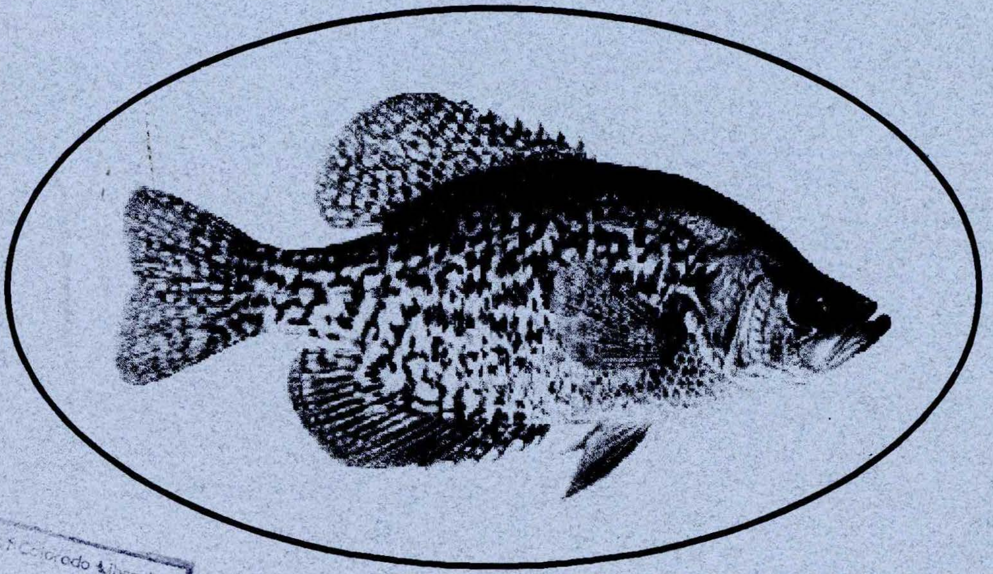
EFFECT OF ENVIRONMENTAL FACTORS AND HARVEST REGULATIONS UPON THE CRAPPIE (POMOXIS) SPORTFISHERY AT RATHBUN LAKE

Technical Bulletin No. 5



Iowa Department of Natural Resources
Larry J. Wilson, Director
August, 1995

ABSTRACT

Crappie ranked second in the creel of Iowa anglers and is particularly important to those who fish large flood control reservoirs such as Rathbun Lake. This investigation determined the environmental factors that influence the abundance of young crappie and how these factors, in addition to angler harvest, impact the crappie fishery. Young crappie survival, measured over a 22-year period, was affected greatly by water level. A positive relationship existed between density of young crappies and water storage in acre-feet days, measured in April-August. Years of high water storage were correlated with high density of young crappie ($R^2 = 0.53$; $p<0.05$). Conversely, low, stable water levels were correlated with less abundant year-classes. Turbidity, water temperature, wind and substrate conditions, measured in 1980-1983, were all correlated with young crappie production. Embayments and protected coves were subjected to less wind resulting in less turbid water; young-of-year crappie numbers were greater in these areas. Water with Secchi disk visibilities of less than 6 inches yielded few larval crappies. Abundance of larval crappie was positively correlated with crappie harvests 2-4 years later. Young crappie were especially abundant in 1973 and 1975 and these strong year-classes produced excellent crappie angling during the 1974-1976 fishing seasons. Record harvests totaling nearly 1 million crappies during the 1987-1989 fishing seasons were primarily the result of a single strong year class established in 1986. This abundant year class was, in turn, the result of high water and optimum spawning conditions. Adult crappie statistics included growth, length distributions, age distributions, body condition, population density, population biomass, mortality and angler harvest. This information was used to determine those factors that influence the health and well-being of the adult crappie population including predicted impacts of several harvest restrictions. Since impoundment of Rathbun Lake, angler harvest of crappie has not been restricted. A creel limit of 10 would need to be imposed if the objective was to reduce harvest and redistribute the catch. Such a severe restriction might be expected to have a negative effect on angler use at Rathbun Lake. Similarly, a minimum size limit designed to reduce crappie harvest should be carefully evaluated prior to implementation. During eighteen years of angling at Rathbun Lake, anglers harvested over 3 million crappies. If a 10-inch size limit had been used to restrict the harvest of crappies during that period the catch would have been reduced by one half. Anglers would have been denied nearly 1.4 million fish and as many would have died of hooking mortality as were harvested. Recommendations were presented for crappie management on large flood control reservoirs with emphasis on the importance of environmental factors that influence the abundance of young crappies. It was determined the well-being of crappie populations and subsequent angling is far more dependent upon water level and water quality than angling at Rathbun Lake.

Effect of Environmental Factors and Harvest Restrictions upon the Crappie (*Pomoxis*) Sportfishery at Rathbun Lake

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INTRODUCTION

Crappie (*Pomoxis spp.*) is the most important sportfish in Iowa flood control reservoirs. The Iowa Angler Survey of 1994, (University of Northern Iowa 1995) showed crappie comprised 24% of the total fish harvest in the Southeast Region. Rathbun Lake, an 11,000 acre flood control reservoir, is located within this management district and is one of the most popular crappie fishing lakes in the state, and undoubtedly was responsible for the high catch of crappie in that area. Crappie have great angler appeal and statewide they are ranked third in preference (16%) by anglers, surpassed only by largemouth bass (21%) and channel catfish (22%). The survey also indicated crappie are the second most eaten fish (18%) surpassed by channel catfish (24%).

The sportfish harvested from Rathbun Lake indicated the importance of crappie to the popularity of the lake and the local economy.

Creel survey results indicated 411,000 crappies were harvested in 1987 and this accounted for 79,000 angler trips. Based on the National Survey of Fishing and Hunting U.S. Department of Interior (1991) statistics of $30 per trip, the estimated value of the fishery at Rathbun Lake in 1987 was 2.4 million dollars.

Crappie fishing at flood control reservoirs can be highly variable. For example, the lowest harvest at Rathbun Lake was estimated at 42,000 crappies in 1981, but 6 years later crappie harvest was the highest on record at 411,000, nearly 10 times higher than the record low. It is vital that the reasons for these population swings not only be monitored, but the factors behind such variation be understood. A good knowledge of the well-being of the crappie population, and those environmental factors that influence population abundance are vital to management of this important sportfish species.

Basic biology and habitat requirements of crappie give some clues to year-to-year fluctuations in crappie populations. Buck (1956) showed high turbidity was associated with lower fish biomass, reduced plankton density and slower fish growth. Hill (1989) found fish populations that contained the most angler-acceptable fish were associated with steep-sided lakes subjected to very little siltation. Populations with the least amount of angler-acceptable fish were found in shallow basins subject to high siltation. Mitzner (1987) found the abundance of young crappie was influenced by turbidity, temperature during spawning, wind and substrate firmness, in that order of importance. Water level was, however, far more influential in determining year class strength (Mitzner 1981). Keith (1975), Groen and Schroeder (1978), and Beam (1983) all found water level fluctuations during critical nesting, incubation and larval stages was important in determining young fish abundance. Although little has been recorded about crappie spawning behavior in reference to turbidity and siltation, there are studies by Breder and Rosen (1966) and Muncie et al. (1979) which indicated spawning activity of centrarchids is inhibited by low light levels even on cloudy days. Vasey (1973) reported crappie spawned at shallower depths as turbidity increased.

Another unknown in crappie management in Iowa is possible angler overharvest. During the 1950's-60's, harvest restrictions (take and size limit) on crappie and other panfish were relaxed or completely abolished in Iowa as well as other midwestern states. Emphasis on fisheries management during the early 1970's shifted towards harvest regulation, primarily size restriction on largemouth bass. Then, in the 1980's several neighboring states applied this trend to crappie. For example, the Missouri Department of Conservation imposed both take and size restriction on crappies in large impoundments during the early 1980's (Colvin 1991a, 1991b). Other states, including Kansas, Nebraska, Texas, Oklahoma, Illinois and Ohio have restricted crappie harvest either in terms of take, size or both. Several states are evaluating the newly implemented restrictions. The usefulness, however, of many of the evaluations is questionable, because of the short duration of the study or scientific objectivity. A need exists for a long-term, objective examination of crappie populations in large reservoirs with emphasis on angling pressure.

The primary focus of this investigation was twofold, the first was to define and identify factors influencing year class strength of crappie in large flood control reservoirs. These factors included water level fluctuation, wind, temperature, turbidity and substrate. The second focus in this investigation was to define and identify the angler's influence on population dynamics of crappie in large reservoirs. The implications of this focus would be an assessment of the need for harvest restrictions.

The general design of the investigation is outlined in three phases of study. The first phase included the development of the relationship between young-of-year (YOY) year class strength and water level. This phase occurred from 1972-1994, and measured the relationship between crappie YOY abundance and the flood storage regime. The second phase (1980-1983) investigated the affect of wind, turbidity, substrate and temperature on crappie YOY beginning with the spawn and terminating 10 days post-nest emergence. The third phase dealt with crappies as they entered the sportfishery. Population statistics for adult crappies, including growth, body condition, abundance, biomass, age structure and size structure, were determined during 1990-1993. Creel survey statistics were available for these years in addition to the 14 years preceding the study. Additional abundance and biomass estimates of crappie were available for the periods 1977-79 and 1985-89. These data were used in a predictive model that provided harvest scenarios for various size and take limits.

STUDY AREA

Rathbun Lake is an 11,000 acre impoundment on the Chariton River and is located in Appanoose, Wayne, Lucas and Monroe counties in Southern Iowa. The project was constructed by the U.S. Army Corps of Engineers (COE) for flood control, recreation and, to a lesser extent, navigational benefits in the lower Mississippi River basin. Normal discharge rates range from 10 to 1,200 cfs with a maximum capacity of 5,000 cfs. Reservoir storage at conservation pool (904 ft above mean seal level (MSL)) is 205,400 ac-ft with a maximum volume of 551,600 ac-ft and area of 21,000 acres at crest elevation (926 MSL). The watershed area to lake surface area ratio is 32:1 at conservation pool and 17:1 at spillway elevation. Impoundment occurred in November 1969, and multipurpose pool elevation was reached in October 1970.

Initial fish stocking focused primarily on walleye (*Stizostedion vitreum*) although white bass (*Morone chrysops*), crappie, striped bass (*M. Saxalitis*), muskellunge (*Esox masquinongy*) and hybrid musky (*E. masquinongy x E. lucius*) were also stocked. Channel catfish (*Ictalurus punctatus*) and largemouth bass (*Micropterus salmoides*) were also stocked each of the first few years of impoundment and sporadically thereafter. The sportfishery is composed of crappie, channel catfish, white bass and walleye, making up about 95% of the harvest. Annually, crappie comprise >80% of the sportfish catch.

METHODS

Young-of-Year

Larval crappie were sampled during the day with a meter net of 0.03-inch nylon mesh towed at a constant speed of 6 feet/second. Biweekly samples were collected in May-July at six stations during 1971-1994. Surface tows were made at six stations (2,3,4,7,8 and 9) (Figure 1). In addition to surface tows, 15-foot deep tows were made at the dam (#2), mid-reservoir, (#3) and upper reservoir (#4). Two of the shallow stations #8 and #9 were in large embayments, and the other was a shoreline station along the main pool (#7).

The number of stations was increased to 24 during the more intensive study in 1980-1983; however, towing time was reduced from 10 min/haul to 5 min/haul. During this study phase, samples were collected daily except on weekends. The 24 sites were located throughout the reservoir, adjacent to a variety of shoreline habitats, and were broadly classed as pool (n=6), large embayments of 300-500 acres (n=8), large coves of 30-50 acres (n = 7) and headwaters (n = 3).

Larval crappies were not identified to species, thus the samples were a mixture of both black and white crappies. The adult population was dominated by white crappie comprising about 85% of the population, therefore the larval sample was assumed to consist primarily of white crappies.

Reservoir hydrology

Water levels were recorded from reservoir hydrology data obtained from the (COE) operating manager at Rathbun Lake, 1972-1994. The most reliable hydrological statistic used was acre-feet days, defined as the daily summation of water volume (acre-feet) stored in excess of the conservation pool elevation (904 MSL) April through August.

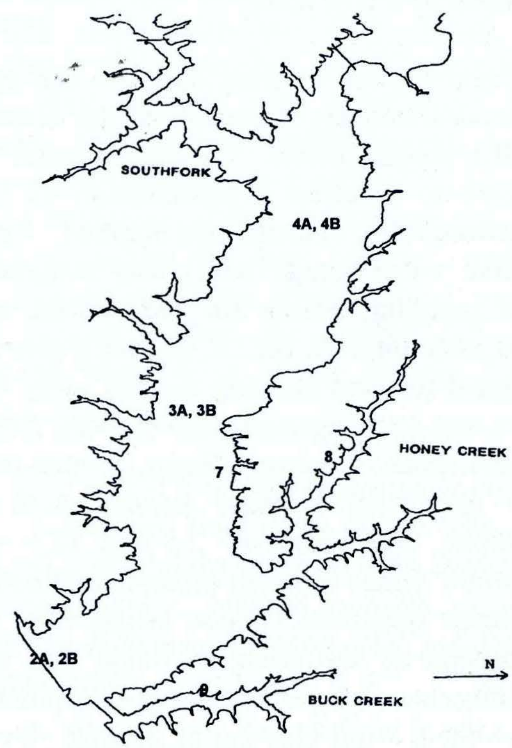


Figure 1. *Rathbun Lake showing meternet sampling stations for young-of-year crappie, 1971-1994.*

Physical factors

During the intensive YOY study, temperatures (°F) and Secchi disk visibility (in) were measured at least every third day at 270 stations along the 150-mi shoreline. Measurements commenced as early as 12 April and continued as late as 13 June, 1980-1983. Temperature was measured on the bottom along the 4-ft contour; turbidity was measured at the same time. Substrate firmness was measured as the penetration depth of a 1-in-diameter rod subjected to the 20 lb of downward force. Thus, pressure equaled 25.5 lb/in^2. These substrate firmness measurements were taken at the onset of crappie spawning activity and again when the water level changed by 4 ft or more.

Data relative to wind direction and speed were continuously recorded at the reservoir (COE) project office. A single value was derived to measure a combination of wind direction, fetch, velocity, and duration. First, a relative value (range 0-15) was assigned at each sampling station for each of the eight wind directions (N, NE, E, SE, etc.); zero was assigned to wind blowing directly away from shore and 15 designated wind blowing directly toward shore. Correspondingly, a value of 7.5 was given for a wind parallel with the shoreline, and values of 2.5 and 12.5 were given for winds blowing offshore and inshore at obtuse quadrants. These values were then multiplied by the fetch, in miles, and wind velocity, in miles per hour. For example, the value for a wind blowing at 25 mi/h directly toward a particular station over a fetch of 0.5 mi would be 15 x 0.5 x 25= 187.5. Finally, wind duration was accounted for by summing the hourly values for each station to yield an accumulation of 24 values, most of which contained a combination of different velocity, direction, and fetch values.

Determination of crappie spawning and hatching dates was essential to the assessment of the influence of physical attributes during incubation. Spawning and incubation periods were estimated from larval crappie length-frequency distributions in tow-net hauls and from temperature-related growth data (Siefert 1968; Vasey 1973). Crappies were vulnerable to the gear at 4-5 mm in length, which was the length Vasey (1973) reported as swim-up, with incubation period ranging from 42-103 hours. In this investigation incubation lasted about 95 hours at 70°F; another 100 hours were required until nest departure. Thus, at least 8-9 d elapsed from fertilization until larvae were off the nest and vulnerable to tow-net capture.

Mean body length during the first three sampling periods was plotted against time in days. Spawning dates were estimated by backward recursion of a line through these points at the intersection with the date on the abcissa. Crappie attained an average length of 5 mm in 7-8 days. Therefore, numerical abundance of 5-mm crappies in tows was compared with the physical conditions that prevailed 8 days earlier. Likewise, extrapolation of the observed length-frequency distribution indicated that 10-mm crappies were 15 days old (day 1 = the first day of incubation). Larval crappies 15 days of age or older were excluded in the regression data sets. This was done because fish may have hatched elsewhere in the lake (Vasey 1973).

Adult crappie

Harvest Crappie harvest was estimated by expandable roving creel surveys during 1972-1994. The daily angler survey period was stratified by early (AM) and late (PM) with further stratification by weekend and weekday, and boat and shore. Angler counts were made on an hourly basis within the stratified design. Two basic creel survey designs were used during the investigation. The first involved segregation of the lake into 4 segments and each segment was sampled 8 hours. These survey periods were selected among the 4 segments on a random basis. This method occurred during 1972-1990; details for this method were described by Bruce (1978). The second method segregated the lake into 8 segments and each segment was sampled for 1 hour at each segment during an 8 hour survey period. These samples were also on a randomized basis. This method was used in 1991-1995 with details given by Mitzner (1994). After obtaining angler counts, the creel clerk conducted angler interviews on the water or at boat ramps. Interview information included number in party, length of time fished, whether the trip was complete, number of each species caught, and which species was primarily being targeted. Lengths were taken throughout the survey period on representative catches of crappie, as well as other species.

Abundance August cove rotenone samples were also used to estimate abundance and biomass of YOY and adult crappie. This method of sampling occurred in 1977-79 and 1985-92. All species were collected, enumerated, weighed, and processed over three consecutive days to describe abundance, biomass, and size structure of both predator and prey. Four to six coves were sampled annually, with rotenone applied at a rate of approximately 3 ppm (1 gallon per ac-ft) through a weighted, perforated hose. This method assured even distribution of the toxicant. Aggregate fish weight, by species, and total lengths of individual fish were measured during the first day. Fish collected during the second and third days were enumerated by species. The composite sample for all coves was adjusted to account for species and size selectivity, distribution within the lake, and the probability of successfully recovering dead fish within a three-day period as determined by Hayne et al (1967).

Exploitation and Mortality Crappie exploitation during 5, eight-week periods, mid-April through mid-June 1989-1994 was estimated by tags returned for Crappiethon rewards. In 1989, 1,304 crappies were tagged, while 1,450, 2,037, 1,522, 1,347, and 1,657 were tagged in 1990, 1991, 1992, and 1993, and 1994. Rewards for individual tags ranged from $25-$65,000, while total potential rewards were $285,000 in 1989, $345,000 in 1990, $428,425 in 1991, $423,800 in 1992, and $173,150 in 1993, and $214,000 in 1994. Fish were marked just previous to the tournament's starting dates with the Floy T-bar tags inscribed with a number and "Crappiethon". Fish were captured with sportfishing gear, tagged, and released within several hours. Capture and marking occurred within 12 days of the beginning of the tournament and took place throughout the lake; however, most of the tagging was done where fishing success was greatest. Thus, the marked fish were released where most of the crappie fishing would occur.

Total annual mortality estimates of crappie were determined from catch curves with ages derived from otoliths obtained from September fyke net samples. Natural mortality estimates were the difference between total and fishing mortality rates.

Age and Growth Adult crappie were sampled with fyke nets on a monthly basis in the summer, 1990-1994. Fish collected were used to determine age, growth and length-weight characteristics of crappie and size structure of the populations. Netting occurred as early as May and concluded with the September sample. Effort varied with the season, but was always adequate to produce a sample of at least 30 crappies. September sampling was based on a minimum of 100 net days. Fyke nets used during the investigation were constructed with 2 ft x 4 ft frames, a 40 ft lead and 7, 2 foot hoops at the cod end. The web was 1-inch mesh bar measure.

Fish were measured to the nearest mm and gm with otoliths extracted from representative

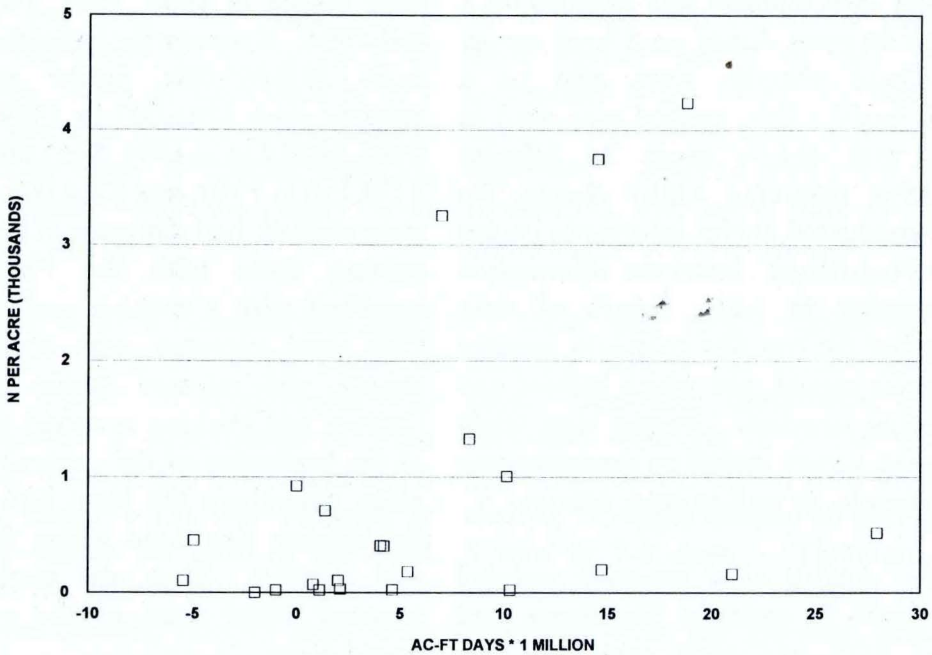


Figure 2. *Relationships between water storage in million acre-feet days above conservation pool from April-August and estimated density of age 0 crappies in number per acre.*

size groups to determine age and growth, as well as length and weight characteristics. Otoliths were prepared and sectioned according to methods of Maceina and Betsill (1987). Otoliths were then measured and aged through an occular grid at 100x magnification. Back-calculated lengths at each age were determined using the software program, DISBCAL (Frie 1982). Relative weights (W_r) were determined from standards prepared by Neuman and Murphy (1991), while size structure was determined by length categories published by Gablehouse (1984).

Harvest Regulation

Key characteristics of the Rathbun Lake crappie population were used to model and simulate the effects of 9- and 10-inch size limits of crappie. Also, an 8-inch size limit was "imposed" to simulate the current condition at the lake. Figure 8 shows at least 95% of the crappie were 8 inches and larger. Thus, an 8-inch limit would for all practical purposes, constitute no restriction whatsoever. Levels of exploitation were selected at 17, 37, and 55%. The model was referred to as General Inland Fishery Simulator (GIFSIM) as developed by Taylor (1981).

FINDINGS

Young-of-Year Crappie

Effect of Water Storage A significant, positive, linear relationship ($r = 0.39$; $P < 0.05$) existed between the density of young crappies and the amount of floodwater stored from April through August (Figure 2). This relationship was described by the function

$Y = 422 + 57X;$

Y = number of age-0 crappies per acre, and X = storage volume in million acre-feet-days. This relationship indicated age-0 crappie density increased by an estimated 57 per acre for each increase of 1 million acre-feet-days of floodwater storage above conservation pool.

Both regression and correlation were significant ($P < 0.05$).

The highest crappie densities occurred in 1973, 1978, and 1986. These were years of flood water storage of at least 6.9 million acre-feet-days (Table 1). The greatest deviations from this relationship occurred in 1982, 1991, and 1993 when high water was not associated with high densities of young crappies. These were also years of poor water quality, a subject to be treated in a later section. Turbidity was an overriding influence that resulted in extremely low age-0 crappie numbers in 1981-1983. If data collected in these years were discounted the *r*-value becomes 0.73.

Crappie year-class abundance was positively related to sportfish harvest 2-4 years later ($r = 0.77$, $P < 0.05$). For example, the highest density of young crappies (4,235/acre) occurred in 1973, and the third highest crappie harvest occurred in 1975 (Table 6). Similarly, catches also were high in 1974 and 1976, 1-3 years after the strong 1973 year-class. The second highest year class occurred in 1986 (3,253/acre) and produced a record harvest of nearly 1 million crappies taken during 1987-1989. Conversely, low sportfish harvests in 1972 and 1984 were associated with weak crappie year-classes established 2-4 years earlier. The year-class abundance indices developed by Mitzner (1981), generated a correlation of 0.77 between young crappie abundance in townet samples and crappie sportfish harvest 2,3, and 4 years later.

Table 1. Reservoir storage in excess of conservation pool and young-of-year population abundance as number per acre at peak density, Rathbun Lake.

Year	Ac-Ft Days Millions	Yearly Juvenile Crappie/Ac
1971		1730
1972	1.39	705
1973	18.78	4235
1974	2.02	104
1975	0.82	70
1976	4.05	403
1977	0	920
1978	14.51	3745
1979	8.31	1327
1980	4.21	400
1981	10.3	23
1982	21.01	161
1983	4.62	24
1984	2.12	31
1985	-2	0
1986	6.94	3253
1987	1.13	22
1988	-0.99	22
1989	-4.95	449
1990	10.13	1005
1991	14.72	198
1992	5.36	181
1993	27.93	514
1994	-5.46	103

Larval Crappie Abundance, 1980-1983

The effects of turbidity, temperature, wind, and substrate on larval crappie abundance were examined during this segment of the study. Estimates of young crappie abundance ranged from 23/acre in 1981, and 1983 to 400/acre in 1980 (Table 1).

Crappie spawning season lasted 45, 47, 27, and 28 days in 1980, 1981, 1982, and 1983. The earliest initiation of spawning was 30 April 1981, and the latest was 27 May 1982. Spawning activity normally ended between 15 and 25 June. At least one period of peak activity occurred each year. For example, in 1980, intense spawning began after 4 June, peaked around 10 June, and decreased rapidly after 14 June even though minor spawning occurred throughout May; During the 1980-1983 period, highest tow-netting success for larval crappies occurred in coves and embayments as well as in the main pool (Table 2). Catch rates in the headwaters were consistently low.

Turbidity was highest in the upper reaches of the reservoir, primarily because of runoff. This was exemplified in 1980 when high inflows during early June caused water clarity to decrease to an average Secchi disk reading of 4.8 inches in the headwaters, whereas more protected stations downlake averaged 21.9 inches.

Table 2. Average catch per effort of larval crappies in 5-min tows at Rathbun Lake.

Sample Locations	Number of Sites	Number/haul 1980	1981	1982	1983
Embayments	8	2.08	0.36	1.77	0.37
Pool	6	3.1	0.08	3.25	0
Coves	7	4.69	0.21	0.91	0.01
Headwaters	3	0.5	0.13	0.39	0

Effect of Turbidity The three main sources of turbidity at Rathbun Lake were wave action, resuspension of bottom sediments, and runoff. Highest turbidities occurred in 1982 and 1983 when Secchi disk readings were rarely greater than 10 inches. Heavy runoff occurred in both years, particularly 1982. High turbidity in 1983 was due primarily to resuspension of littoral silt as the water level receded during the entire crappie spawning season. Water clarity was greatest during periods of reservoir stability such as in May, 1980. During this period Secchi disk readings of 40 inches were not uncommon in protected embayments. Secchi disk readings of 20 inches were common in early June, 1981 as water level became stable.

Increased turbidity was associated with fewer larval crappies and was best described by the following relationship derived from the Secchi disk measurements associated with the 24 townet stations;

$\log_e Y = -6.766 + 2.204 \log_e X$;

Y = catch of larvae per haul adjusted to onset of incubation and X = turbidity in inches measured by Secchi disk. Thus, crappie young decreased geometrically as water clarity decreased. The model predicted crappie young were not present at a Secchi disk reading of 2 inches or less.

Effect of Temperature Water temperature during crappie spawning was subject to minor diurnal fluctuations, but the main trend was a progressive increase. For example, water temperature increased from 53°F on 13 May to 72°F on 12 June 1980. The sharpest increase was 9°F from 19 to 22 May. Water temperature increased more rapidly in coves, intermediate in embayments, and slowest in the main pool. The threshold temperature for crappie spawning was 61°F, and major spawning activity was associated with temperatures near 70°F.

Regression analyses for individual spawning seasons were completed to identify the relationship between water temperature and the number of larval crappies in townets, adjusted to the time of egg deposition. Data sets included values collected from the onset of spawning to the date of maximum spawning activity. The relationships between mean temperature and numerical catch were positive in all years, but only those for 1980 ($r = 0.67$) and 1981 ($r = 0.48$) were significantly different from zero ($P < 0.05$). It appeared after the threshold spawning temperature was attained, larval crappie abundance was only partially dependent on the temperature regime. Coefficients of determination (R^2) showed that 22% and 1.4% of the variability in larval crappie abundance in 1981 and 1982, respectively, were attributable to temperature.

Effect of Substrate Firmness Substrate firmness was determined at 270 sites spaced at approximately 0.6-mile intervals around the entire shoreline of the lake. These values were examined by pooling the firmness of all values at each townet station and then plotting a histogram to determine numerical distribution. The mean value was 5.2 inches of penetration with a range of 0 inches (riprap and submerged stumps) to 30 inches (soft sediments).

The substrates in Rathbun Lake were firmest in 1982. About 67% of the penetration depths were less than 2 inches and the average was 1.2 inches. The primary cause of the harder substrate in 1982 was the high water level; most measurements were made on submerged terrestrial sites.

The softest substrates were recorded in 1983. The average penetration for all stations in that year was 5.8 inches. The firmest substrate occurred at Honey Creek (site 1) where mean penetration was 3.2 inches. The softest substrate was found at pool site 4 where the average reading was 14.5 in. Most of the 1983 measurements were associated with continually receding water levels.

Regression analyses of crappie abundance and substrate firmness identified an optimum spawning substrate firmness of about 4 inches of penetration. Substrates of harder or softer magnitude were associated with lower crappie numbers. The catch statistics from 1980 and 1982 were combined and tested to refine these relationships. Fit to a second-degree polynomial function, these data gave the relationship

$$Y = 0.88 + 0.301X - 0.026X^2;$$

Y = adjusted catch of larval crappies per haul, and

X = substrate firmness in inches of penetration.

The relationship, however, was not significant ($r = 0.14$; $P > 0.05$).

Effect of Wind Wind factor at the townet stations ranged from 224 at cove site 1 in 1983 to 4,908 at pool site 4 in 1980. Wind-factor values were consistently higher at the pool stations than at other locations because pool stations were more exposed to wind action and fetch (pool stations 2 and 4 averaged more than 3,000). Protected sites in the upper reservoir and in embayments had the least wind effects. Wind values at the cove stations ranged from 200 at cove station 1 in 1983 to 2,500 at cove station 6 in 1980. Cove station 6 was exposed to a long fetch from the South, whereas fetch was much less at cove station 1.

High and low wind values depended upon day-to-day weather patterns. For example, wind values for the pool stations ranged from about 1,000 (23 May and 18 June) to nearly 6,000 (21 May and 9 June). Day-to-day fluctuations of 2,000 were not uncommon for pool stations. Conversely, fluctuations at embayment stations rarely exceeded 200 units.

Regression analysis described the interaction between abundance of young crappies and wind factor as negative with a correlation coefficient of -0.15. Regression and correlation coefficients were not significant ($P > 0.05$). However, some evidence associated high wind values with fewer crappies and low wind values with more crappies. Larger catches of 2 per haul, or more, were associated with wind values less than 1,000. Conversely, catches exceeding 2 per haul never occurred at wind factors above 1,000.

Adult Crappie

Growth White crappie growth was based on 536 scale or otolith samples taken during 1990-1994. Most rapid growth occurred during the first year of life with an average of 4.7 inches. Average back-calculated lengths at age 1 ranged from 3.7 to 6.0 inches, depending on the year of collection (Table 3). Average length at age 2 was 6.7 inches, and by age 9, white crappie attained an average length of 11.8 inches (Figure 3).

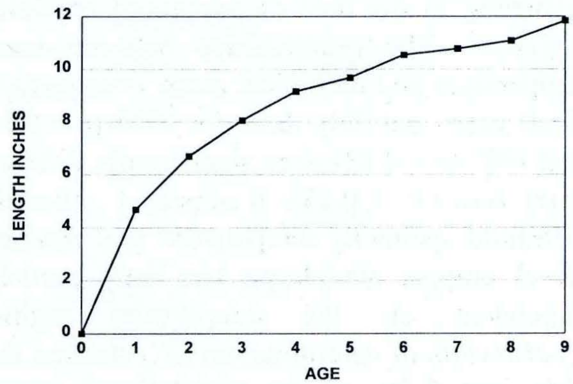


Figure 3. *Average back-calculated lengths of white crappie at Rathbun Lake from collections taken in 1990-1994.*

Table 3. Back-calculated lengths, in inches, of white crappies sampled at Rathbun Lake.

		Age								
Year	N	1	2	3	4	5	6	7	8	9
1990	122	4.4	5.8	7.5	8.7	9.7	10.6	11.1	11.2	11.6
1991	116	4.2	6.8	8.4	9.4	10.1	10.6	11.2	11.8	12.1
1992	96	6	6.8	7.5	8.8	9.2	9.8	10	10.3	
1993	134	3.7	6.6	8.2	8.9	9.7	11.2			
1994	68	5.2	7.5	9	10.1					
Average		4.7	6.7	8.1	9.2	9.7	10.5	10.8	11.1	11.8

Length-Weight Length-weight characteristics of white crappies are presented in Table 4. Regression statistics were calculated for monthly samples taken during the investigation, with b-values ranging from 2.6148 in July 1991, to 3.2021 in June 1990. R^2-values were all greater than 0.919 with some values near 0.99. Similarly, relative weight calculated for each monthly sample ranged from 79.9 in June, 1991 to 102.2 in May, 1994. (Table 4 and Figure 4).

Table 4. Length-weight characteristics of white crappies at Rathbun Lake, including sample size (N), a- and b-values of the length-weight regression, standard deviation of b, coefficient of determination (R^2), relative weight (W_r) and standard deviation of W_r.

		N	a	b	S_b	R^2	W_r	S_{wr}
1990	June	30	-5.4266	3.2021	0.0466	0.971	81.3	5.9
	July	44	-4.6117	2.8556	0.0572	0.983	82.7	10.7
	Sept.	51	-5.2583	3.1500	0.0548	0.985	90.7	5.5
1991	May	27	-5.3387	3.1710	0.0934	.0979	84.8	6.8
	June	37	-5.1810	3.0964	0.1275	0.944	79.9	10.3
	July	76	-4.0401	2.6148	0.0368	0.986	97.8	14.6
	Aug	28	-5.1984	3.1295	0.0733	0.986	95.3	8.4
	Sept	103	-5.2335	3.1202	0.0436	0.981	83.5	7.9
1992	May	27	-4.9626	3.0279	0.0636	0.989	91.8	11.5
	June	45	-4.4810	2.8184	0.0719	0.973	93.7	14.7
	July	78	-4.7544	2.9364	0.1001	0.919	97.1	11.3
	Sept	54	-5.1728	3.1188	0.0698	0.975	94.0	7.5
1993	June	48	-4.9235	2.9939	0.0970	0.954	86.8	8.8
	July	55	-4.8682	2.9841	0.0585	0.980	94.0	7.8
	Aug	105	-4.9616	3.0289	0.0526	0.970	94.5	7.0
	Sept	114	-5.1179	3.0811	0.0508	0.971	87.2	6.8
1994	May	81	-5.0253	3.0764	0.0863	0.942	102.2	11.8
	June	242	-4.9224	2.9914	0.0417	0.956	85.2	7.0
	July	70	-4.3310	2.7451	0.0537	0.975	89.3	11.3
	Aug	103	-5.1309	3.0830	0.0465	0.978	85.4	6.1
	Sept	73	-5.3591	3.1854	0.0421	0.988	87.1	5.3

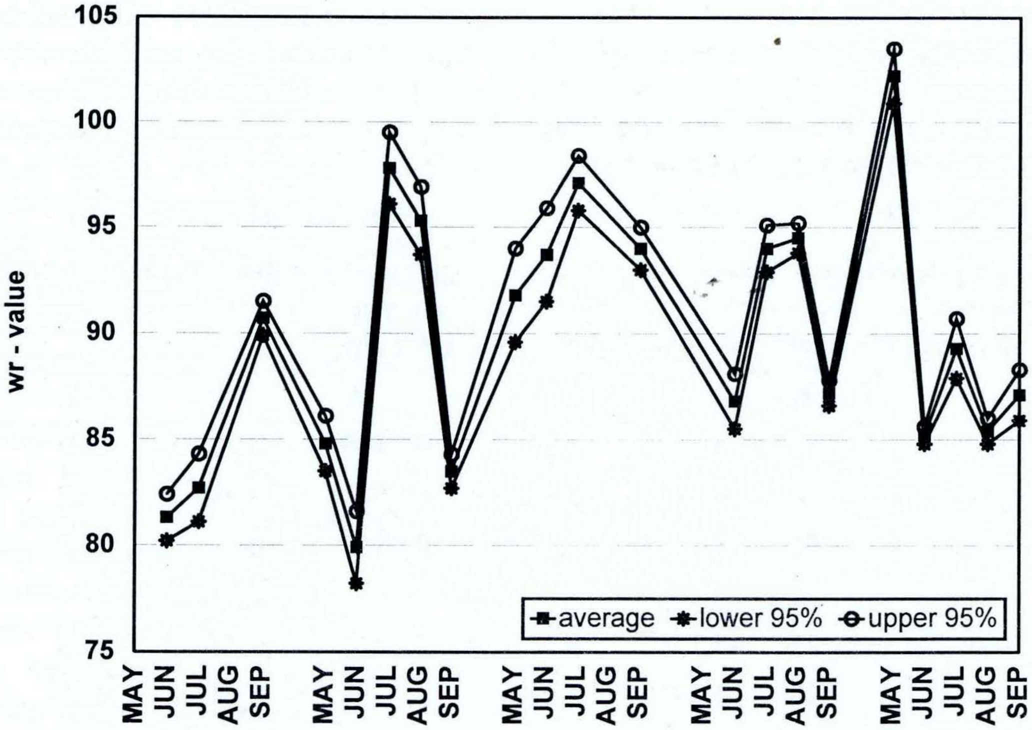


Figure 4. *Relative condition of white crappies at Rathbun Lake, 1990-1994, with lower and upper 95% confidence intervals.*

Calculation of 95% confidence intervals showed many of the samples appeared significantly different. These differences in average W_r-values, however, may have been masked by the relationship between body length and W_r. This relationship was always negative, that is, the trend was for W_r-values to decrease as crappie lengths increased. Regressions were calculated for the 21 monthly samples and all showed significant negative relationships, with the exception of three months. These b-values ranged from -0.038 to -0.358 for the 21-month group of samples. The overall b-value for W_r on length was -0.13, thus for each increase of 1 inch in body length, the expected W_r-value would decrease by about 3 W_r units. For example, a group of eight-inch crappies might have an average Wr-value of 91.4, while a group of nine-inch crappies might be expected to have an overall W_r of 88.1. Examination of the data sets by analysis of covariance showed, however, that adjustments due to any length differences in the samples were not justified. That is, overall monthly means and associated variances were valid estimates of relative weight of the crappie populations for these particular months.

Size and age structure Crappie length distributions are a reflection of age structure, mortality rate and growth. These size structure indices are shown as RSD-values in Table 5. Only rarely did RSD-Q (8-10 inches) fall below 20%. In fact, the only time this situation occurred was in May-July, 1992. Of the 22 samples collected 10 had RSD-Q of 50% or greater. RSD-P (10-12 inches) was similarly well represented and ranged from 5% in July 1991, to 45% in May 1992. During the investigation, half of the samples had RSD-P values greater than 10%. The memorable category (12-15 inches) was also fairly well represented during the study with as high as 18% of the population in this category in May 1992; however, most of the RSD-M values were < 5%.

Length-frequency distributions in September were used to evaluate the effect of recruitment because age 1 crappies, after completing nearly two summers of growth, would be fully vulnerable to the fyke net gear.

For example, the 1990 year class was shown in the 1991 histogram by the 6-7 inch size group (Figure 5). This age group dominated the 8-9 inch size group in 1992 and the 9-10 inch group in 1993. Poor recruitment of the 1989 age class was represented by a paucity in the 7- inch group of 1990. In 1992 this was reflected by fewer numbers of crappie over 9 inches.

Table 5. Relative stock density and sample size (N) of white crappies at Rathbun Lake.

Year	Month	N	RSD-S 5 to 8	RSD-Q 8 to 10	RSD-P 10 to 12	RSD-M 12 to 15	RSD-T 15 & over
1990	May	94	5.3	71.3	18.1	5.3	0
	June	37	18.9	64.9	13.5	2.7	0
	July	44	22.7	47.7	22.7	6.8	0
	Sept	50;	30	46	24	0	0
1991	May	46	37	34.8	26.1	2.2	0
	June	37	10.8	43.2	43.2	2.7	0
	July	76	59.2	35.5	5.3	0	0
	August	28	35.7	46.4	10.7	7.1	0
	Sept	103	42.7	44.7	9.7	2.9	0
1992	May	91	28.6	8.8	45.1	17.6	0
	June	163	64.4	15.3	14.1	6.1	0
	July	95	76.8	20	2.1	1.1	0
	Sept	54	24.1	66.7	5.6	3.7	0
1993	June	155	36.1	56.8	5.2	1.9	0
	July	55	29.1	61.8	9.1	0	0
	August	105	15.2	78.1	6.7	0	0
	Sept	114	34.2	56.1	8.8	0.9	0
1994	May	81	6.1	53.1	35.8	3.7	1.2
	June	529	33.8	57.1	7.9	1.1	0
	July	148	43.2	48.6	6.8	1.4	0
	August	150	18	68.7	13.3	0	0
	Sept	73	20.5	58.9	19.2	1.4	0

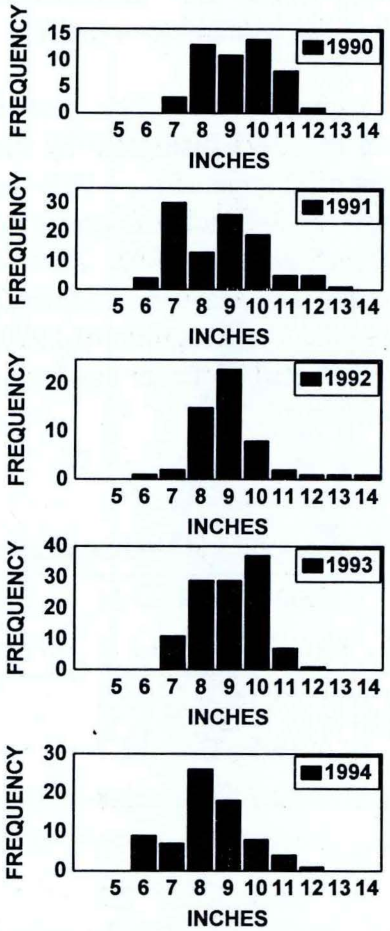


Figure 5. *Length-frequency distribution of white crappies in September fyke net catches, at Rathbun Lake, 1990-1994.*

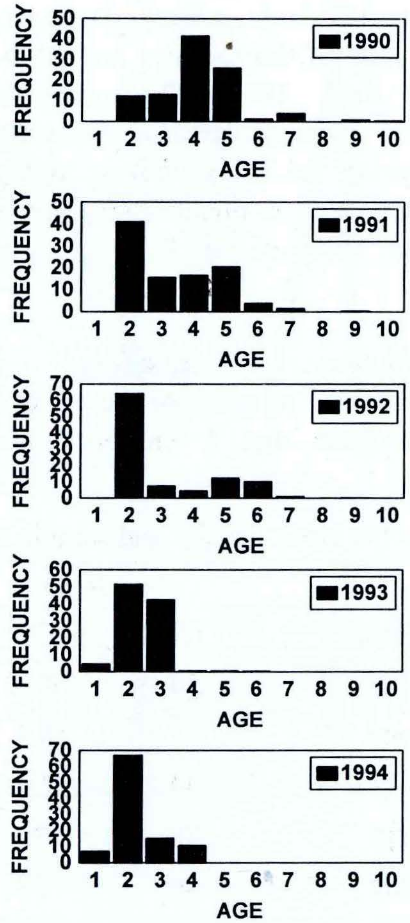


Figure 6. *Age distribution of white crappies at Rathbun Lake, 1990-1994.*

Age structure for white crappies at Rathbun Lake ranged from a dominance of age 2 fish in 1991, 1992, and 1994 to age 4 fish in 1990. Age 2 and 3 crappies were equally dominant in 1993. Ages 9 and 10 were rare, but occurred in limited numbers in 1990-1992 (Figure 6).

Mortality rates based upon the catch curve method ranged from 66% in 1993 to 33% in 1990. Values in 1991, 1992, and 1994 were 41%, 39%, and 58%. The overall average was 47%, while the value attained from combining yearly samples was 49%.

Abundance Crappie abundance ($\geq$ 8 in), as estimated from cove sampling, ranged from 18 fish/ac in 1990 to a high of 92 fish/ac in 1989 (Figure 7). Biomass ranged from 6 lbs/ac to 29 lbs/ac during the same years. Average density and biomass was 53 fish/ac at 19 lbs/ac.

Sportfishery Crappie harvest at Rathbun Lake ranged from 11,562 fish in 1972, two years after initial impoundment, to 410,626 fish in 1987 (Table 6). Crappie comprised the majority of the total catch of sport anglers and contributed from 14-92% of the fish in the creel. Angler effort expended at the lake

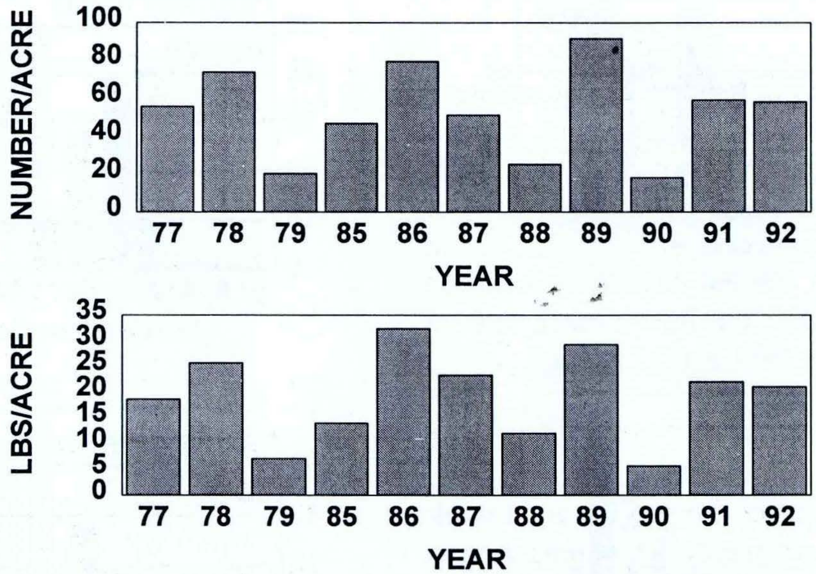


Figure 7. *Biomass and abundance estimates of crappies at Rathbun Lake based on August cove samples, 1977-1992.*

Table 6. Sportfishery catch statistics for crappie at Rathbun Lake.

Year	Crappie Harvest	% Crappie In Total Harvest	Angler Hours	Total Fish/Hr
1972	11,562	14	139,599	0.62
1973	117,347	80	177,020	0.94
1974	211,615	87	204,479	1.19
1975	334,759	89	361,768	1.04
1976	128,807	81	220,344	0.73
1977	94,676	86	160,555	0.71
1978	168,206	87	176,621	1.10
1981	41,739	61	185,399	0.37
1984	51,562	73	117,790	0.60
1985	88,340	86	96,234	1.06
1986	116,441	84	123,081	1.16
1987	410,626	87	275,198	1.72
1988	227,635	78	323,761	0.94
1989	304,439	82	350,840	1.06
1991	82,325	74	111,853	1.00
1992	100,335	69	156,664	0.98
1993	179,533	92	190,004	1.02
1994	341,737	88	314,373	1.24

ranged from 96,234 hours in 1985 to 361,768 hours in 1975.

Angler success in fish/hr was not measured for anglers targeting crappie; however, because crappie made up the majority of the catch, overall fish/hr was an indicator of success. For example, greatest success occurred in 1987 at 1.72 fish/hr, the second highest harvest on record. Conversely, the lowest catch rate on record occurred in 1981 at 0.37 fish/hr.

Exploitation rates in 1989-1994 were estimated from Crappiethon tagging and subsequent tag returns. During the eight-week period of the tournament, tag returns ranged from 61 in 1990 to 431 in 1993. Returns during the other years were between 300-400. Estimated exploitation rates ranged from 4% in 1990 to 32% in 1993. Exploitation in 1989, 1991, 1992 and 1994 was 29%, 18%, 21% and 13%. Weighted average for six years was 19%. These values are minimal estimates because it was assumed that 100% of the tags were returned for rewards; tag loss and mortality, due to tagging, were inconsequential. Also, the estimates are valid only for the eight-week period in which rewards were offered. Examination of creel statistics during these eight-week periods showed about 60% of the harvest was taken during the Crappiethon event.

Lengths of crappies harvested ranged from 5-18 inches with the majority of the catch at 8, 9 and 10 inches (Figure 8). A 10-inch mode in the crappie harvest was attained 8 out of 18 years of the survey. Eight and nine-inch modes in length of crappie harvested occurred 5 and 4 years of the survey, respectively. Smaller fish dominated in the creel only in 1985 and 1981.

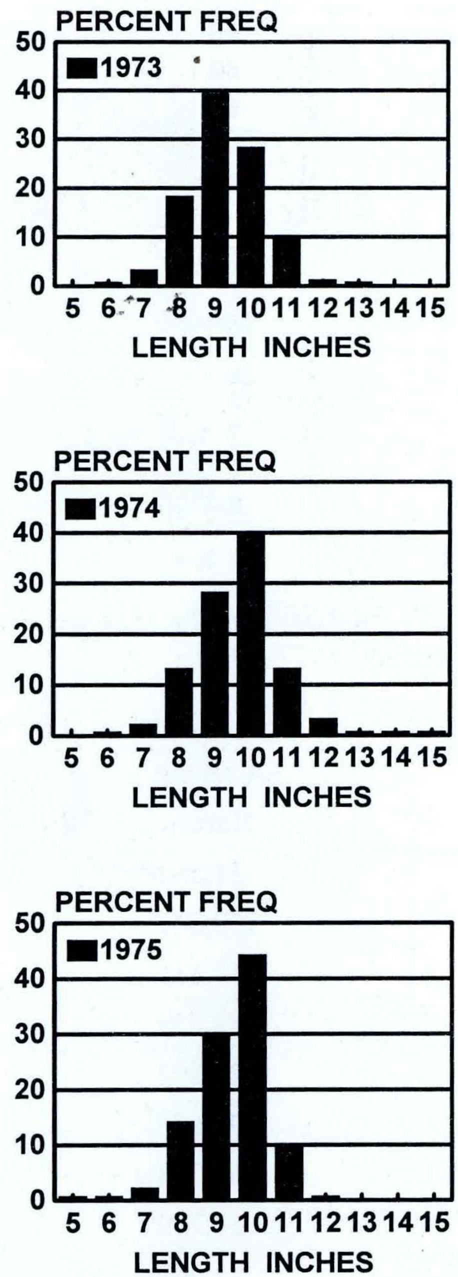


Figure 8. *Length-frequency distribution of harvested crappies measured during creel survey at Rathbun Lake, 1973-1994.*

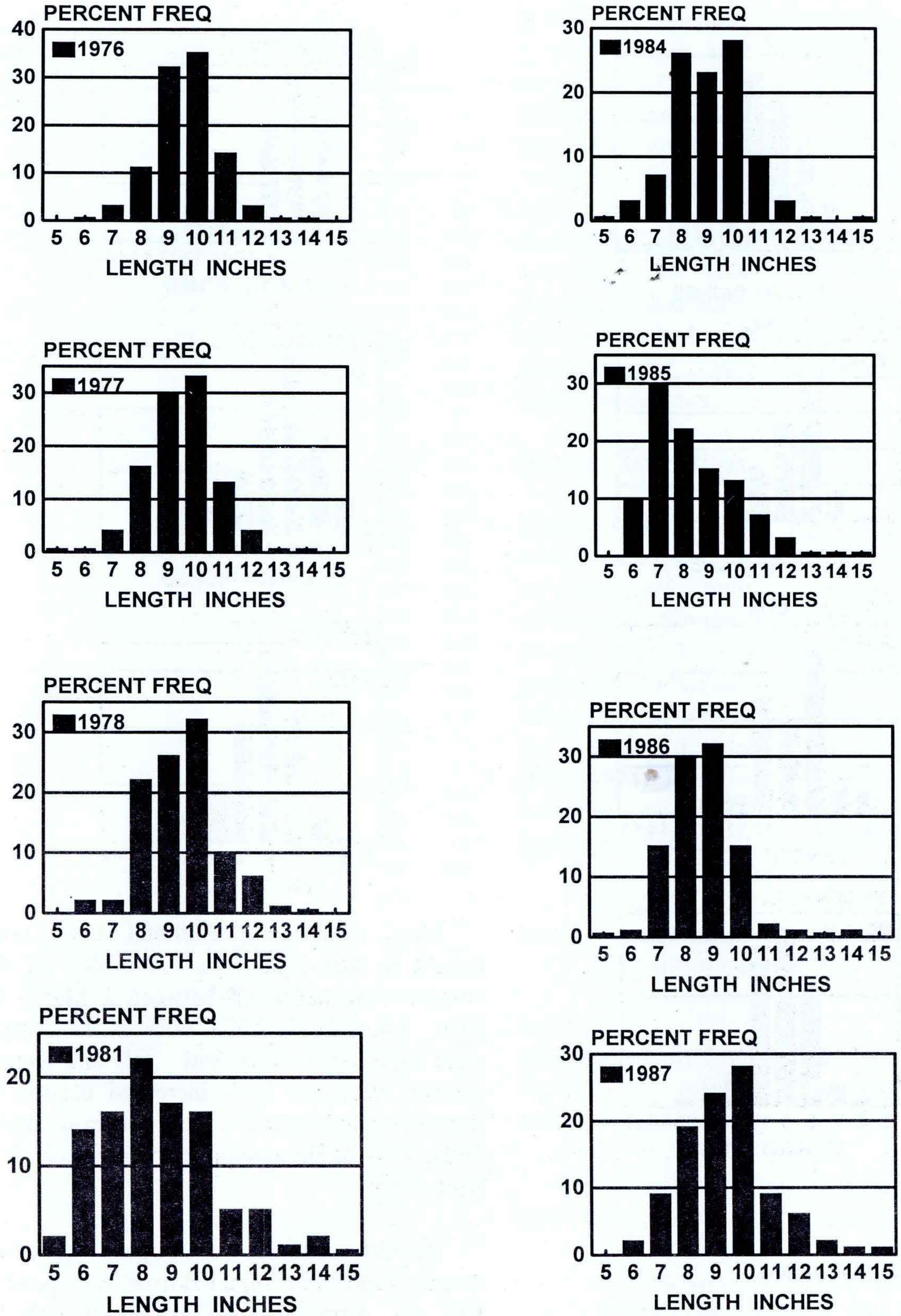
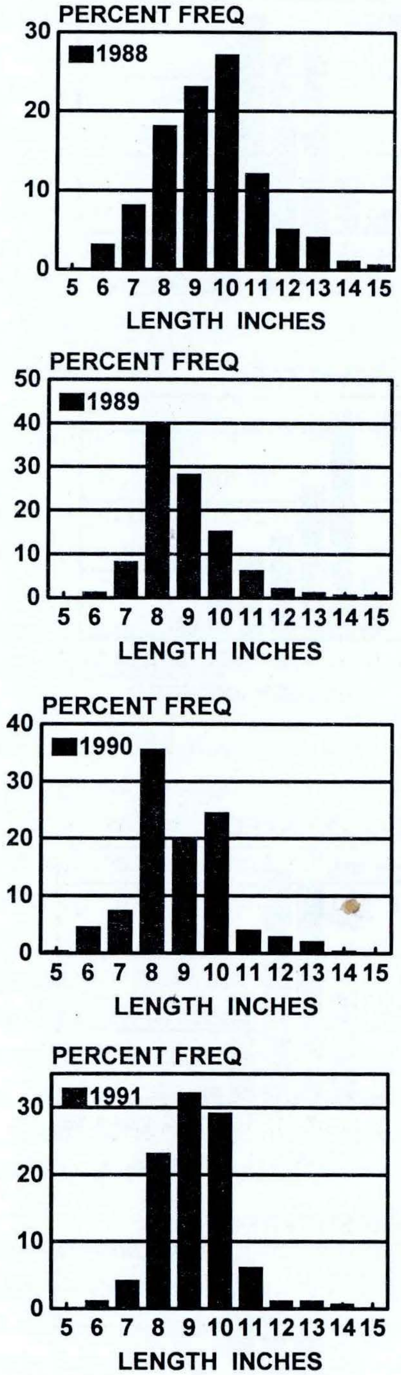


Figure 8. *Continued.*



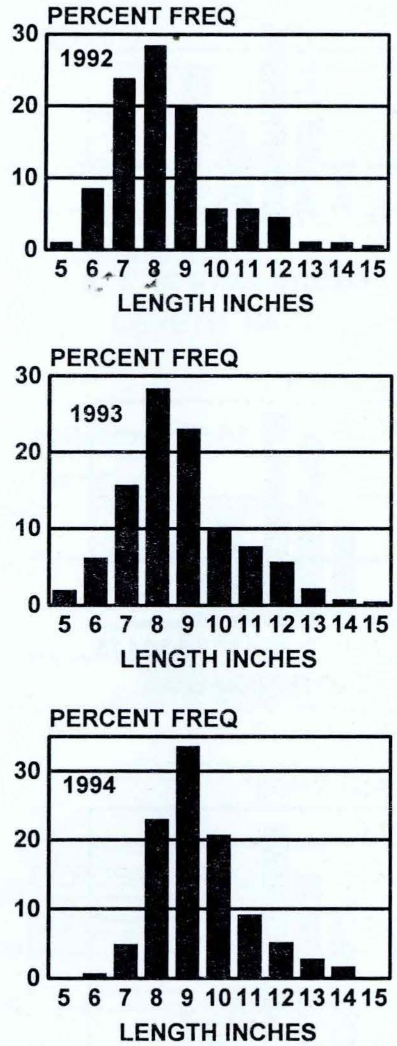


Figure 8. *Continued.*

Most crappies at Rathbun Lake were caught in May-June. In 1994, 69% of the crappie were harvested between 1 May - 30 June. Likewise, in 1993, 66% of the crappie were harvested in May-June. July and August catches were low with increased catches in September and early October. For example, in 1993, 15% of the crappie harvest occurred in September.

Harvest statistics of anglers targeting crappie, who had completed trips, were used to find the distribution of harvested fish by number in the creel. Most crappie anglers harvested fewer than 6 crappies per trip (Table 7).

Table 7. Completed trip creel statistics of anglers targetting crappie at Rathbun Lake.

No. of Crappie in Creel	Number Anglers			Cumulative Percent Crappie Harvested		
	1991	1992	1994	1991	1992	1994
0	93	106	26			
1	33	67	12	100	100	100
2	12	38	8	97.16	97.01	99.19
3	11	27	13	95.1	93.63	98.11
4	10	25	9	92.27	90.02	95.49
5	12	13	16	88.83	85.56	93.06
6	15	15	5	83.68	82.66	87.67
7	7	16	8	75.95	78.65	85.65
8	5	15	7	71.74	73.66	81.87
9	1	14	10	68.3	68.32	78.1
10	32	11	10	67.53	62.7	72.04
11	3	2	2	40.03	57.8	65.3
12	1	6	7	37.2	56.82	63.81
13	0	3	7	36.17	53.61	58.15
14	3	2	2	36.17	51.87	52.02
15	4	4	9	32.56	50.62	50.13
16	2	15	4	27.41	47.95	41.04
17	2	9	2	24.66	37.25	36.73
18	2	4	1	21.74	30.44	34.43
19	1	0	2	18.64	27.23	33.22
20	0	0	3	17.01	27.23	30.66
21	1	2	1	17.01	27.23	26.62
22	2	1	0	15.21	25.36	25.2
23	0	1	1	11.43	24.38	25.2
24	0	2	1	11.43	23.35	23.65
25	0	4	3	11.43	21.21	22.04
26	0	0	0	11.43	16.76	16.98
27	0	0	1	11.43	16.76	16.98
28	1	0	0	11.43	16.76	15.16
29	1	0	0	9.02	16.76	15.16
30	0	1	3	6.53	16.76	15.16
31	0	1	0	6.53	15.42	9.1
32	0	0	0	6.53	14.04	9.1
33	0	0	0	6.53	14.04	9.1
34	0	0	0	6.53	14.04	9.1
35	0	1	0	6.53	14.04	9.1
36	0	1	0	6.53	12.48	9.1
37	0	0	0	6.53	10.87	9.1
38	2	0	0	6.53	10.87	9.1
39	0	0	0	0	10.87	9.1
40	0	0	1	0	10.87	9.1
41	0	0	0	0	10.87	6.4
42	0	0	0	0	10.87	6.4
43	0	0	0	0	10.87	6.4
44	0	0	0	0	10.87	6.4
45	0	0	1	0	1.87	6.4
46	0	0	0	0	10.87	3.37
47	0	2	0	0	10.87	3.37
48	0	0	0	0	6.68	3.37
49	0	0	0	0	6.68	3.37
50+	0	3	1	0	6.68	3.37

In 1991, for example, 67% of the anglers with ≤ 5 fish per trip were responsible for harvesting 89% of the crappies. In 1992 and 1994, 69% and 48% of the anglers with ≤ 5 fish, harvested 86% and 93% of the crappies. Anglers harvesting more than 25 crappies were rare at Rathbun Lake. In 1991, 1.5% of the anglers had more than 25 crappies and were responsible for 11% of the harvest. Two percent and four percent of the anglers in 1992 and 1994 had more than 25 crappies, accounting for 17% of the harvested crappies during those years.

Harvest Restrictions

Creel Limits Based upon statistics from completed trips of anglers targeting crappie, various creel limit scenarios could be examined. Simple regression was used to develop a model from the empirical data to predict the reduction in harvest of crappies in Lake Rathbun if bag limits of from 0-50 fish per day were imposed. The combined data (1991-1994) is shown in Figure 9. Both variables were transformed with natural logarithms because the relationship was not

$$X = \left(\frac{Y+1}{2.0724}\right)^{-5.0246} - 1,$$

linear. The combined model for all years is

$$Y = 2.0724(X+1)^{-0.1992} - 1$$

and

where X = daily bag limit (0-50) crappies per day and Y = reduction in harvest (proportion of total harvest)

$$R^2 = 0.949, P < 0.001$$

These models can be used to answer two types of questions:

1. What reduction in crappie harvest in Lake Rathbun could be expected if an X fish per day bag limit were imposed on anglers
2. What creel limit would be necessary if harvest were to be reduced by Y?

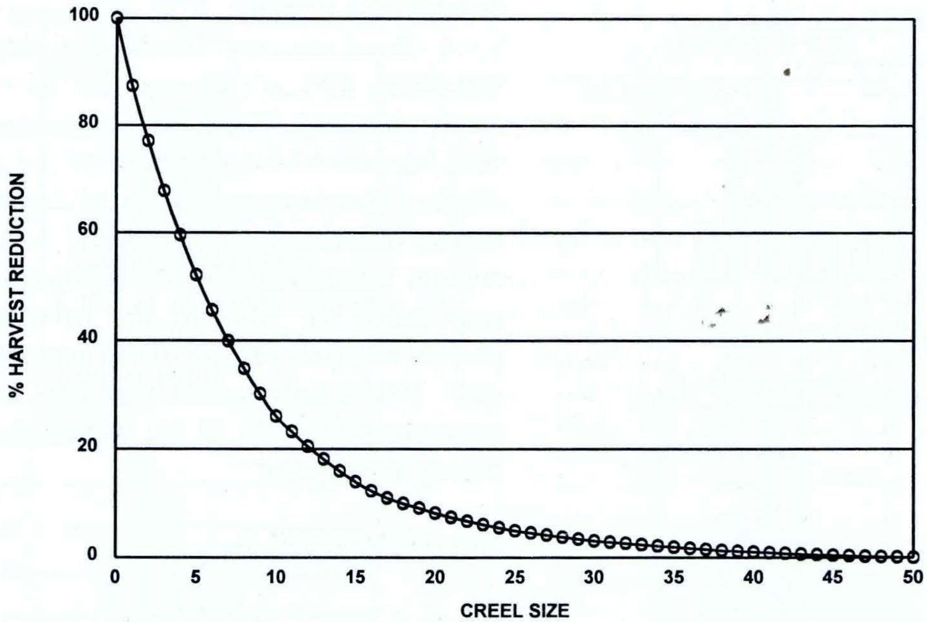


Figure 9. *A summary of the effect various creel limit restrictions would have upon crappie harvest at Rathbun Lake. Relationships are based on data from completed trips by anglers targeting crappie, 1991, 1992 and 1994.*

The following examples show how the model can be used to predict the impact of harvest restrictions on the fishery. The current rate of exploitation of crappies at Rathbun can be as high as 40%. The manager would like to reduce the daily bag limit such that exploitation would be 30%.

The first step is to determine the percentage reduction in harvest that would be required to decrease exploitation rate to 30%. The following relationship can be used to determine this reduction.

$$H = \frac{CE - DE}{CE}$$

where CE = The current annual exploitation rate

DE = The desired level of exploitation

H = Necessary reduction in harvest (proportion of total harvest).

In this example, CE = 40% and DE = 30%. Thus, (H) or total harvest of crappies must be reduced by 25% to attain 30% exploitation. Next, this value is applied to the first equation:

$$X = \left(\frac{0.250+1}{2.0724}\right)^{-5.0246} - 1 = 11.7$$

or 12 fish per day. Thus, a restriction of 12 crappies per day would be necessary to decrease exploitation by from 40% to 30%.

In another application the affect of a 25 fish daily bag limit on the crappie fishery can be assessed.

$Y = 2.0724\ (25 + 1)^{-0.1992} - 1 = 0.083$ or approximately 8%.

Thus, the implementation of a 25-fish daily limit would, on the average, reduce the harvest by only 8%.

Size Limits Use of the GIFSIM simulation model showed yield would decrease if minimum size limits of 9 and 10 inches were imposed on crappie at Rathbun Lake. Current yield of crappie with no size limit was estimated at 4 lb/ac; however, with 9 and 10 inch size limit restrictions, estimated yields decreased to 3.5 and 2 lb/ac at an exploitation rate of 17% (Figure 10). With a much higher exploitation rate of 55%, yield was slightly greater under a 9-inch limit, but decreased drastically at the 10-inch limit.

regulations became more restrictive. For example, currently about 35% of the crappie caught are released (17% exploitation, no size limit). However, at the same exploitation rate, under a 10-inch minimum size limit, about 90% of the fish would have to be released (Figure 12). Also, as regulations became more restrictive, more fish perished from hooking loss. At a modest 10% hooking mortality, under a 10-inch minimum limit, an equal number of fish would perish from hook-and-release (4 per acre) as would be harvested (4 per acre) (Figure 13).

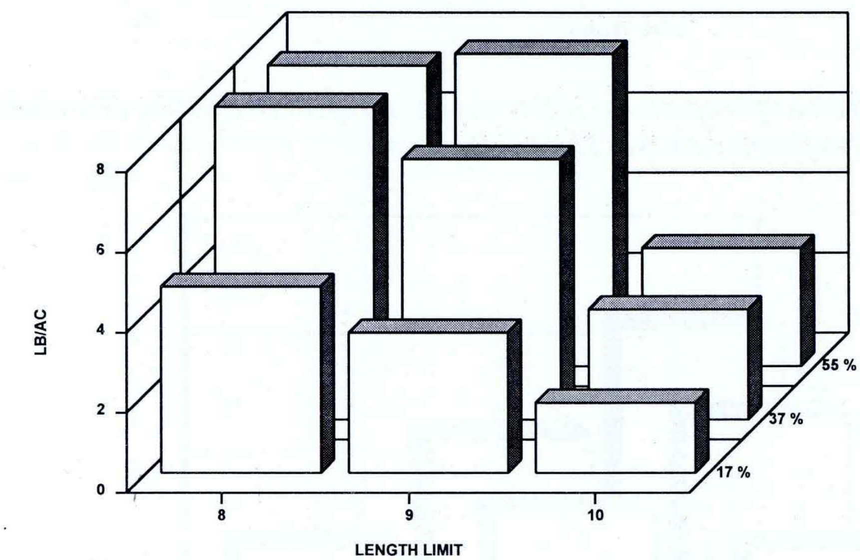


Figure 10. *Predicted yield of crappie, in lbs per acre, to the sportfish harvest regulated by three harvest restrictions and subjected to three levels of exploitation at Rathbun Lake.*

As harvest scenarios became more restrictive, angler's catches decreased accordingly. Crappie harvest, given a 17% level of exploitation, was estimated to decrease by about 75% with the 10-inch restriction and 30% with a 9-inch restriction (Figure 11). This reduction in catch, as harvest restrictions increased, was very pronounced even at higher exploitation rates.

Likewise, percentage of crappie caught which were larger than the minimum size decreased precipitously as simulated

To test the affect of a 10-inch length limit on a realistic situation, the foregoing information was applied to creel survey statistics collected on the fish harvested by anglers at Rathbun Lake since 1972. Analysis in the previous segment was based on the GIFSIM model which included the assumptions of equilibrium yield and constant recruitment. In the real world these constraints do not exist. Therefore, the following treatment will deal with realistic statistics including variable recruitment rate and variable

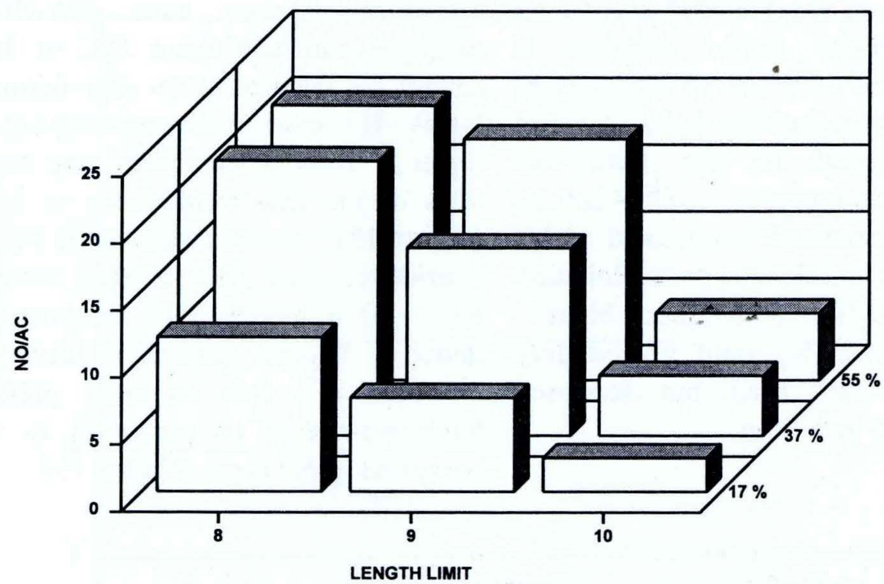


Figure 11. *Predicted catch of crappie, in number per acre, regulated by three restrictions and subjected to three levels of exploitation at Rathbun Lake.*

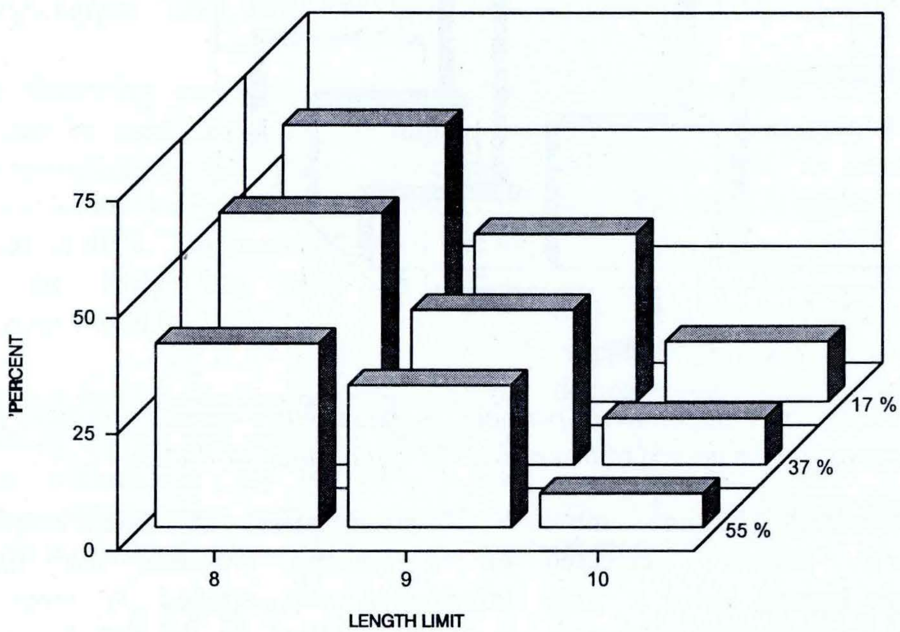


Figure 12. *Predicted percent of crappie harvested of the total number caught. These data are based on three harvest restrictions and subjected to three levels of exploitation at Rathbun Lake.*

catch statistics. An example is 1987 when 410,626 crappies were harvested at Rathbun Lake. If a 10-inch size limit had been imposed, the estimated harvest would have been 219,399 crappies or a reduction of nearly 50% (Figure 14). A three-fold reduction in harvest would have occurred if this regulation would have been in place during 1993.

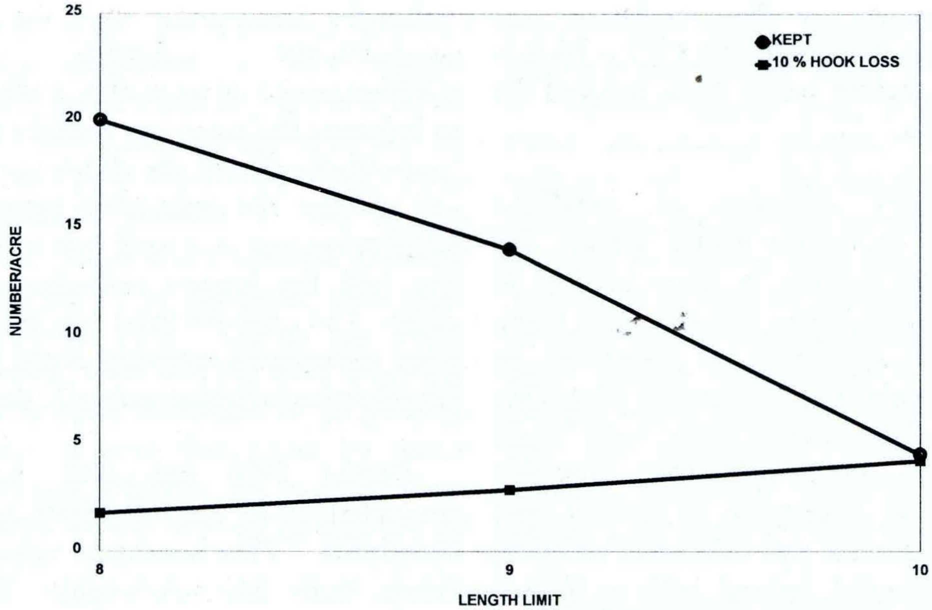


Figure 13. *Predicted number of crappie harvested, and the estimated hooking loss in number per acre, from three harvest restrictions which result, and an exploitation rate of 37% at Rathbun Lake.*

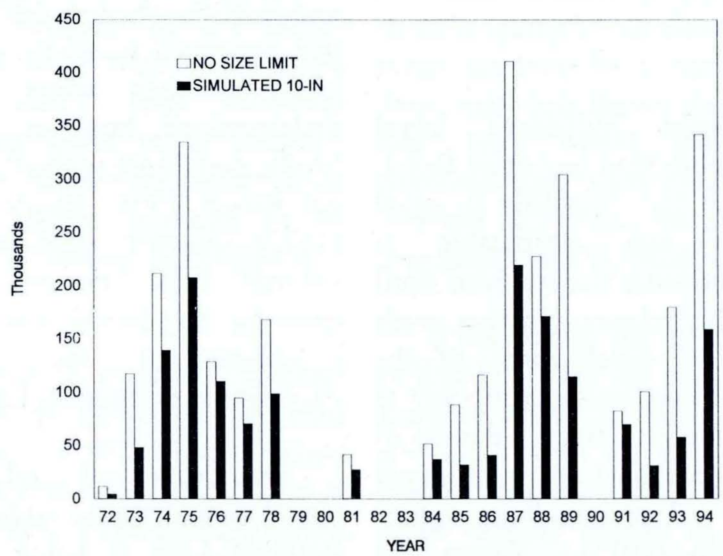


Figure 14. *A comparative summary of the impact of a 10-inch minimum length limit restriction on the harvest of crappie at Rathbun Lake is made with the unrestricted sport angler harvest of crappie documented at the lake.*

Length limit regulations would have resulted in the most severe curtailment in crappie harvest when the harvest was increasing from year-to-year. Conversely, harvest reduction would have been least impacted when harvest was on downward trend. The best example of this occurred in 1973-1975 when the crappie harvest was on an upward trend. The prediction indicated crappie harvest would have been reduced by about

45%. However, as the population was declining, such as in 1976 and 1977 a 10-inch size limit restriction would have reduced the harvest by 17%.

The primary objective of restrictive regulations is to reduce angler harvest and redistribute the harvest to more anglers in future months and years. The important point, however, is regardless of increasing or decreasing populations, the harvest of crappie at Rathbun Lake would have been much reduced under a 10-inch length limit compared to no regulation. During the 18 years of creel surveys, total harvest was 3,011,400 crappies, while the estimated harvest with a 10-inch minimum size restriction would have been 1,640,000. Anglers would have been denied the harvest of nearly 1.4 million crappies, or about 78,000 fish annually.

DISCUSSION

Floodwater storage influenced larval crappie abundance more than any other factor. Thirty-one percent of the variability in age-0 crappie abundance was attributable to acre-feet-days of floodwater storage from April through August. This relationship was much stronger during early development of the reservoir from initial impoundment in 1969 to 1980, when 90% of the variability in density of age-0 crappie was accounted for by summer floodwater storage. These findings agreed with those of Keith (1975), Groen and Schroeder (1978), and Aggus (1979).

Temperature also influenced crappie spawning, but only to the extent that a threshold of about 60°F was required to begin spawning. A gradual, steady temperature rise during the spawning season with minimal fluctuations, as in 1980, yielded the most coherent production of age-0 crappies. Although temperature was the paramount environmental influence on the commencement of spawning, it did not appear to influence the duration. Rapidly rising water temperatures during the spawning season did not shorten the spawning period - water temperature rose at a rapid rate in 1981, which also had the longest spawning season (47 days). The opposite trend was noted in 1982, when temperature increased at the slowest rate yet spawning subsided within 27 days.

During 1980 and 1982, turbidity accounted for 49% of the variability in crappie abundance. Two important inferences were drawn from this relationship: first, young crappies were never observed if Secchi disk readings were 2 inches or less; second, crappie abundance increased at a geometric rate as water clarity increased to values above 25 inches of Secchi disk depth. The mechanisms that prevented spawning or survival of young crappies when water was turbid were undetermined; however, at these low light levels, nests were probably abandoned. Breder and Rosen (1966), Vasey (1973), and Coutant (1975) reported inhibition of spawning at reduced light intensity. Suffocation of embryos in turbid conditions could also contribute to the poor reproduction experienced at Rathbun Lake

Knowledge of relationships between abundance of young crappies and turbidity at Rathbun Lake is being used to select key spawning areas on the lake for protection by bank armoring and breakwater jetties. This protection would benefit the fishery in two ways. First, turbidity, wind, and molar action would be greatly reduced. Second, in addition to protecting spawning and nursery coves, the structures would benefit anglers by attracting fish.

Evaluation of the effects of wind action on larval crappie abundance indicated slightly more than 2% of the variability in catch values was due to wind. Although this value was not significant, sustained high winds over a great fetch consistently resulted in low crappie numbers. The two extremes were the protected embayments and coves compared with areas on the windswept pool. Kramer and Smith (1962) reported wind was the most important factor in year-class formation of largemouth bass because of nest destruction by molar action. Crappies, likewise, are nest spawners and are subject to nest and egg destruction by strong winds.

Substrate firmness at Rathbun Lake, as measured by penetration, showed a parabolic relationship with young crappie abundance. High catch per effort was associated with moderate substrate firmness of 4-8 inches penetration. Littoral zones with values below 1.5-inches and greater than 10-inches penetration produced fewer larval crappies. Soft substrate that produced penetration values of 14 inches or greater appeared to be unsuitable for crappie nesting and survival of the young.

Hansen (1951, 1965) reported crappies used a wide variety of substrates, but most used hard clay. Vasey (1973) observed nests on dirt or fine gravel with exposed root hairs of nearby inundated plants. Both authors agreed some growth of plants such as *Chara* sp., *Elodea* sp., or filamentous algae, occurred in or next to crappie nests. Most substrate types in this investigation were silt, clay, and clay overlain by silt. Sand, gravel, and rock were less common.

Abundance of age-0 crappies at Rathbun Lake was influenced by water storage regimes, by turbidity, and to a lesser degree by temperature, substrate firmness, and wind. During the study period (1971-1989), estimated densities of age-0 crappies during the summer ranged from 0 to 4,235/acre. These year-classes produced annual angler catches of 11,500-410,600 crappies. Information attained from standardized townet sampling at Rathbun Lake has been and will continue to be used to predict angler harvests for future fishing years. Although the extent of water storage was linked with year-class strength, exact cause-and-effect relationships were not determined. The causes were probably associated with protection from predators and more abundant food supplies.

These findings, combined with the results of other studies, can provide guidelines for the development of water storage regimes beneficial to fish populations and angling at Rathbun. For example, a plan to store water in early spring to an elevation of 908 ft above mean sea level by 1 April, held there until 1 June, and then drawn down to 904 ft during late June would generate 2.3 million acre-feet-days. Such a plan would result in an increase in harvest, on average, of 163,000 crappies during the following 4 years.

Dynamics of the adult crappie population in Rathbun Lake are similar in many ways to characteristics at other reservoirs in the midwest, with the exception that Rathbun crappie tended to grow slower. In Missouri, white crappie lengths at age 3 at Stockton, Pomme de Terre, Lake of the Ozarks and Wappapello were 10.1, 9.5, 9.1, and 8.6 inches (Colvin 1991a). Crappies at Fort Supply Reservoir in Oklahoma averaged 11.0 inches after 3 years of growth (Boxrucker 1994). Average length of age 3 crappies at Clinton Lake, Illinois, was 10.1 inches (Lutterbie 1993), while Rathbun Lake crappies averaged 8.1 inches at age 3.

Slower growth was undoubtedly a function of the shorter growing season experienced by Rathbun Lake crappie. South Dakota crappies, for example, averaged 8.2 inches at age 3 in Lake Goldsmith (Guy and Willis 1994). This was nearly identical to lengths attained by Rathbun Lake crappies.

Slower growth could also have been a function of density and trophic competition with white bass, largemouth bass and walleye. Mitzner (1980) found when forage fish abundance was sparse at Rathbun Lake, white crappies < 8 inches were relegated to feeding on plankton for subsistence.

Body condition of crappies at Rathbun Lake was equal to or greater than body condition of crappies at other reservoirs. This finding indicated trophic competition did not limit growth. Lowest W_r-values for crappies at Rathbun Lake occurred in 1990 and the spring of 1991 with monthly averages of < 85. Poor body condition during this period was probably the result of high density and biomass of crappies the previous year. The 1989 crappie population estimates were 92 per acre and 29 lbs per acre. This was the highest crappie biomass during 11 years of cove sampling. W_r-values after the spring of 1991 were all greater than 85 and averaged 92 during the remainder of the study. Crappie populations in the United States had an overall value of 93 (Neumann and Murphy 1991).

Crappie harvest statistics estimated for the sportfishery at Rathbun Lake were slightly below those of study lakes in Missouri (Colvin 1991a) and Illinois (Lutterbie 1993). Rathbun Lake crappie harvest ranged from 4 to 37 / acre, averaging 16 / acre. Angler harvests at four Missouri study lakes ranged from 7 to 41 crappies / acre with an overall average of 22 / acre. Harvest at Clinton Lake, IL ranged from 6 to 110 / acre, averaging 59 / acre. At many other lakes, however, crappie sportfish harvest was lower than Rathbun Lake. Fort Supply Reservoir, OK averaged 13 / acre (Boxrucker 1994). Three Texas lakes averaged 0.18 crappie harvested / acre over a 4-year period and the range in harvest was 0.05 to 0.42 crappie / acre (Webb and Ott 1991). Three Georgia reservoirs, involved in a 2-year study, yielded crappie sportfish harvests of 2 to 16 crappies / acre with an average of 9 / acre (Larson et al 1991).

Whether harvest is high, intermediate or low, the question of restricting crappie harvest has been raised over the last two decades, particularly in the midwest. Generally the trend is toward more restrictive crappie harvest. Evidence of this trend was shown at the Crappie Biology and Management Symposium held in 1990, where five papers dealt with harvest restriction (Hooe, 1991). The two basic forms of restrictions used are bag limits and size limits.

Studies completed to date agree bag or creel limits, unless very restrictive, have little influence upon crappie populations. At Rathbun Lake a creel limit of 10 fish would reduce the crappie harvest by only about 20%. A daily creel limit of 8 crappie would be required to reduce the harvest by 30%. Similar findings were presented by Colvin (1991b) where a 10-daily bag limit was required to reduce harvest by 23%, 26%, and 25% at Stockton, Wappapello and Lake of the Ozarks. Overly restrictive daily creel limits may be questionable from a practical standpoint. It is doubtful local businesses associated with the fishery (such as bait vendors, marinas and motels) would favor such highly restrictive regulations because it would result in decreased income. Many anglers, particularly from surrounding states, would find it less desirable to travel and fish such a restricted fishery.

Size limit restrictions may be justified if crappie growth is rapid, rate of angler exploitation is high and/or recruitment is a major problem. These conditions are not present at Rathbun Lake. Growth is more rapid than at many, smaller Iowa fishing lakes, but cannot be considered high when compared to other midwestern reservoirs. Natural mortality would negate the potential benefit of a restrictive harvest at Rathbun Lake. A restriction in crappie harvest would allow more fish to perish from natural causes before they become vulnerable to fishing. A 10-inch minimum length limit restriction on crappie harvest at Rathbun Lake, for example, would require a period of 5 years for crappie to grow to harvestable size. Many fish during this period would have succumbed to natural causes or hooking mortality. A 9-inch minimum length limit would require 4 years of growth for crappie to enter the fishery.

Equilibrium yield statistics show a 10-inch length restriction would probably be totally unsatisfactory because the harvest would be reduced by 50% and crappie loss due to hooking mortality would equal that harvested. A 9-inch minimum length limit, although more realistic, would still be unsatisfactory. Harvest would be greatly reduced with little benefit to the population.

Exploitation rate at Rathbun Lake was not precisely estimated, yet it could not have been excessive, because age structure showed a fair number of 4+ crappies. Total annual mortality was not excessive, averaging about 50%. Fishing mortality was at least 20% and may have approached 40% on occasion. Crappie populations in Missouri reservoirs experienced much higher rates of exploitation where total annual mortality was 70%-80%, with most of that due to fishing mortality (Colvin 1991a).

The only justification for minimum size limit restriction at Rathbun Lake might be based on inconsistent and sporadic recruitment. However, missing year classes are uncommon at the lake. Young-of-year crappie abundance showed densities below 100 / acre in only 7 out of 24 years and these were usually followed by one or two strong year classes, therefore, the population, as it entered the fishery, was buffered by a mixture of strong and weak year classes. There were only two years where YOY density was 92 per acre. The median density was 56 per acre during 11 years of cove sampling. There is no doubt that if a size limit had been imposed, some crappie would have been saved for harvest a year later. However, as Figure 14 shows, the total harvest would never have equaled the harvest without a size restriction.

This study evaluated juvenile and adult populations, angler harvest, and important environmental factors that influence the well-being of crappie in Rathbun Lake. This investigation determined the most important influence on the well-being of the crappie population was not angling, as many had thought, but rather the abundance of crappie recruiting to the fishery at age 2 and 3. Recruitment was, in turn, a function of combined environmental variables, of which water level was most important.

RECOMMENDATIONS

1. The Iowa Department of Natural Resources should request the Corps of Engineers to revise the reservoir water management plan and address benefits to the recreational fishery. Water level management as described by Mitzner (1981), and experiences from Beam (1983) and Groen (1978) can provide a basis for developing a water level management strategy for Rathbun Lake. The plan should encourage a 4-foot elevated water level in April-June, followed by a return to normal elevation in July. This plan should be written and authorized through a cooperative effort with the Corps of Engineers; such a plan should become an integral segment of the operation procedures at Rathbun Lake.

2. Knowledge of relationships between abundance of young crappies and turbidity at Rathbun Lake is being used to select key spawning areas on the lake for protection by bank armoring and breakwater jetty construction. This protection will benefit the fishery in two ways. First, turbidity, wind, and molar action would be greatly reduced. Second, in addition to protecting spawning and nursery coves, the structures would benefit anglers by attracting fish.

3. Improved soil conservation practices, water level management, and shoreline protection should be included in a comprehensive fisheries management plan for Rathbun Lake. Such a strategy should be completed as soon as possible, with consideration to predator fish stocking, forage fish management and harvest regulations. Implementation of the plan would result in a sport fishery approaching optimum yield.

4. Maximum use of the sportfishery at Rathbun Lake should be viewed for both fishing success and angler use. Moreover, angler success and use should become elements in the overall goal of the fishery management program. A realistic level of success should be set at 0.8 to 1.2 fish per hour, a range that prevailed in the mid-1970's, and certainly within the realm of attainment.

5. Restrictive crappie harvest of Rathbun Lake is not necessary at the present rate of exploitation. The single most important factor in the success of the crappie fishery at Rathbun is crappie recruitment to age 2 and 3, not harvest restriction.

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