 1968	0.03	3.82	3.76	1.14
Sept. 1968	0.43	4.07	2.41	0.62
Oct. 1968	12.83	2.65	2.71	7.81
Total	149.50	130.07	144.27	54.72
Mean	11.50	10.01	11.09	4.21
Mean of means	9.176			

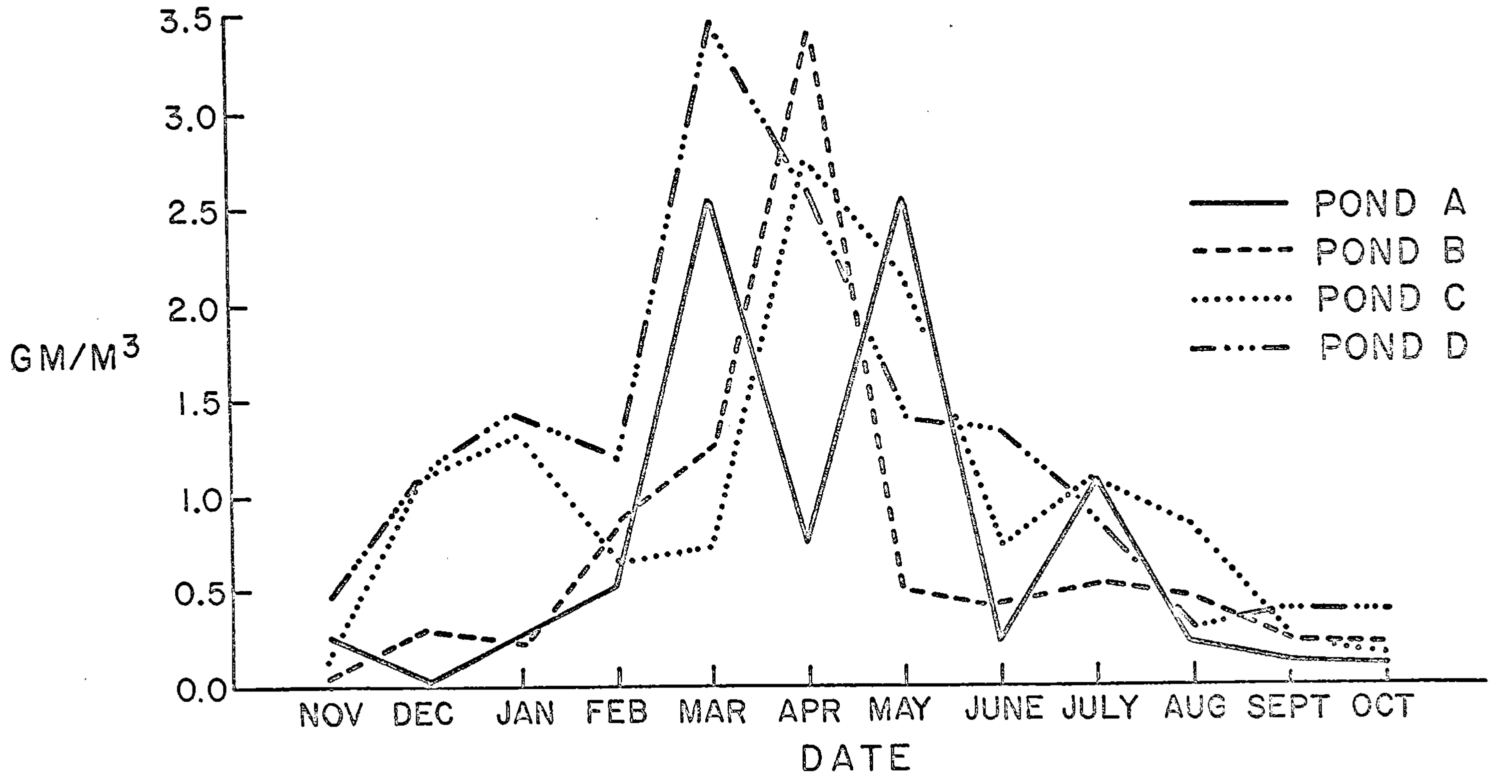

Figure 3. Benthic Biomass (Standing Crop) of all Ponds.

Depressed standing crop values generally correlate with periods of rapid fish growth. The predominant benthic form was Chironomus larvae. Libellulid larvae were frequently present, although they rarely comprised more than 15% of a given sample. Coenagrionid larvae and aquatic beetles, both larvae and adults, were found frequently in benthic samples, but they were relatively unimportant on a dry weight basis. Interestingly, the mean dry weight of benthic invertebrates in pond D, 4.2 gm per m^2, was low. When compared to each of the other three ponds, it was found to approach significance at the 95% level, using Tukey's very stringent W procedure (Steel and Torrie, 1960). The annual mean standing crop for all ponds was 9.176 gm per m^2.

Spring peaks in net zooplankton densities (Figure 4) were caused almost entirely by small cyclopoid copepods. Throughout much of the remainder of the year, corixids were important. Cladocerans, nepids, belostomatids, and water mites were occasionally taken in the samples, although they were never important on a dry weight basis. Differences between sample means existed (Table 6), but none approached significance. The annual mean zooplankton standing crop for all ponds was 0.92 gm per m^3.

Gross photosynthesis measurements were taken throughout the study as an indication of the rate of production of organic matter. The data are presented in Table 7. The greatest range in oxygen evolution, 0.5 to 24.0 gm O_2 per m^3 per day, was found in pond B. The lowest mean productivity rate, 8.12 gm O_2 per m^3 per day, was recorded

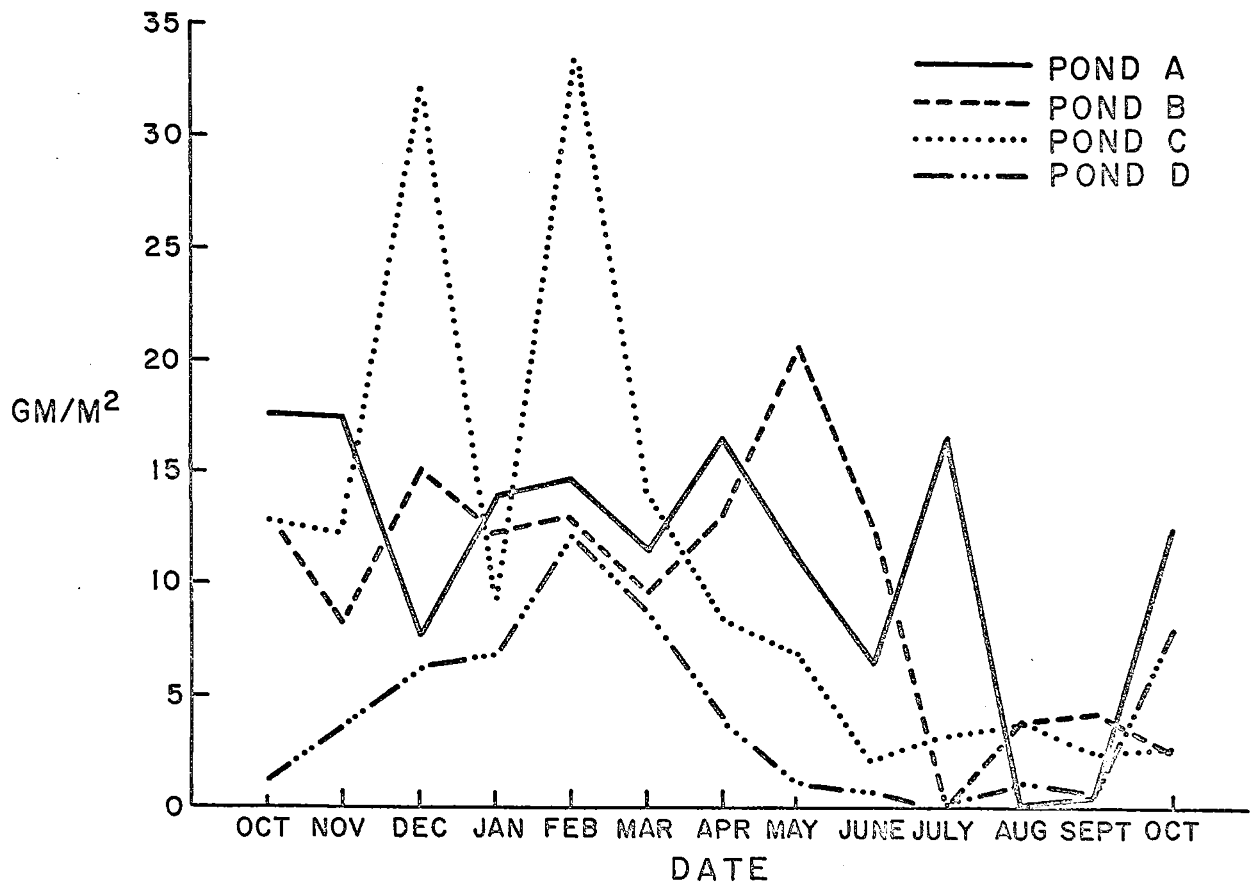

Figure 4. Zooplankton Biomass (Standing Crop) of all Ponds.

Table 6

Zooplankton Biomass (Standing Crop) gm / m^3.

Month	Pond A	B	C	D
Nov. 1967	0.25	0.05	0.12	0.46
Dec. 1967	0.03	0.28	1.09	1.09
Jan. 1968	0.25	0.23	1.33	1.44
Feb. 1968	0.53	0.86	0.65	1.22
Mar. 1968	2.53	1.27	0.74	3.41
Apr. 1968	0.74	3.39	2.75	2.60
May 1968	2.52	0.54	2.13	1.41
June 1968	0.23	0.42	0.75	1.32
July 1968	1.07	0.53	1.09	0.90
Aug. 1968	0.23	0.45	0.85	0.32
Sept. 1968	0.14	0.24	0.26	0.38
Oct. 1968	0.14	0.22	0.17	0.37
Total	8.66	8.48	11.93	14.83
Mean	0.72	0.71	0.99	1.23
Mean of means	0.92			

Table 7

Gross Primary Productivity.

Date	Number of Representative Days	Gms O_2/m^3/day by pond			
		A	B	C	D
Sept. 14, 1967	13	17.10	16.97	15.08	10.63
Sept. 30, 1967	9	9.00	14.06	14.64	15.79
Oct. 6, 1967	11	7.60	14.38	12.62	9.34
Oct. 17, 1967	16	8.38	12.39	14.07	13.81
Nov. 2, 1967	12	7.18	10.96	12.48	11.14
Nov. 14, 1967	14	7.92	13.16	23.85	17.12
Nov. 28, 1967	14	9.01	14.65	11.05	12.58
Dec. 12, 1967	19	4.66	1.49	12.52	7.04
Dec. 31, 1967	11	1.24	0.51	9.16	1.67
Jan. 11, 1968	20	3.71	6.46	3.82	2.24
Jan. 31, 1968	10	3.36	13.55	9.21	4.79
Feb. 10, 1968	10	6.48	3.07	16.21	11.66
Feb. 20, 1968	10	5.59	9.78	9.77	8.89
March 2, 1968	10	9.32	14.64	16.05	12.67
March 12, 1968	11	10.87	17.26	13.45	11.41
March 23, 1968	9	6.46	7.63	8.74	3.50
April 1, 1968	11	11.82	10.58	7.78	9.57
April 12, 1968	11	14.68	3.90	18.13	9.58
April 23, 1968	10	7.50	12.07	11.76	8.60
May 3, 1968	11	9.25	10.29	1.95	10.24
May 14, 1968	14	3.64	4.41	4.21	14.50
May 28, 1968	10	0.10	9.99	9.28	9.21
June 7, 1968	12	6.94	3.39	7.44	13.21
June 19, 1968	11	5.44	2.45	11.23	12.63
June 30, 1968	12	12.57	23.98	11.33	7.14
July 12, 1968	11	10.99	10.12	16.15	12.13
July 23, 1968	10	10.37	14.88	10.95	18.74
Aug. 2, 1968	12	10.17	12.43	16.21	19.26
Aug. 14, 1968	9	10.68	11.03	20.36	14.22
Aug. 23, 1968	12	8.01	15.45	14.02	18.07
Sept. 4, 1968	13	7.83	8.64	18.65	21.54
Sept. 17, 1968	18	8.37	16.77	19.85	11.83
Oct. 4, 1968	12	11.72	16.18	20.46	16.28
Mean	12	8.12	10.84	9.78	12.06

in pond A, and the highest, 12.06 gm O_2 per m^3 per day, was recorded in pond D. This was the only difference that approached significance using Tukey's W procedure at the 95% level.

Temperature gradations up to 8° C were frequently found in 1.5 meters of water on spring and summer afternoons. By the following sunrise, a homothermous situation was again established. This temporary stratification was not as pronounced in the fall and winter months. Water temperatures appeared to follow changes in mean daily air temperature closely (Figure 5). A minimum water temperature of 7° C was recorded in December 1967 and a maximum of 30° C in August 1968.

Water samples for pH determinations were taken periodically. Extremes of 8.6 and 10.8 were recorded. There was a general correlation between lower pH values near 9 and lower gross primary productivity in winter months. Similarly, both tended to increase in the summer months when the pH typically exceeded 9.8. Sunrise pH readings tended to be from 0.2 to 0.4 units lower than preceeding sunsets. It appears that these waters, like most sewage effluents, are well buffered.

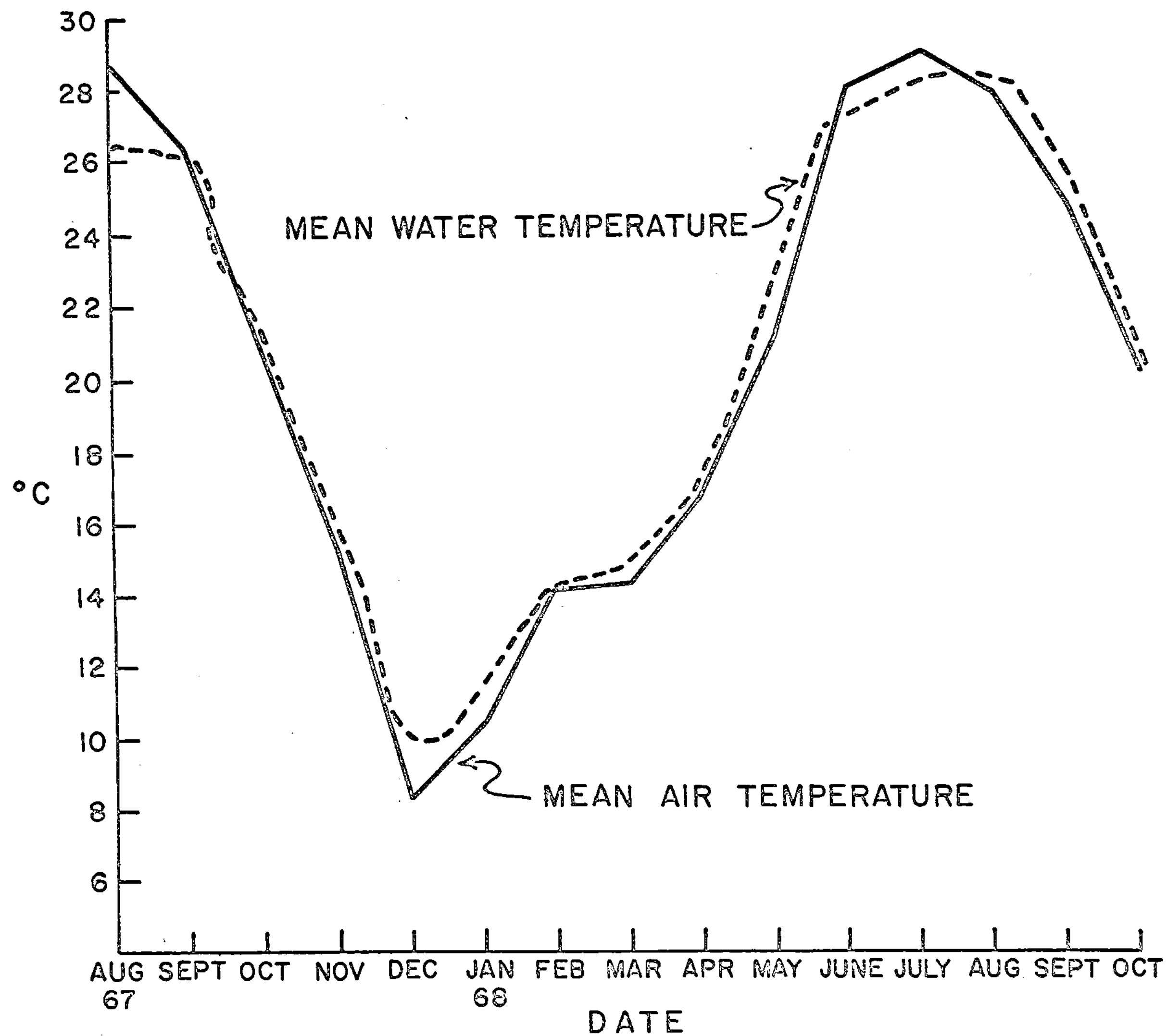

Figure 5. Mean Air and Water Temperatures During the Study.

DISCUSSION

In evaluating the suitability of the waters provided for an intensive sport fishery, survival and growth rates, net fish production, stocking schedules, maximum stocking densities, and acceptability of the fish selected will be considered, in that order.

Factors Affecting Survival

Less than one percent of the fish planted in five Rainbow trout experiments and one Channel catfish experiment survived until the proposed termination date. In the remaining Channel catfish experiments and in all *Tilapia* experiments, survival was considered adequate.

Channel catfish

Channel catfish kills occurred in pond A on April 1 and May 3, 1968: only three catfish survived. In both instances, sunrise oxygen tensions less than 0.5 mg/l were recorded. It was assumed that low oxygen tensions were associated with phytoplankton die-offs. To test this assumption, chlorophyll measurements were taken during both periods as an indicator of phytoplankton density. Average values of 207 and 297 mg chl. per m^3 were recorded on April 1 and May 3, respectively. These values indicated that a substantial phytoplankton population did exist but the technique used makes no distinction between dead and alive, functional phytoplankton. In both instances, the water was brownish with bacterial blooms which completely masked the presence of high phytoplankton concentrations. Therefore, respiration from both the phytoplankton and the bacterial blooms and possible decomposition of phytoplankton was probably responsible for the fish kills.

The extremes of dissolved oxygen tension recorded in this study were 0.24 and 37.4 mg/l. These figures were taken from 528 sunrise and 1,056 sunset samples. Merrell et al. (1967) states that similar extremes, 0.0 and 30.2 mg/l, were found in the fish ponds at Santee. Both at Santee and here, fish kills were associated with low oxygen tensions. Although evidence is inconclusive, high oxygen tensions may be a source of fish stress. The low oxygen tensions found in this study resulted from instability of phytoplankton blooms. These phytoplankton blooms, in turn, were influenced by water chemistry.

Phosphorus is the most biologically explosive element in aquatic systems. High phosphate concentrations stimulate phytoplankton blooms. Although these blooms cause the water to become supersaturated with oxygen during the daylight hours, respiration associated with an extensive phytoplankton bloom can depress oxygen tensions to zero during the night.

In evaluating the influence of phosphorus only total phosphate should be used, and both flow rates and concentrations should be considered. An annual figure in gm available per m^2 of habitat is a valid basis for comparing phosphate in two or more bodies of water.

Data on orthophosphate obtained in the present study do not warrant such consideration, but they do generally indicate the quality of the water found in the fish ponds.

Phosphate measurements, taken as orthophosphate, from the pilot filter effluent indicate considerable variation in the output quality. The extremes recorded, 2 and 20 mg/l, were influenced primarily by the mode of filter operation. The filter influent averaged 33 mg/l and the effluent averaged in excess of 14 mg/l phosphate. Ponds B and C, first to receive this effluent, acted as nutrient traps. The extreme phosphate concentrations in the water leaving these ponds were 3 and 15 mg/l, with an average of about 6.7 mg/l. Ponds A and D received overflow from ponds B and C, respectively. These ponds also acted as nutrient traps. Although extremes of 1.5 and 12 mg/l were recorded at the overflow pipes in these ponds, phosphate measurements at these points averaged about 4.2 mg/l.

It is apparent that the pilot filter and the ponds in series were useful in reducing the phosphate levels, but even the water leaving ponds A and D, with an average of about 4.2 mg/l, is far from acceptable. A desirable influent for successful fish ponds should contain less than 0.3 mg/l total phosphate at all times. Stern and Dryden (1968) reported that algal blooms are not inhibited by total phosphate concentrations above 0.5 mg/l. With phosphate concentrations less than 0.25 mg/l algal productivity was greatly reduced, but actual algal concentrations were not. At 0.25 mg/l, each m^2 of a 10,000 gallon holding basin (40 day retention period) was presented with approximately 2.45 gm total phosphate per year. With lower phytoplankton productivity, oxygen tensions did not greatly exceed saturation, nor were oxygen tensions greatly reduced at night through respiration. The resulting stability facilitated fish survival (Stern and Dryden, 1968).

The Santee project had several extensive fish kills in 1965 (Merrell *et al.*, 1967). In that year, the average total phosphate concentration in the influent water increased from 1.1 to 5.8 mg/l.

Kemmerer *et al.* (1968) discussed total phosphate measurements in the interflood influent of seven eastern Arizona impoundments. Woods Canyon, Hawley, Becker, Parker Canyon, Pena Blanca, and Rose Canyon lakes all averaged less than 0.45 mg/l. Becker Lake, with an average of 0.32 mg/l, is considered quite productive. Only Fool Hollow Lake, with an average of 4.6 mg/l, was comparable to the fish ponds used in this study. Fool Hollow Lake is considered polluted and is generally avoided for recreation. The only fish of importance there is the Brown bullhead, *Ictalurus nebulosus*, a very tolerant species.

A shortage of nitrate nitrogen can be limiting to productivity. Although there is no conclusive evidence about the effects of nitrate in high concentrations, it appears to stimulate rapid algal growth and increase the rate of productivity at all trophic levels.

Like phosphate, total nitrate should also be considered on a gm per m^2 per year basis, but the data available in this study is insufficient to make accurate calculations. Nitrate nitrogen levels in the pilot filter effluent varied from 0.8 to 15.0 mg/l and averaged about 4.5 mg/l. Nitrate removal was apparent in all ponds. The effluent from ponds B and C, showed an average of 2.5 and 3.8, respectively, for the period June 1967 to March 1968. For a similar period, effluents from ponds A and D averaged 1.0 and 2.3 mg/l.

Of seven eastern Arizona impoundments discussed by Kemmerer et al. (1968), only two had interflood inflow nitrate nitrogen concentrations as high as 0.5 mg/l. Merrell et al. (1967) reported that nitrate nitrogen entering the first recreational lake at Santee averaged about 0.9 mg/l. As water passed through the Santee lakes, an increased concentration of organic nitrogen accompanied a reduction of nitrate nitrogen. According to Hart, Doudoroff, and Greenback (1945) only 50% of the waters in the U. S. that are supporting a stable fish population have nitrate values in excess of 0.9 mg/l. Only 5% exceed 4.2 mg/l nitrate.

Limiting nitrate nitrogen levels in future ponds to 1.0 mg/l, preferably less, could help insure a more stable aquatic community with no substantial loss of productivity. Limitation of nitrate values should be accompanied by a reduction in other forms of nitrogen, as well. However, there is no assurance that algal productivity can be curtailed by limiting nitrogen, because nitrogen fixing blue-green algae such as Anabaena, Gloeotrichia, Nostoc, etc. would be essentially uninhabited if other nutrients were available in sufficient supply (Sawyer, 1968).

Rainbow trout

The nearly complete mortality in all five trout experiments is not so easily accounted for. Fish died throughout the first experiment. Generally one or several fish would be picked up on each trip to the ponds. On a few occasions, 15 to 20 fish died overnight. The morning of February 10, 1968, about 60 fish were found dead. On the mornings of April 8 to 10, another 57 dead trout were collected. These mortalities were associated with, but probably not directly caused by low oxygen tensions. Dissolved oxygen as low as 2.7 mg/l was recorded on February 10, but data collected during the April mortality was not indicative, since an air compressor had been installed to prevent further fish losses. The oxygen tensions recorded should not have been lethal at the prevailing temperatures. Other factors, such as ammonia and disease must also be suspected.

Many of the trout developed tail-rot and lesions on the body. Most of the fish grew poorly, while some probably lost length because of missing tails. On April 10, ten trout were recovered. A few of these were relatively large, exceeding 200 grams, but the others were much smaller. About half of the fish recovered showed symptoms of bacterial diseases. When fish are subject to stress, disease can secondarily cause mortality. In this case, the primary source of stress was probably low oxygen tensions. However, during the winter of 1967-1968, ammonia concentrations up to 8 mg/l from vertical pumpage was traced by dye studies into pond B (personal communication, John Stafford, project chemist). Ammonia, as undissociated ammonium hydroxide, can be highly toxic with high pH values (Doudoroff and Katz, 1950). During the winter and spring of 1968, pH values were typically in excess of 9. Merkins and Downing (1957) stated that the toxicity of ammonia is greatly increased with low dissolved oxygen tensions. High ammonia concentrations can also reduce oxygen tensions when ammonia is converted to nitrate.

It is possible that the trout used in this phase of the project had latent bacterial diseases, but fish of the same lot were introduced into a local pond where they thrived until summer. In December 1966, 17 trout from the same hatchery were stocked in pond B. These fish grew remarkably well and all but one were recovered the following spring.

Another series of Rainbow trout experiments was started in October 1968. All ponds were seined in January 1969, and two fish were recovered. Then rotenone, at 3 mg/l was used in ponds C and D. Of 350 fish originally stocked in four ponds, only three were recovered. Channel catfish stocked in ponds A and B were recovered during the seining operation. It is unlikely that predation by Channel catfish could account for the missing trout, since trout also disappeared from ponds C and D without catfish.

Tilapia

Predation probably played a significant role in *Tilapia* survival. When planted, fingerling *Tilapia* averaged about 4 cm. Only 71% of these fish survived in pond D with about 450 Channel catfish. In pond C, with 200 catfish, 86% of the *Tilapia* were recovered.

Finally, 94% survival was realized in pond B with only Tilapia present.

Basis for Fish Growth

Fish growth was outstanding in experiments that were not plagued with mortality. It was assumed that productivity would be high and that the fish would be presented with an abundance of forage organisms. Benthic and zooplankton standing crop measurements were taken for comparison with other waters. To further the comparisons and establish the magnitude of the food chain base, the phytoplankton productivity was measured.

Benthos

Benthic organisms were primarily responsible for supporting the fish populations. Stomach analysis revealed that all three fish species were competing for the same food organisms. The predominant benthic form, *Chironomus* larvae, was the most important fish food. Since *Chironomus* larvae are primary consumers, a short food chain existed and trophic efficiency was maximized.

Benthic biomass (standing crop) measurements tended to be higher when colder winter water temperatures slowed feeding and assimilation. Standing crop values were generally higher in ponds without fish (Hayne and Ball, 1956). In pond D, the mean standing crop was substantially lower than in all other ponds, primarily because dense populations of fish were present throughout the study. The high total accumulation of fish biomass in pond D suggests that the lower standing crop estimates were concurrent with a high turnover rate.

Owen (1956) found that tendipedid larvae averaged about 89% water. Using this ratio, the over-all mean standing crop value of 9.18 gm per m^2 in this study was converted to 834 Kg per hectare, wet weight. This exceeds by more than eight times the over-all average value from 255 lakes compared by Mrachek and Bachmann (1967). According to Hayne and Ball (1956), benthic fauna cropped by fish had an annual turnover rate about 17 times the mean standing crop in two southern Michigan lakes. Fish cropping tends to depress the standing crop of food organisms while the rate of their production increases. The turnover rate quoted by Hayne and Ball (1956) is based on an 150 day growing season. In the Tucson area, about 31° north latitude, the growing season lasts throughout the year, with a reduced rate apparent from December through March. In the present study, with intensive fish cropping and a longer growing season, a turnover rate greater than 17 would not be unreasonable. Using this turnover rate and the above mentioned standing crop values, the total benthic production was estimated at 14,180 Kg per hectare per year, wet weight. Hayne and Ball (1956) reported annual production of 811 Kg per hectare per year, wet weight, for southern Michigan lakes.

Zooplankton

Zooplankters were not important fish food organisms. Throughout most of the study, very small cyclopoid copepods were the dominant planktonic form. These copepods were too small to be cropped efficiently by the fish stocked. Corixids and ostracods were occasionally found in fish stomach samples.

The over-all mean zooplankton biomass (standing crop) was 0.92 gm per m^3. This is not outstanding when compared with natural waters in this area. Kemmerer et al. (1968) reported mean zooplankton biomass values of 2.42 and 3.7 gm per m^3 dry weight for Becker and Fool Hollow lakes, respectively. In four other eastern Arizona lakes considered by the same authors, the mean biomass values were less than 0.65 gm per m^3. In view of the coarser mesh net, #20 mesh, used by these authors, the standing crop estimates in the present study are even less significant.

Gross Primary Productivity

Primary productivity measurements were taken throughout the study as an indicator of the rate of organic matter synthesis and as an indicator of the magnitude of the food chain base. The average rate of gross photosynthesis for all ponds during the study was 10.2 gm O_2 per m^3 per day. This production is unusually high, but not particularly desirable.

In nearby ponds containing well water, Lewis (1969) measured gross photosynthesis during a similar period. He found an over-all mean evolution of 4.31 gm O_2 per m^3 per day. This production was not entirely planktonic, as an extensive rooted aquatic community existed in the ponds.

Kemmerer et al. (1968) reported 1.70 gm O_2 per m^3 per day for Fool Hollow Lake. This productivity, as in the present study, was attributable almost entirely to phytoplankton. Fool Hollow Lake receives domestic sewage and is generally considered polluted and highly productive. Of six other eastern Arizona impoundments considered by Kemmerer et al. (1968), only Pena Blanca Lake, with 2.90 gm O_2 per m^3 per day, exceeded Fool Hollow Lake. However, three-fourths of the productivity in this lake was due to benthic photosynthesis, a parameter of little importance in exceptionally fertile waters.

Fish Production

In natural waters in temperate regions the annual yield of all species present rarely exceeds 300 Kg per hectare per year. In this area, 225 Kg per hectare per year would be exceptional. Barnickal and Campbell (1952) reported annual yields from 20 to 300 pounds per acre (22.4 to 336 Kg per hectare) from a series of Missouri impoundments. McConnell (1963) stated that the yearly average harvest over a three year period from Pena Blanca Lake, Arizona, was 216 pounds per acre (243 Kg per hectare). In two Michigan lakes, Hayne and Ball (1956) reported a net production of 95.2 Kg per hectare. The preceeding three studies were concerned primarily with centrarchid fishes. The net fish production figures quoted in this study represent the actual weight increase experienced. Fish that were taken for stomach samples or accidently killed were also included in these figures, since it was assumed that they would have lived for the duration of the experiment. It is anticipated that with heavy fishing pressure and high stocking densities in future recreational lakes, harvest will approach the high rate of production experienced in this study.

Channel catfish

The net production of Channel catfish was 38.8 Kg in pond C and 54.1 Kg in pond D. Mean weights of fish comprising these totals were 204 and 130 gm for pond C and D, respectively. Although the yield was greater, most of the fish in pond D were considered unacceptable by local size standards. By expanding the total production of pond C, an annual figure of 383 Kg per hectare (343 pounds per acre) of acceptable fish was achieved. Such a high rate of production is rarely achieved in natural waters or even in artificially fertilized situations.

Unfed Channel catfish experiments in Kansas indicated that a net production of about 95 Kg per hectare per year of 109 gm fish is an optimum figure for that area (Simco and Cross, 1966). In the same study, yields were increased about 50% by adding organic and inorganic fertilizers.

Swingle (1958) reported Channel catfish were produced at rates up to 2,625 Kg per hectare per year (2,348 pounds per acre per year) with an intensive feeding program. These fish averaged 370 gm at the end of the 252 day experiment. The stocking density was 7,413 fish per hectare.

Tilapia

The differences in total yield found in the *Tilapia* experiments were small. Increases in total yield were inversely associated with the density of Channel catfish present, and directly associated with the percentage of *Tilapia* surviving. Interestingly, the largest

Tilapia (averaging 210 gm) were recovered from pond D with about 450 Channel catfish. Catfish growth was poor in pond D. Stomach analyses indicated that both species were relying on the same food organisms. This suggests that the Tilapia which survived initial catfish predation were dominant foragers. It would be reasonable to assume that the stocking density used was near maximum for the proposed fishery since the growth was adequate but not exceptional for the species and since the average size of Tilapia harvested was inversely related to the percent surviving. In pond C, 86% of the Tilapia planted survived. Since a realistic number of catfish were present, it is assumed that this experiment best represents what can be expected in future ponds. In pond C, the total yield of Tilapia was 40.3 Kg in a 5 to 6 month growing season. The fish comprising this yield averaged 190 grams. Upon expanding data from pond C, it is shown that Tilapia were produced at the rate of 397 Kg per hectare (356 pounds per acre) per year.

St. Amant (1966) reported that Tilapia hybrids in Lake 2 of the Santee Recreation Project survived only three months. The period of survival was from July 7, 1965 to September 8, 1965. Growing conditions during this period were comparable to those in the present study. Tilapia fingerlings, 0.17 gm (3.6 cm), were planted at 440 per hectare. The fish averaged only 58 gm when recovered. This weight increase is approximately one-third that experienced in the present experiments during a comparable period.

In natural waters in the Tucson area, McConnell (1965) reported unfed hybrids stocked as 1.9 cm fingerlings on May 1 reached 168 gm by September and 252 gm by November, with 75% survival. These fish were stocked at 1,483 per hectare. Fish were produced at roughly 280 Kg per hectare in a six month growing season.

Feeding experiments were also conducted by McConnell (1965). In mid April, 2.5 cm fingerlings were planted at 4,940 per hectare. The fish were fed cottonseed meal pellets at 3% of body weight per day. By October many fish weighing 280 to 338 gm were recovered. The highest harvest reported by McConnell (1966) was 861 Kg per hectare per growing season. This is a minimum figure since complete recovery was impossible.

At the Fish Culture Research Station, Malacca, *Tilapia* hybrids greater than 454 gm were produced at the rate of 1,341 Kg per hectare in six months, with no supplemental feeding. Phosphate at the rate of 44.7 Kg per hectare P_2O_5, as triple phosphate was added (Hickling, 1962).

Even without a trout fishery, the productivity, in terms of fish flesh produced, is outstanding in these waters. When the net production of 383 Kg per hectare of acceptable Channel catfish is added to 397 Kg per hectare of acceptable *Tilapia*, a total of 780 Kg per hectare per year (about 700 pounds per acre per year) results. Generally, such a high rate of fish production is achieved only with supplemental feeding. In comparison, the annual calculated production of all species at the Santee Project was only 400 pounds per acre (442 Kg per hectare), with pan fish less than 13 cm comprising much of this production (Merrell *et al.*, 1967).

Stocking and Acceptability

Of the three initial stocking densities used for Channel catfish, 2,471 fish per hectare (1,000 fish per acre) was the most satisfactory. At this density, Channel catfish reached about 25 cm in nine months. This was the minimum size acceptable by local standards. A reduction in stocking density would allow the growth of larger fish in less time. It is unlikely, but not impossible, that natural reproduction of Channel catfish would occur in future recreational ponds of this type. Additional recruitment would greatly alter the stocking densities and subsequent growth rate. For economical operation, fingerling Channel catfish should be planted initially at 2000 fish per hectare (800 per acre). Fingerling Channel catfish are generally available in the fall. Channel catfish are easily caught on worms and cheese, a locally popular bait. Project personnel and city employees ate some of these fish and the consensus was that they were comparable in eating qualities to catfish taken in natural waters.

Tilapia were stocked at 2,471 fish per hectare (1,000 fish per acre) in all experiments. At this rate, *Tilapia* reached 17 cm by July. Thus, the goal of acceptable fish in three months was achieved. In future recreation lakes where *Tilapia* are forced to compete with Channel catfish, it is suggested that fingerlings be released at 6 cm, or better, 8 cm, to increase the survival rate.

It is desirable to release fingerlings as early as possible because the Tucson area offers, at best, a six month growing season for *Tilapia*. By May 1, Tucson water temperatures should reach 19° C and be acceptable for *Tilapia*. Later introductions are unlikely to produce acceptable fish early enough to benefit the fishery. To produce hybrids in excess of 6 cm by May 1, adult fish should be bred no later than December 15.

Catching *Tilapia* with hook and line can be difficult because they bite lightly. The only satisfactory bait found was worms. *Tilapia* were eaten by city employees, project personnel, and members of the local press club. There was uniform agreement that they were an excellent food fish. They are one of the most palatable fish the author has ever eaten.

Under present conditions, Rainbow trout should be given no further consideration. Should the water quality be upgraded in future recreational lakes, 10 cm fingerlings may be planted at 1,853 fish per hectare (750 per acre). At this density, 18 cm fish should be available in three months. October 15 is a reasonable date for planting trout. By this date, water temperatures should have dropped to less than 21° C.

CONCLUSIONS

Both Channel catfish and *Tilapia* hybrids proved to be satisfactory and are recommended for use in future recreation ponds of this type. Both species generally survived and grew well at the selected densities. Their combined net production was about 780 Kg per hectare. This is a remarkable figure, since the fish were provided no supplemental food. Rainbow trout were incapable of surviving the waters provided. An important factor in trout mortality was oxygen depletion.

Fish were presented with an abundance of food throughout most of the year. It was estimated that the annual production of benthic organisms was 14,180 Kg per hectare. Zooplankton was found to be unimportant as fish food organisms. Although present in reasonable quantities, most zooplankters were too small to be utilized by these fish.

The high average rates of primary productivity measured in this study, 10.2 gm O_2 per m^3 per day, had both favorable and unfavorable effects. This rate of primary productivity provided a broad food chain base which supported extensive benthic and fish populations. However, associated with this productivity was an extreme range of dissolved oxygen tension. Low oxygen tensions were associated with fish kills.

To curtail primary productivity and help stabilize oxygen tensions, it is recommended that phosphate concentration be limited in the influent water of future recreational lakes to a level that will not provide more than 2.45 gm total phosphate per m^2 of lake habitat per year. Also it is recommended that the influent waters of these lakes should never exceed 0.30 mg/l total phosphate. This rate of fertilization was found to be satisfactory for similar ponds at the Antelope Valley Project.

The waters evaluated, although highly productive, cannot be expected to support a dependable fishery. The phosphate level in the water finally discharged from the fish ponds is still well above reasonable limits for a successful fishery.

It is recommended that Channel catfish be stocked at not more than 1,950 per hectare as 10 cm fingerlings. A reduction in density would provide larger fish in a shorter time. Tilapia hybrids greater than 6 cm should be planted at about 2,470 fish per hectare on or soon after May 1.

LITERATURE CITED

Barnickal, P. G., and R. S. Campbell. 1952. Summary of Selected Pond Studies in Missouri. J. Wild. Mgt., 16(3): 270-274.

Doudoroff, P., and M. Katz. 1950. Critical Review of Literature on the Toxicity of Industrial Wastes and Toxic Components to Fish. Sewage and Industrial Wastes, 22(11): 1432-1458.

Hart, W. B., P. Doudoroff, and J. Greenback. 1945. Evaluation of Toxicity of Industrial Wastes, Chemicals, and Other Substances to Fresh-Water Fishes. Water Control Lab., Atlantic Refining Co., Philadelphia, Pennsylvania. 317 pp.

Hayne, Don W., and Robert C. Ball. 1956. Benthic Productivity as Influenced by Fish Predation. Limnol. Oceanogr., 1(3): 162-175.

Hickling, C. F. 1962. Fish Culture. Faber & Faber, Ltd., London. 295 pp.

Kemmerer, Andrew J., Joseph Glucksman, Phillip A. Steward, and William J. McConnell. 1968. Some Productivity Relationships in Seven Fishing Impoundments in Eastern Arizona. Ariz. Acad. Sciences, 5(2): 80-85.

Lewis, Steven A. 1969. Some Effects of Mechanical Evaporation Barriers on Fish Growth and Pond Productivity. M.S. Thesis, Univ. Ariz., Tucson.

McConnell, William J. 1962. Productivity Relationships in Carboy Microcosms. Limnol. Oceanogr., 7(3): 335-343.

_____. 1963. Primary Productivity and Fish Harvest in a Small Desert Impoundment. Trans. Am. Fish. Soc., 92(1): 1-12.

_____. 1965. <u>Tilapia</u>, a Fish for Ranch Ponds. Progressive Agriculture in Arizona, 17(2): 3-4.

_____. 1966. Preliminary Report on the Malacca <u>Tilapia</u> Hybrid as a Sport Fish in Arizona. The Progressive Fish Culturist, 28(1): 40-46.

Merkins, J. C., and K. M. Downing. 1957. The Effect of Tension of Dissolved Oxygen and The Toxicity of Un-ionized Ammonia to Several Species of Fish. Ann. Appl. Biol., 45: 521-527.

Merrell, John C., William F. Jopling, Roderick F. Bott, Albert Katka, and Herbert E. Pintler. 1967. The Santee Recreational Project, Santee, California, Final Report. F.W.P.C.A. Publication No. WP-20-7. 165 pp.

Mrachek, Roger J., and R. W. Bachmann. 1967. Quantitative Studies of the Benthic Fauna of Clear Lake, Iowa. Iowa State J. of Sci., 42(2): 161-170.

Odum, H. T., Wm. J. McConnell, and W. Abbott. 1958. The Chlorophyll "A" of Communities. Publ. Inst. Mar. Sci., Univ. Texas, 5: 65-69.

Owen, J. B. 1956. Invertebrate Fish Food from Dredged and Undredged Portions of North Twin Lake. Unpubl. Ph.D. Thesis. Iowa State Univ., Ames, Iowa. 168 pp.

St. Amant, James A. 1966. Progress Report of the Culture of Tilapia mossambica (Peters) Hybrids in Southern California. Inland Fisheries Administrative Report No. 66-9. Calif. Department of Fish and Game, Sacremento. 25 pp.

Sawyer, Clair N. 1968. The Need for Nutrient Control. J. Water Pollution Control Federation, 40(3): 363-370.

Scarola, J. F., and J. H. Giberson. 1967. A Device for Sorting Bottom Organisms. The Progressive Fish Culturist, 29(4): 242.

Simco, B. A., and Frank B. Cross. 1966. Factors Affecting Growth and Production of Channel Catfish, Ictalurus punctatus. University of Kansas, Museum of Natural History, 17(4): 191-256.

Steel, Robert G. D., and James H. Torrie. 1960. Principles and Procedures of Statistics. McGraw-Hill, Inc., New York. xvi + 481 pp.

Stern, Gerald, and Franklin D. Dryden. 1968. Renovated Waste Water Creates Recreational Lake. Environmental Science and Technology, 2(4): 268-278.

Swingle, H. S. 1958. Experiments on Growing Fingerling Channel Catfish to Marketable Size in Ponds. Proc. 12th. Ann. Conf. S. E. Game and Fish Comm. 12: 63-72.

U. S. Department of Commerce, Weather Bureau. 1967a. Climatological Data, Annual Summary, 71(13).

______. 1967b. Climatological Data, National Survey, 18(13).