PRODUCTION OF THE THREADFIN SHAD, Dorosoma petenense (Gunther)[1]

By HUGH A. SWINGLE
Alabama Department of Conservation
Seafoods Division
Alabama Marine Resources Laboratory
Dauphin Island, Alabama

ABSTRACT

Adult threadfin shad, *Dorosoma petenense* (Gunther), were stocked alone in ponds at rates from 100 to 1,600 per acre to determine the most efficient rate of stocking for maximum production. Total production varied from 84.5 to 290.0 pounds per acre while net production ranged from 36.4 to 169.0 pounds per acre. The number of young per surviving parent varied from 1,392 at a stocking rate of 100 adults per acre to 82 young at a stocking rate of 1,600 adults per acre.

Threadfin shad stocked in April spawned from May (76°F) through August.

The net production of threadfin and gizzard shad, *Dorosoma cepedianum* (LeSueur) stocked at 200 per acre was 70.0 and 85.5 pounds per acre, respectively. Gizzard shad spawned 2 months before the threadfin and both species grew at the same rate.

Threadfin shad stocked together with other species gave varying results. Young-of-the-year shad were completely eliminated in one pond containing largemouth bass, *Micropterus salmoides* (Lacepede), and bluegill, *Lepomis macrochirus* Rafinesque.

INTRODUCTION

During recent years the threadfin shad has been widely introduced into states outside of its natural range as an additional forage species. It has been stocked primarily into large reservoirs in an attempt to increase the survival and growth of piscivorus game species. The effects of introducing threadfin shad have been poorly evaluated because of the difficulty in detecting and evaluating population changes within large reservoirs.

The purpose of this study was to determine if threadfin shad will provide adequate forage for piscivorus species when stocked in small ponds. This study was directed at the following objectives:

1. To determine the most efficient rate of stocking to obtain maximum production of young.
2. To determine if there is a prolonged spawning period during the summer and to what extent small threadfin shad are available during the growing season of piscivorous species.
3. To determine the growth rate of threadfin shad in ponds with different population densities and in ponds receiving fertilization and supplemental feeding.
4. To determine if threadfin shad can withstand predation in small ponds stocked with largemouth bass and bluegill.
5. To determine if threadfin shad can be used economically to provide the large amount of forage necessary for commercial production of piscivorous species.

Spawning

Threadfin shad spawn in the spring and early summer. In Oklahoma, Shelton (1964) found that rapid ovarian development began in March

[1] This article is based on a thesis submitted to the Graduate Faculty of Auburn University, Auburn, Alabama on March 16, 1967.

when the water temperature was 53.4°F and spawning began in mid-April at a temperature of 67°F reaching a peak by mid-May when the water temperature averaged 75°F. He found that threadfin shad retain eggs in various stages of development throughout most of the spring and summer and those that spawn in the early spring may spawn again in July. He also showed that young shad hatched in early spring were also capable of spawning by July. Kimsey *et al.* (1957) reported two spawning periods for threadfin shad in California—one in May followed by another in September when both adults and young may spawn. Beers (1965) and Hida and Thompson (1962) reported that spawning takes place repeatedly during the summer and that small shad are available for forage throughout the summer. Anderson (1966) found that threadfin shad spawn from April to June in Kentucky and that the optimum spawning temperature was from 68-75°F. Rawstron (1964) observed spawning threadfin shad in California when the water temperature was 58°F.

McConnell and Gerdes (1964) in studies at Pena Blanca Lake, Arizona, found that threadfin shad had only one short spawning period in mid-May, and that in some years they may fail to form a successful year class. They found no evidence of spawning by young shad after the first year of introduction. Burns (1966) reported that a 4-inch threadfin shad may have from 6,700 to 12,400 eggs. Kilambi and Baglin (1969), counting only mature ova, calculated regression equations of fecundity based on both total length and weight. One 6-inch specimen taken in May contained approximately 22,000 mature ova.

Growth

In Lake Havasu, California, threadfin shad grew at the rate of about one inch per month until reaching three inches. At the formation of the first annulus lengths range from 1.8 to 3.4 inches (Burns, 1966). Few attain an age of over two years or lengths over seven inches (Parsons and Kimsey, 1954).

Diet

Threadfin shad feed on both phytoplankton and zooplankton. Miller (1961) found that utilization of plant and animal matter was about equal and listed protozoa, microcrustacea, and several genera of Chlorophyta and Chrysophyta as the most important food items. Beers (1965) listed nonfilamentous green algae and rotifers as the most important organisms in the gut of threadfin shad, and organic debris as most abundant on a volumetric basis. Large threadfin shad feed extensively near the bottom as evidenced by the amount of organic debris and sand found in the digestive tract (Haskell, 1959; Miller, 1961). However, Strawn (1965) reported that small threadfin shad did not feed near the bottom and that large shad are not predominantly bottom-feeders.

Temperature tolerance

Temperature tolerance of the threadfin shad is the most important limiting factor in establishing populations outside of its natural range (Domrose, 1963). Temperatures below 41°F are usually fatal to threadfin shad (Parsons *et al.*, 1954; Strawn, 1965).

The success of establishing threadfin shad outside its natural range has been varied. In more northern states introductions have not been successful (Anderson, 1966; Bruce, 1961; Minckley *et al.*, 1960). In Virginia threadfin shad had to be restocked annually because of winter die-off (Domrose, 1963).

In the South and West there have often been tremendous population expansions of threadfin shad where they were introduced. In 1954, 1,020 threadfin shad were introduced into Lake Havasu, California. Eighteen months later threadfin shad had populated the entire Colorado River from Davis Dam southward to the Mexican border, related irrigation canals, and the Salton Sea (Kimsey *et al.*, 1957).

Threadfin shad were stocked into Lake Martin, a 40,000-acre reservoir in central Alabama, in August, 1957 (Alabama Dep. Conserv. Annu.

Rep., 1957-1958). A total of 575, 3-inch threadfin shad were stocked at two sites in the reservoir. In a population study made on October 2, 1958, eight and 14 miles, respectively, from the two stocking sites a total of 6,077 threadfin shad weighing 44.6 pounds per acre was recovered. If this acre were representative of the entire reservoir the progeny of the original 575 threadfin shad, after 13 months, numbered 243 million weighting 1.784 million pounds.

Food for piscivorous species

Threadfin shad contribute an important percentage of the food consumed by the major piscivorous game species (Table 1).

TABLE 1. The importance of threadfin shad in the diet of major game species, expressed in per cent volume of stomach contents

Species	Per Cent Volume	Location	Reference
Largemouth Bass			
Micropterus salmoides (Lacepede)			
under 6.0 inches	72.5	California	Goodson (1965)
6.0-9.9	82.2	"	"
above 10.0	66.5	"	"
3.3-7.7	33.0	Arizona	McConnell *et al.* (1964)
6.5-11.9	49.6	Kentucky	Anderson (1966)
above 12.0	67.9	"	"
Spotted Bass			
Micropterus punctulatus (Rafinesque)			
6.5-11.9 inches	47.2	Kentucky	Anderson (1966)
above 12.0	47.0	"	"
Black Crappie			
Pomoxis nigromaculatus (LeSueur)			
2.8-7.8 inches	17.0	Arizona	McConnell *et al.* (1964)
9.4-14.6	90.0	"	Beers (1965)
6.0-9.9	76.0	California	Goodson (1965)
above 3.9	[1] 91.0	Florida	Reid (1950)
7.0-14.0	53.9	"	Huish (1958)
2.0-14.0	74.3	Florida	Huish (1958)
Striped Bass			
Roccus saxatilis (Walbaum)			
8.0-10.0 inches	45.0	California	Goodson (1964)
21.0-24.0	94.0	"	"
Channel Catfish			
Ictalurus punctatus (Rafinesque)			
above 5.0 pounds	[1/2] 5.4	South Carolina	Stevens (1959)
White Catfish			
Ictalurus catus (Linnaeus)			
above 8.0 inches	32.5	California	Goodson (1965)
13.0	[1/2] 18.6	South Carolina	Stevens (1959)

1 Includes both threadfin and gizzard shad.
2 Per cent occurrence by numbers.

Threadfin shad provided 100 per cent of the food of sauger, *Stizostedion canadense* (Smith) in a steam plant effluent where shad had congregated during the winter in a Tennessee Reservoir (Dryer and Benson, 1957). Threadfin shad contributed 57 per cent of the food consumed by large bluegill, *Lepomis macrochirus* Rafinesque, during the winter in one California lake (Goodson, 1965).

Threadfin shad constitute a larger percentage of the diet of fish during the fall and winter months than at other times of the year. In the spring chironomid larvae and pupae, mayfly nymphs, cladocerans, and other organisms surpass shad in importance (Beers, 1965; Goodson, 1965; Reid, 1950; Stevens, 1958).

The introduction of threadfin shad is thought to be responsible for increased success in fall trout fishing in Philpott Reservoir and crappie and bass fishing in Claytor Lake, Tennessee (Domrose, 1963). Beers (1965) noted an increase in size of black crappie in Roosevelt Lake, Arizona after the introduction of threadfin shad. Following introduction of threadfin shad into Lake Martin, Alabama there was a significant increase in the average weight of spotted bass and an increase in the standing crop of channel catfish, bluegill and other sunfish (Auburn Univ. and Ala. Dep. Conserv., 1960). Strawn *et al.* (1962) found that the numbers of crappie and largemouth bass caught during one year that threadfin shad were especially abundant were lower than in other years. There was also some indication that the growth rate of largemouth bass was lower during the presence of threadfin shad. There is some evidence that threadfin shad compete with and decrease the growth rate of Centrarchids (McConnell *et al.*, 1964) and smallmouth buffalo, *Ictiobus bubalus* (Rafinesque) (Beers, 1965). In Pena Blanca Lake, Arizona threadfin shad failed to provide adequate forage for yearling largemouth bass and black crappie because of a single short spawning period in May followed by rapid growth (McConnell *et al.*, 1964).

METHODS

Experimental fish

On April 25, 1965, 648 threadfin shad were collected from Chewacla Creek, a tributary of the Tallapoosa River, and transported to experimental ponds of the Farm Ponds Project at Auburn University. The other source of threadfin shad in 1965 was the Tallapoosa River near Tallassee, Alabama. On May 11 and 14, 195 and 70 threadfin shad, respectively, were collected and transported to the experimental ponds at Auburn University.

All threadfin shad used in 1966 experiments were obtained from the Coosa River below the dam of Lake Jordan. On May 23-24, 1,102 threadfin shad were taken from this location.

The 208 gizzard shad used in 1966 experiments were collected from Chewacla Creek, near Auburn, Alabama, on March 23, 1966.

Shad were transported to the ponds at Auburn in aluminum tanks filled with water and aerated with compressed oxygen. Tricaine methanesulphonate (MS-222) at a concentration of 1 gram per 12 gallons of water and 0.5 per cent salt (Collins and Hulsey, 1963) was used to reduce mortality. Mortality over distances of 5, 35, and 70 miles was 9, 4, and 9 per cent, respectively, when using salt and the anesthetic. Mortality over a 5-mile distance was about 90 per cent when neither salt nor MS-222 was used.

Experimental ponds

E - and F - Ponds

The E-series ponds are 1.0-acre earthen ponds with average depths of about 4 feet and maximum depths of 8 feet. These ponds are supplied with stream water that is filtered through a saran mesh screen to prevent the entrance of unwanted fish.

The F-series ponds are 0.25-acre earthen ponds with average depths of about 4 feet and maximum depths of 6 feet. The water supply is the same as that for the E-series. Both E- and F-series ponds are drained by a 4-inch diameter standpipe.

Fecundity

The numbers of eggs from 6 threadfin shad collected from Chewacla Creek on April 25, were estimated and are presented in Table 2. Both ovaries were removed from each fish and weighed to the nearest 0.01 gram. Three random transverse sections were then cut from each ovary, weighed to the nearest 0.01 gram, and the number of eggs counted in each section. The estimated total number of eggs contained in each ovary was obtained by multiplying the total ovary weight by the number of eggs per gram of section.

Shad stocked into a pond on April 25 did not spawn until mid-May so it is presumed that the numbers of eggs per female found here is typical of threadfin shad prior to spawning.

TABLE 2. Estimated number of eggs from threadfin shad collected on April 25, 1965

Total Length inches	Weight grams	Ovary Weight grams	Ovary as % Body Weight	Estimated Total No. of Eggs	Eggs per Gram of Ovary
6.6	42.21	2.92	6.92	14,860	5,089
6.7	40.28	0.93	2.31	16,770	18,032
6.7	43.46	1.56	3.59	15,845	10,157
6.9	45.05	2.72	6.04	18,850	6,930
6.9	56.49	7.65	13.54	46,720	6,107
7.0	52.10	2.00	3.84	20,840	10,420
6.8	46.60	2.86	6.04	22,314	9,456

Fertilization and supplemental feeding

Two 0.25-acre ponds were stocked with equal numbers of threadfin shad to determine if supplemental feeding can be used to increase the production of threadfin shad. F-565 was stocked with 1,000 threadfin shad (5-7") per acre on May 11, 1965 and received a total of 150 pounds of triple superphosphate per acre from February to September, 1965. Seining checks were begun on May 12 and threadfin shad fry were found on May 19 when the water temperature was 76.0°F. at a depth of 6 inches. Seining samples taken at approximate 2-week intervals until September indicated that there was only one major spawning period, beginning in the second week of May and ending by the first week of June. By September 13 the young shad were in the 1-, 2-, and 3-inch groups with 90 percent being 2-inch fish. When the pond was drained on November 5, 1965, the threadfin shad still remained in those inch groups and 94 per cent were 2-inch fish. Threadfin shad grew little, if at all, between September and November. The brood fish were 5 to 7 inches when stocked on May 11. When the pond was drained approximately 6 months later these fish were still 5 to 7 inches except for one that had reached 8 inches. The survival of brood fish was 46.8 per cent. It is assumed that the mortality occurred shortly after stocking as a result of handling although no dead, or dying shad were observed at any time after being released into the pond.

The standing crop 178 days after stocking was 121.2 pounds per acre with a net production of only 36.4 pounds per acre. The 36.4 pounds of threadfin shad cost $0.11 per pound after considering the cost of fertilization. The number of young shad present when the pond was drained was 46,440 per acre.

F-1565, stocked with 1,000 threadfin shad per acre on April 25, received a total of 2,848 pounds of Auburn No. 2 pelleted feed from April

27 to November 2, 1965. These fish were 5 to 7 inches in length and 47 per cent were females. Seining checks were made weekly from April 27 to May 19. Threadfin shad fry were found on May 19, the same day they were found in F-565. Seining at approximate 2-week intervals until November showed fry to be numerous throughout the summer. An increase in the number of fry found on June 15 may indicate the second spawning peak reported by other authors. The bi-modal length frequency (Figure 1) of a sample of young shad taken when F-1565 was drained on February 2, 1966, also indicates two major spawning peaks. The normal distribution of lengths of young shad from F-565 shows only one major spawning peak. The size difference of young shad from F-565 and F-1565 was not due to supplemental feeding but resulted from differences in draining dates.

Measurements of young shad taken in samples from F-565 and F-1565 are presented in Table 3. Until June 15 the mean lengths of shad from the pond receiving supplemental feed were longer than those taken from F-565. After the spawning period in June in F-1565 small shad were more abundant in this pond than in the pond receiving fertilization, and consequently, depressed the mean lengths of shad collected until September. The presence of shad less than 20mm in length in both ponds until mid-July showed that some spawning occurred throughout most of the summer. The maximum sizes of shad collected from both ponds from May to September were not different so apparently the addition of supplemental feed does not add materially to the growth of young shad, but may contribute to the growth of adult shad resulting in multiple spawning periods.

The standing crop in F-1565, 283 days after stocking, was 181.8 pounds per acre. A total of 2,848 pounds of Auburn No. 2 feed was used per acre at a cost of $0.05 per pound. The net production of threadfin shad was 108.6 pounds per acre costing $1.31 per pound. Survival of adult threadfin shad was 57.6 per cent. The standing crops and net productions are not comparable between F-565 and F-1565 because of different draining dates; however, the number of young produced in each pond should be comparable as no spawning occurred between the time F-565 and F-1565 were drained. The number of young shad present when F-1565 was drained was 28,004 compared to 46,440 in F-565. The reason there were fewer young shad in the pond receiving supplemental feeding than in the pond receiving fertilization is unknown. Seining checks made in both ponds showed shad to be more abundant in the fed pond during the summer and fall. There was a 3-month difference in draining dates and evidently natural mortality during November, December, and January severely reduced the population in the fed pond.

TABLE 3. Mean and range of lengths of threadfin shad from a fertilized and a fed pond [1]

	Fertilized Pond (F-565)			Fed Pond (F-1565)		
Date	Number	Range in mm	Mean	Number	Range in mm	Mean
May 19, 1965	5	13-15	14.2	10	15-18	16.1
May 26	..	....	...	54	15-22	17.8
June 4	18	17-21	18.4	30	15-34	23.3
June 15	35	20-28	24.3	45	18-29	22.1
June 21	28	16-36	27.3	60	19-34	25.0
July 12	65	19-35	29.1	74	18-36	24.7
August 9	59	27-54	32.7	71	22-57	29.8
September 13	61	31-47	39.3	78	24-50	34.3

1 Fry first were found on May 19 in both ponds.

Various rates of stocking

Two 1.0-acre and two 0.25-acre ponds were stocked at different rates to determine the optimum stocking rate. These ponds were stocked on May 23-24, 1966, with 100, 200, 800, and 1,600 adult threadfin shad per acre, respectively, and fertilized with equal amounts of triple superphosphate.

E-266, stocked with 100 threadfin shad per acre on May 23, was drained on October 21, 1966. Eggs were found on floating grass in the pond on June 1 and on a spawning mat on June 17. Fry were found first on June 17 and were abundant as late as August 16.

E-366, stocked with 200 threadfin shad per acre on May 23, was drained on October 25, 1966. Eggs and fry were found on June 17. The last date fry were found was August 1.

F-366, stocked with 800 threadfin shad per acre on May 24, was drained October 18, 1966. Eggs were found on floating grass on June 1 and fry were found on June 17. The last date fry were found was on August 16.

F-1566, stocked with 1,600 threadfin shad per acre on May 24, was drained on October 18, 1966. Eggs were found on June 1 and fry on June 17. Fry were found last on August 31.

Population statistics from the four ponds are compared in Table 4. The numbers of young produced per acre at first appear to be little related with stocking density; however, when the numbers of young shad are placed on a young-per-parent basis it becomes obvious that spawning was depressed at the higher stocking rates. In Figure 2 this relationship is graphically demonstrated. Because the time of mortality of the adult shad could not be established the actual number of surviving parents, and not the number of parents stocked, is used in this relationship. The greatest mortality most likely occurred very soon after stocking as a result of handling and probably the majority died prior to spawning.

The first, second, and third degree polynomial equations were computed from the observed number of young threadfin shad per parent from the four ponds drained in 1966.

TABLE 4. Population statistics from ponds stocked at rates of 100, 200, 800, and 1,600 threadfin shad per acre

	Location			
	E-266	E-366	F-366	F-1566
Number stocked per acre	100	200	800	1,600
Date stocked	5-23-66	5-23-66	5-24-66	5-24-66
Date drained	10-21-66	10-25-66	10-18-66	10-18-66
Number days in experiment	151	155	147	147
Total production (lb./acre)	176.2	84.5	152.0	290.0
Net production (lb./acre)	169.0	70.0	88.0	162.0
Number of young produced/acre	93,253	48,974	54,510	96,431
No. of surviving parents/acre	67	138	556	1,172
No. of young/surviving parent	1,392	355	98	82

and one pond, F-565, drained in 1965. Only the linear and quadratic equations were significant ($P < .010$) and are presented below:

Linear $Y = -96.58 + 93{,}059.58X$

Quadratic $Y2 = 91.53 - 11{,}084.32X + 6{,}579{,}353.38X^2$

Where $X = 1/\text{number of surviving parents per acre}$ over a range of 67 to 1,172 parents per acre and $Y =$ number of young per parent.

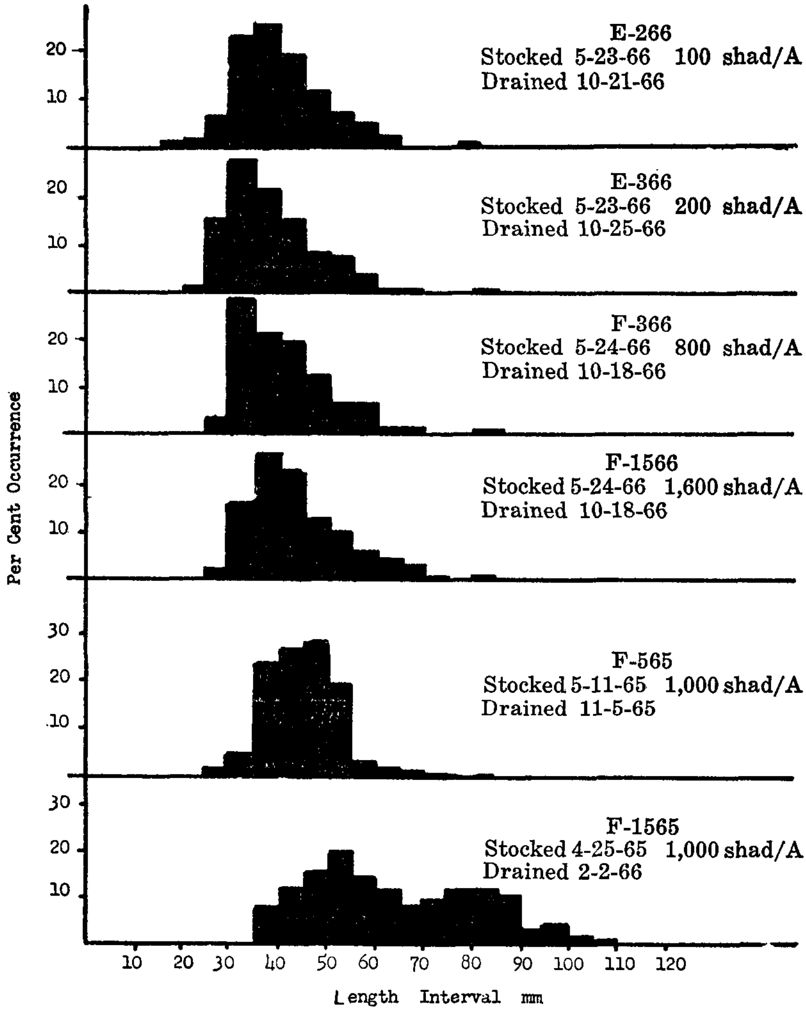

Figure 1. Length distributions of young-of-the-year threadfin shad taken after draining six ponds.

While the standing crop of shad varied from 84.5 to 290.0 pounds per acre there was no apparent difference in the rate of growth of the young shad. Figure 1 is the length distribution of young threadfin shad taken when four ponds stocked at different rates were drained.

Comparison of length distributions among these populations shows little difference in growth of threadfin shad at population densities of 85 to 290 pounds per acre.

Threadfin shad with flathead catfish fry

E-765 was stocked with threadfin shad (664/A) on April 28, 1965, and flathead catfish (2,000/A) on June 2, 1965 to determine if threadfin shad would provide adequate forage for commercial production of flathead catfish. The pond received a total of 1,610 pounds Auburn No. 2 feed

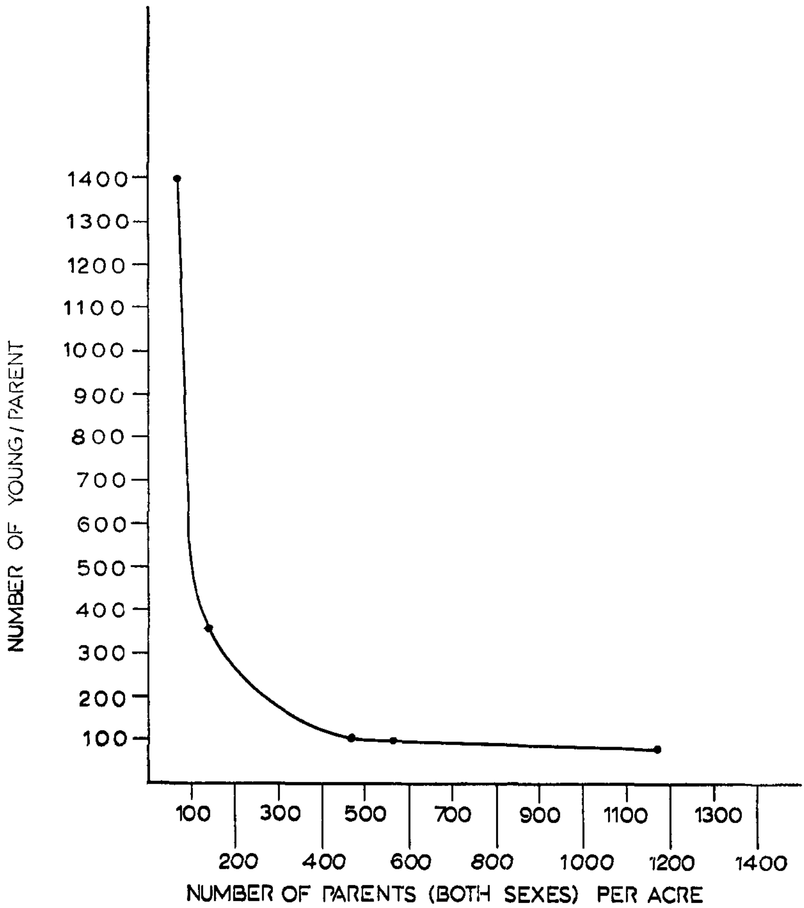

Figure 2. Number of Young Threadfin Shad Per Parent at Five Stocking Rates.

per acre at a cost of $80.50. Threadfin shad fry were found on May 26, 1965 and were found as late as August 11. The pond was drained on February 7, 1966. The standing crops of threadfin shad and flathead catfish were 107.6 and 47.5 pounds per acre, respectively. The net production of flathead catfish was 47.3 pounds per acre costing $1.70 per pound considering only the cost of feed used. Only 170, or 8.5 per cent, of the 2,000 flathead catfish were recovered. Lengths of these fish ranged from 5 to 11 inches and none were of a harvestable size.

The F/C ratio [2] and Y/C ratio [3] were 2.27 and 1.52 respectively. Both

[2] The F/C ratio is the total pounds of all sizes of forage species per pound of piscivorous species.

[3] The Y/C ratio is the total pounds of small forage species per pound of piscivorous species. It includes only the weight of forage species small enough to be eaten by the average size piscivorous species.

ratios are the lower limits of the desirable range of prey-predator ratios reported by Swingle (1950).

On February 3, 1966, the temperature at Auburn, Alabama dropped rapidly to a minus 3°F. and ice formed approximately 3 inches thick on the pond surface. It was believed all threadfin shad had been killed by the low temperature and the pond was drained as soon as most of the ice had melted. About 20 pounds of the total 106.8 pounds of threadfin shad were still alive when the pond was drained after having been covered with ice for 4 days.

During 1965 an undetermined number of small threadfin shad entered the adjacent pond, E-865, through a hole in the dam separating the two ponds. This pond had been stocked per acre with 1,000 bluegill, 1,000 fathead minnows, and 100 spotted gar, *Lepisosteus oculatus* (Winchell), in the spring of 1965. When the pond was drained on October 6, 1966, 22,231 bluegill, 103 fathead minnows, 75 spotted gar, and 594 threadfin shad were recovered per acre. The threadfin shad ranged in length from 1 to 5 inches and included the following numbers:

Inch Group	*Number*
1	1
2	7
3	87
4	234
5	265

Shad from a random sample of the 4 - and 5-inch fish were aged and found to be from the 1965 year-class and it is assumed that all 499 had entered the pond from E-765 in 1965. The remaining 95 were the only progeny recovered from the 499 adult shad.

Threadfin shad with largemouth bass and fathead minnows

F-266 was stocked on May 23, 1966, with 400 adult threadfin shad per acre weighing 28.9 pounds. On June 3, 1966, 100 3-inch largemouth bass weighing 1.0 pound and 1,000 fathead minnows weighing 6.8 pounds were stocked per acre. The pond received 15 pounds of triple superphosphate per acre each month from May to September. A total of 75 pounds of fertilizer was used per acre costing $2.48.

Threadfin shad fry were found on June 17 and were found as late as August 1. Fathead minnow fry were found on June 1 and were very abundant. By August no fathead minnows were found in seine samples and when the pond was drained on September 28, 1966, only 0.64 pound of fathead minnows was present per acre.

The survivals of threadfin shad and largemouth bass were 28 and 88 per cent, respectively. Standing crop of threadfin shad was 69.6 pounds per acre. The net production of largemouth bass was 37.0 pounds per acre and 21.5 pounds, or 58.1 per cent, were of a harvestable size of 0.4 pound or larger.

The F/C and Y/C ratios were 2.3 and 1.7, respectively. These ratios are in the lower limits of the desirable range (Swingle, 1950). The largemouth bass were large enough to prey upon the adult threadfin shad and could have possibly reduced their numbers to a point where reproduction would be reduced the following spring.

Threadfin shad with largemouth bass, bluegill, and fathead minnows

Largemouth bass and bluegill are the most important species used to provide sport fishing in managed ponds in the Southeast. Fathead minnows are sometimes included to provide additional forage for largemouth bass.

The objective of this experiment was to determine the value of threadfin shad as an additional forage species in a largemouth-bass-bluegill-fathead minnow combination. An additional source of forage could conceivably permit the use of higher stocking rates of largemouth bass or increase their rate of growth.

F-665, was originally scheduled to be used in other experiments so it was not stocked with threadfin shad until June 29, 1965. The average weight of ovaries from these shad was significantly less than those stocked in other ponds in April and it is assumed that these shad had begun to spawn prior to being stocked in F-665. The pond was stocked per acre with the following species:

Species	*Date*	*Number*	*Pounds*
Fathead minnows	January 7, 1965	1,000	1.6
Bluegill	January 8, 1965	1,500	2.0
Largemouth bass	June 25, 1965	140	8.8
Threadfin shad	June 29, 1965	500	36.0

F-665 received a total of 150 pounds of triple superphosphate per acre from February to September 1965, costing $4.98 per acre. The pond was drained on February 9, 1966.

Small threadfin shad were first found on August 27 when they were 1 inch in length. Since no fry were ever found in this pond it is assumed that either shad spawned only once, in late July, or that predation by bluegill and largemouth bass was sufficient to eliminate most of the small threadfin shad soon after hatching.

Small bluegill were very abundant from June until the pond was drained in February. Fathead minnows were less abundant and few fry were found in seine samples. No fathead minnows were found after August 9 and when the pond was drained only 0.30 pound of fathead minnows was recovered per acre. One-and 2-inch threadfin shad were numerous in samples taken in August and the first week of September. When the pond was drained all small shad had been eliminated and only 16.8 pounds of the original stock of adult shad was recovered. The total weight of all fish when the pond was drained was 275.4 pounds per acre of which 41.8 per cent was composed of fish of harvestable size. The F/C and Y/C ratios were 1.75 and 0.66, respectively. Both values are in the range characteristic of ponds with overcrowded piscivorous species and indicate that the forage species are disappearing due to predation (Swingle, 1950).

The survivals of brood threadfin shad and largemouth bass were 32.8 and 100 per cent, respectively. All of the largemouth bass had attained harvestable size in 229 days and weighed an average of 0.71 pound. These bass averaged 11 inches in length and were large enough to have eliminated the 4-and 5-inch brood shad. Only 6- and 7-inch brood shad were recovered when the pond was drained in February.

Gizzard shad production

Threadfin shad, together with the gizzard shad, *Dorosoma cepedianum* (LeSueur), are numerous in the river systems of the Southeast and may constitute more than 50 per cent of the total weight of all species present (Fetterolf, 1957; Phillippy, 1967; Swingle, 1954). Population studies conducted in the rivers and impoundments of Alabama since 1949 have added much to the knowledge of the relative abundance of these two species. Average pounds per acre and average E-values (percent of the total weight of all species attributed to one species) of threadfin shad and gizzard shad taken from 146 population studies in Alabama are summarized in Table 5.

These data show that where threadfin shad and gizzard shad occur together in both rivers and impoundments the latter species is predominant. It is also worthy of note that both species appear more suited to reservoirs where they become more numerous and constitute a larger percentage of the standing crop of all fishes present.

TABLE 5. Relative abundance of threadfin shad and gizzard shad in Alabama rivers and impoundments [1]

	Years	Number of samples	Threadfin Shad Avg. lbs. per acre	Threadfin Shad Avg. E-value	Gizzard Shad Avg. lbs. per acre	Gizzard Shad Avg. E-value
Rivers	1950-1963	40	9.2	1.01	42.6	5.89
Impoundments	1949-1960	106	44.1	9.72	208.4	41.51

Gizzard shad were stocked at a rate of 208 adults per acre on March 23, 1966 to compare production and rate of growth with threadfin shad stocked at a similar rate. Both ponds received equal fertilization.

Gizzard shad eggs were found on the spawning mat on April 7, 1966, when the water temperature was 60°F. The first small gizzard shad were not found until May 10 at which time they averaged 1 inch in length. Fry were later found on May 26 and June 7.

The young of gizzard shad and threadfin shad grew at approximately the same rate (Table 6).

TABLE 6. Average lengths of young threadfin shad and gizzard shad at various times after finding eggs on spawning mats

Days	Threadfin Shad [8] Length (mm)	Gizzard Shad Length (mm)
42	28.9	28.1
61	29.1	29.3
91	30.9	32.8
110	34.9	34.9
146	35.9	39.2

Population statistics from F-666 and E-366 are compared in Table 7. While the standing crop of gizzard shad was over twice that of threadfin shad, the net production of both species was approximately equal. There were significant differences in both the survival of adult brood fish and in the number of young produced for the two species. Gizzard shad fry were found as late as June 7 indicating an extended spawning period similar to that of the threadfin shad.

TABLE 7. Comparison of population statistics from two ponds stocked with gizzard and threadfin shad

	Threadfin Shad	Gizzard Shad
Number stocked per acre	200	208
Pounds stocked per acre	14.5	93.7
Date stocked	5–23–66	3–23–66
Date drained	10–25–66	10–19–66
Number of days in experiment	155	210
Standing crop when drained (lb./acre)	84.5	179.2
Net production (lb./acre)	70.0	85.5
Per cent survival of adults	72.0	98.1
Number of young per acre when drained	48,974	14,008
Average length of young when drained	1.5in.	2.4in.

CONCLUSIONS

It is apparent from the reproduction curve (Figure 2) obtained from 5 ponds stocked at different rates of threadfin shad in 1965 and 1966 that

[1] Data from Auburn University Agricultural Experiment Station Fisheries Research Annual Reports, 1949-1963.

[8] Threadfin shad eggs found on June 1.

the optimum stocking rate is 100 or less per acre. Densities of adult threadfin shad of 67 and 1,172 per acre resulted in 93,253 and 96,431 young per acre, respectively. The number of young per parent at parent densities of 67 and 1,172 was 1,392 and 82, respectively. The higher rate of stocking is obviously an inefficient utilization of brood stock. The lower rate of stocking is more efficient but may not be the most efficient use of adult shad.

When adult threadfin shad were stocked on April 25 fry were found on May 19. These fry were 14mm. long and could not have been more than several days old. Spawning apparently occurred during the second week of May when the water temperature was about 76°F. In other ponds eggs were found on spawning mats on June 1, 17, 22 and on July 12, 1966. Spawning mats became covered with silt by midsummer and no eggs were found on them later than July. Seining with ⅛-inch mesh seines showed that fry were present during the summer months and until about the second week of August.

The rate of growth of threadfin shad is slow in ponds with population densities of 70 to 290 pounds per acre. Shad hatched in May and the first week of June reached a maximum size of 3 inches by mid-October; however, the majority of shad were 1- and 2-inch fish. When threadfin shad were stocked alone, there was no apparent difference in the rate of growth at different population densities.

Pelleted feed was apparently not utilized by small shad, but may have contributed to the growth and spawning frequency of the adult fish. However, the benefits from supplemental feeding did not justify the cost. The cost per pound of threadfin shad ranged from $1.34 with feeding to $0.02 with fertilization only.

Threadfin shad stocked together with flathead catfish fry produced low standing crops of both species, 108 and 48 pounds per acre, respectively. Even with additional supplemental feeding the survival of flathead catfish was only 8.5 per cent. The F/C and Y/C ratios were in the lower limits of the desirable range of prey-predator ratios.

Threadfin shad stocked with largemouth bass and fathead minnows also gave low F/C and Y/C values. The young fathead minnows were eliminated from the pond and the standing crop of shad was only 70 pounds per acre. The largemouth bass grew large enough to prey on the adult shad and only 28 per cent of the adult shad were recovered when the pond was drained. It would appear doubtful that threadfin shad would have provided forage after the bass had spawned the following year.

When shad were stocked with bluegill, largemouth bass, and fathead minnows young-of-the-year shad and fathead minnows were both eliminated from the population. No fathead minnows were found after August and shad were absent after September. The largemouth bass grew from a length of 3 inches in June to 11 inches in February and averaged 0.71 pound. Shad added materially to the rate of growth of the largemouth bass but could not withstand predation by both bass and bluegill.

LITERATURE REVIEW

Alabama Department of Conservation. 1959. Annual Report 1957/1958, pp. 113-115.

Anderson, Jon K. 1966. Fish investigations. Kentucky Fish and Wildl. Dep., D-J Fed. Aid Proj. F-26-R1.

Auburn University Agricultural Experiment Station and Alabama Department of Conservation. 1960. Effect of threadfin shad on fish populations in Lake Martin. Auburn Univ., Spec. Rep., Oct., 75 pp. (Mimeo.).

Auburn University Agriculture Experiment Station. (unpublished). Fisheries Research Annual Reports. 1946-1966.

Beers, Gary D. 1965. Effects of a threadfin shad introduction upon black crappie and smallmouth buffalo populations in Roosevelt Lake. M. S. Thesis. Univ. Ariz. 35 p.

Berry, Frederick H., Melvin Huish, and Harold Moody. 1956. Spawning mortality of the threadfin shad, *Dorosoma petenense*, in Florida. Copeia 1956 (3) :192.

Bodola, Anthony. 1966. Life history of the gizzard shad, *Dorosoma cepedianum* (LeSueur), in western Lake Erie. U. S. Fish and Wildl. Ser. Fish. Bull. 65(2)391-425.

Bruce, James R. 1961. Experimental introduction of the threadfin shad into small impoundments. Ariz. Dep. Game and Fish, D-J Fed. Aid Proj. F-7-R-4. 2 p.

Burns, James W. 1966. Threadfin Shad *In* Inland Fisheries Management edited by Alex Calhoun. Calif. Dep. Fish and Game. pp. 481-488.

Cole, C. F., J. Trenary, and S. Finkelstein. 1958. Experimental introduction of threadfiin shad. Ark. Game and Fish Comm., Annu. Rep.

Collins, James L., and Andrew H. Hulsey. 1963. Hauling mortality of threadfin shad reduced with M. S. 222 and salt. Prog. Fish-Cult. 25(2) : 105-106.

Domrose, Robert J. 1963. Evaluation of threadfin shad introductions. Va. Comm. Game and Inland Fish., D-J Fed. Aid Proj. F-5-R-8. 8 p.

Dryer, William, and Norman G. Benson. 1957. Observations on the influence of the new Johnsonville steam plant on fish and plankton populations. Proc. Ann. Conf. Southeast. Assoc. Game and Fish Comm. 10:85-91.

Fetterolf, Carlos M. 1957. Stocking as a management tool in Tennessee reservoirs. Proc. Ann. Conf. Southeast. Assoc. Game and Fish Comm. 10:275-284.

Goodson, Lee F. 1964. Diet of striped bass at Millerton Lake, California. Calif. Fish and Game. 50(4) :307.

.... 1965 Diets of four warmwater game fishes in a fluctuating, steep sided California reservoir. Calif. Fish and Game. 51(4) :259-269.

Hanson, Willis D. 1963. Acclimation and utilization of the threadfin shad. Missouri Cons. Comm. D-J Fed. Aid Proj. F-1-R-11 and 12. 10 p.

Haskell, William L. 1959. Diet of the Mississippi threadfin shad, *Dorosoma petenese atchafalayae*, in Arizona. Copeia 1959(4) : 298-302.

Hida, Thomas S. and Donald A. Thompson. 1962. Introduction of the threadfin shad to Hawaii. Prog. Fish-Cult. 24(4) : 159-163.

Hubbs, Clark. 1951. Minimum temperature tolerances for fishes of the genera *Signalosa* and *Herichthys* in Texas. Copeia 1951(4) : 287.

Huish, Melvin T. 1958. Food habits of three Centrarchidae in Lake George, Florida. Proc. Ann. Conf. Southeast. Assoc. Game and Fish Comm. 11:293-302.

Isaacson, Peter A., and Richard L. Poole. 1965. The threadfin shad, *Dorosoma petenense*, in northern California ocean waters. Calif. Fish and Game. 51(1) :56-57.

Kilambi, Raj V., and Raymond E. Baglin, Jr. 1969. Fecundity of the threadfin shad, *Dorosoma petenense*, in Beaver and Bull Shoals reservoirs. Trans. Amer. Fish. Soc. 98(2) 320-322.

Kimsey, J. B. 1954. The introduction of the redeye bass and the threadfin shad into California. Calif. Fish and Game. 40(2) :203-204.

.... 1958. Possible effects of introducing threadfin shad, *Dorosoma petenense*, into the Sacramento-San Joaquin Delta. Calif. Inland Fisheries Admin. Rept. No. 58-16, 21 p. (Mimeo.).

............, Robert Hagy, and George W. McCammon. 1957. Progress report on the Mississippi threadfin shad in the Colorado River for 1956. Calif. Inland Fisheries Admin. Rept. No. 57-23, 48 p. (Mimeo.).

Lambou, Victor W. 1965. Observations on size distribution and spawning behavior of threadfin shad. Trans. Amer. Fish. Soc. 94(4):385-386.

McConnell, William J., and John H. Gerdes. 1964. Threadfin shad, *Dorosoma petenense*, as food of yearling centrarchids. Calif. Fish and Game. 50(3):170-175.

Miller, Robert V. 1961. The food habits and some aspects of the biology of the threadfin shad, *Dorosoma petenense* (Gunther). M.S. Thesis. Univ. Arkansas.

Minckley, W. L., and Louis A. Krumholz. 1960. Natural hybridization between the clupeid genera *Dorosoma* and *Signalosa*, with a report on the distribution of *S. petenensis*. Zoologica 45(12):171-180.

Parsons, John W. and J. B. Kimsey. 1954. A report on the Mississippi threadfin shad. Prog. Fish-Cult. 16(4):179-181.

Phillippy, C. L. 1967. Results of selective shad treatments in six central Florida lakes. Proc. Ann. Conf. Southeast. Assoc. Game and Fish Comm. 18:198-212.

Rawstron, R. R. 1964. Spawning of threadfin shad, *Dorosoma petenense*, at low water temperatures. Calif. Fish and Game. 50(1):58.

Reid, George K. 1950. Food of the black crappie, *Pomoxis nigromaculatus* (LeSueur), in Orange Lake, Florida. Trans. Amer. Fish. Soc. 79:145-154.

Shelton, William L. 1964. The threadfin shad, *Dorosoma petenense* (Gunther): Oogenesis, seasonal ovarian changes and observations on life history. M.S. Thesis. Oklahoma State Univ. 48 p. (Mimeo.).

Smith, William A., Jr. 1959. Shad management in reservoirs. Proc. Ann. Conf. Southeast. Assoc. Game and Fish Comm. 12:143-147.

Stevens, Robert E. 1958. The striped bass of the Santee-Cooper Reservoir. Proc. Ann. Conf. Southeast. Assoc. Game and Fish Comm. 11:253-264.

.... 1959. The white and channel catfish of the Santee-Cooper Reservoir and tailrace sanctuary. Proc. Ann. Conf. Southeast. Assoc. Game and Fish Comm. 13:203-219.

Strawn, Kirk, J. E. Coward, W. C. Houghton, and H. Brant. 1962. Experimental introduction of threadfin shad. Arkansas Game and Fish Comm. D J Fed. Aid Proj. F-8-R, Final Report. 23 p.

Strawn, Kirk. 1965. Resistance of threadfin shad to low temperatures. Proc. Ann. Conf. Southeast. Assoc. Game and Fish Comm. 17:290-293.

Swingle, H. S. 1950. Relationships and dynamics of balanced and unbalanced fish populations. Auburn Univ. Agri. Exp. Sta. Bull. 247. 74 p.

.... 1954. Fish populations in Alabama rivers and impoundments. Trans. Amer. Fish. Soc. 83:47-57.

Thomas, James C. 1962. The occurrence and distinction of threadfin shad in southern California ocean waters. Calif. Fish and Game. 48(4): 282-283.

Trelease, Thomas J. 1956. The introduction of the threadfin shad, *Signalosa petenense atchafalyae*, into Lakes Mead and Mohave, Nevada. Nevada Fish and Game Comm., D-J Fed. Aid Proj. F-5-D-1 and 2.