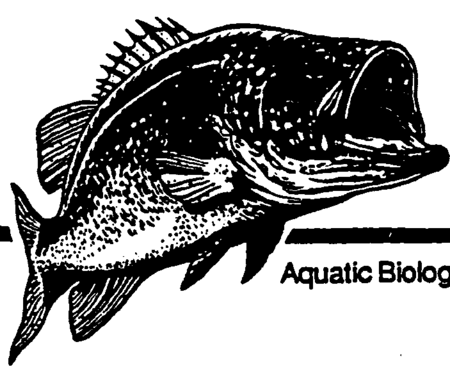
ILLINOIS NATURAL HISTORY SURVEY

EVALUATION OF THE INTRODUCTION OF TIGER MUSKELLUNGE INTO IMPOUNDMENTS DOMINANTED BY THE BASS-BLUEGILL COMBINATION, EVALUATION OF A PARTIAL CREEL, AND SIZE-SPECIFIC SURVIVAL OF STOCKED CHANNEL CATFISH

Aquatic Biology Section
Technical Report

Ted W. Storck and Dennis L. Newman



Final Report
Federal Aid Project F-40-R

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EVALUATION OF THE INTRODUCTION OF TIGER MUSKELLUNGE INTO IMPOUNDMENTS DOMINANTED BY THE BASS-BLUEGILL COMBINATION, EVALUATION OF A PARTIAL CREEL, AND SIZE-SPECIFIC SURVIVAL OF STOCKED CHANNEL CATFISH

Federal Aid Project F-40-R

by

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Study 101. Impact of tiger muskellunge on resident bass-bluegill populations.

OBJECTIVE: To evaluate the effectiveness of the introduction of tiger muskellunge as a management tool to increase sport fish harvest and to provide management recommendations.

DESCRIPTION OF THE STUDY AREA: Ridge Lake, a 6.1-ha impoundment in Coles County, Illinois (Fig. 1), was constructed by impounding Dry Run Creek, an intermittent stream flowing through Fox Ridge State Park. The original area of the lake at overflow level was 7.3 ha, with a maximum depth of 7.6 m, but the current surface area is 6.1 ha. The primary overflow structure at Ridge Lake, a tower spillway, discharges water from the lake bottom into a wolf-type weir below the dam. When the capacity of the tower spillway system (0.71 cms) is exceeded, water is discharged over the surface spillway. The elevation of the surface spillway is 0.3 m above that of the tower spillway. A further description of the physical characteristics of Ridge Lake may be found in Bennett (1954).

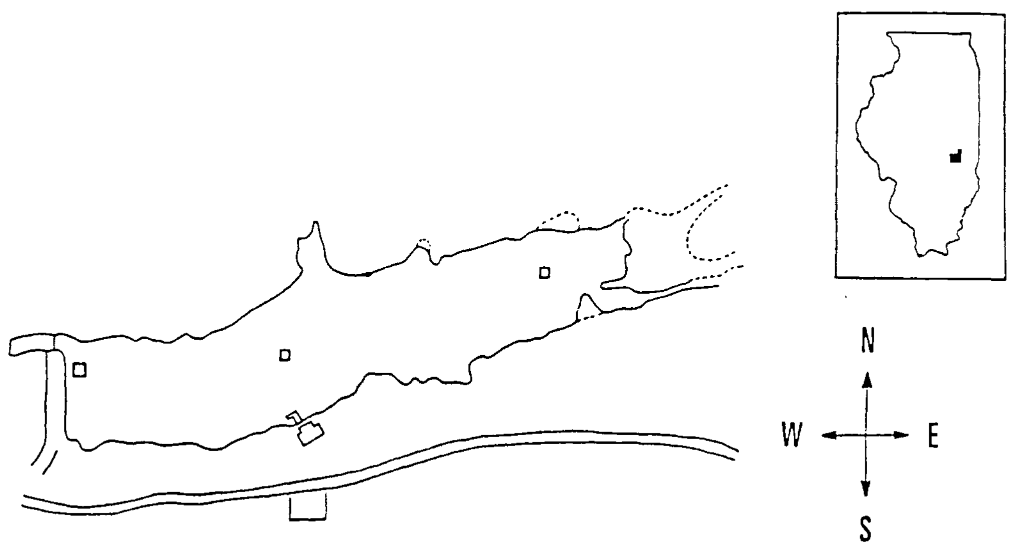

Fig. 1. Ridge Lake, a 6.07-ha impoundment located in Fox Ridge State Park, Coles County, Illinois.

Ridge Lake was drained in October 1980 (Burkett *et al.* 1981) and restocked during the summer and autumn of 1981 (Table 1). The adult largemouth bass, *Micropterus salmoides*, were offspring of original Ridge Lake stock (Bennett *et al.* 1969), while yearling bass were obtained from Coffeen Lake (N = 113) and Lake Shelbyville (N = 358) (Table 1). Bluegills, *Lepomis macrochirus*, (N = 1,026) were taken principally from Lake Shelbyville. Adult channel catfish, *Ictalurus punctatus*, (N = 179) were held over from the 1980 draining of Ridge Lake; yearling catfish were purchased. The tiger muskellunge stocked in autumn 1981 were raised to 125 mm TL on a dry pellet diet; after transport to Illinois, they were conditioned to a fish diet in nursery ponds. Contaminant species present in Ridge Lake included black crappie, *Pomoxis nigromaculatus*, and green sunfish, *L. cyanellus*.

Table 1. Stocking summary for Ridge Lake, 1981 and 1982.

Species	Year	Number stocked	Weight (kg)	No./ha	kg/ha	Mean length (mm TL)
Largemouth bass	1981					
Yearlings		471	25	78	4	170
Adults		416	116	68	19	278
Bluegill	1981	1,026	--	169	--	--
Channel catfish	1981					
Young-of-year		435	--	72	--	204
Adults		179	242	30	40	517
Tiger muskellunge	1981	151	--	25	--	238
	1982	75	--	12	--	221

Two other central Illinois impoundments that contained established centrarchid populations and stocked with tiger muskellunge, Allerton Lake (6.1 ha) in Piatt County and Lake of the Woods (10.1 ha) in Champaign County, were sampled at monthly intervals to evaluate growth and food habits of tiger muskellunge. Elks Pond (1.2 ha) in Champaign County was also sampled in autumn to evaluate the impact of tiger muskellunge on the size structure of its bluegill population.

Job 1. Stocking tiger muskellunge.

OBJECTIVE: To establish tiger muskellunge populations in four Illinois impoundments: Ridge Lake, Allerton Lake, Elks Pond, and Lake of the Woods.

INTRODUCTION: The supplemental stocking of a predator species has been used as a management tool to improve predator-prey balance and enhance the growth rate of the prey species. The tiger muskellunge (the F_1 hybrid of female muskellunge *Esox masquinongy* x male northern pike *E. lucius*) has been used in this capacity but has not been adequately evaluated. The purpose of this job was to establish populations of tiger muskellunge in four central Illinois lakes so that growth, food habits, angling vulnerability, and effects on resident bass-bluegill populations may be assessed.

METHODS: Age-0 pellet-reared tiger muskellunge (10-100 mm) were obtained from various sources over the 4 years of this study (Newman and Storck 1983, 1984, 1985). These fish were reared to larger sizes in small ponds that were stocked with various combinations of age-0 minnows, bluegill, and gizzard shad as forage. The tiger muskellunge were removed from the ponds by seining in summer or by draining in fall and were stocked in study impoundments during daylight hours.

Table 2. Stocking history of tiger muskellunge at four study lakes from 1981 through 1984.

Lake	Lake size (ha)	Year	Number stocked		Length (mm)	
			Total	No./ha	Mean	Range
Ridge Lake	6.07	1981	151	24.3	238	160-327
		1982	75	12.5	221	188-268
		1984	73	11.7	161	90-240
Allerton Lake	6.07	1982	150	24.2	225	190-292
Elks Pond	1.20	1982	20	16.7	193	153-226
		1983	6	5.0	215	170-252
		1984	10	8.3	175	150-200
Lake of the Woods	10.10	1982	250	24.8	193	153-226
		1984	49	4.9	180	132-203

RESULTS: Tiger muskellunge were stocked at high densities in the study impoundments (Table 2) to evaluate their maximum impact on bass-bluegill combinations and to provide a larger sample size for food habits and hooking mortality estimates. With the exception of the 1984 stocking of tiger muskellunge in Ridge Lake (Job 8), our objective was to maximize survival of stocked fish. Survival of tiger muskellunge is positively correlated with size at stocking (Stein *et al.* 1981, Johnson 1978), and is substantially greater for forage-reared than for pellet-reared individuals (Andrews 1983, Johnson 1978, Gillen *et al.* 1981). Consequently, we fed tiger muskellunge live forage in rearing ponds before stocking them into impoundments containing predators. Although a stocking size of 200 mm is considered necessary to insure a good survival rate of tiger muskellunge in impoundments containing established predator populations, it was often necessary to stock them at a smaller size (Table 2).

Job 2. Tiger muskellunge impact on bluegill.

OBJECTIVE: To determine the impact of tiger muskellunge introductions on growth rates, size structure, and standing crops of bluegill.

INTRODUCTION: When bluegill become too abundant in small impoundments, they grow slowly and frequently suppress largemouth bass recruitment. The size composition and abundance of the resulting predator and prey populations do not provide optimum sport fishing opportunities. Traditional management techniques employed to increase bluegill harvest assume that a sufficient reduction in bluegill density can stabilize recruitment, increase the growth rate, and ultimately produce a desirable population size structure. Bluegill density may be reduced by mechanical removal, by increasing angling harvest, by selective chemical rehabilitation, or by increasing predation pressure. The supplemental stocking of a large predator species has been recommended as a management tool to reduce prey abundance and thus enhance the growth rate of the prey species (Anderson 1973). The tiger muskellunge has been used, but inadequately evaluated, as an additional predator. This job tested the hypothesis that a supplemental stocking of tiger muskellunge can influence bluegill density sufficiently to elicit compensatory increases in growth rate and thus improve population structure.

METHODS: Elks Pond, a 1.2-ha impoundment in Lake of the Woods Park, Champaign County, was selected as the principal site for this research because it had a poorly structured, slow-growing bluegill population (Newman and Storck 1983). Other species present included largemouth bass, green sunfish, golden shiner, blackstripe topminnnow, and white crappie. In addition, a high density of tiger muskellunge was stocked into Elks Pond in the fall of 1982, 1983 and 1984 (Table 2).

The pond was sampled annually in the fall (1982-1985) with a 230-v AC electrofishing unit. With the exception of bluegill, electrofishing catch rates were low for all species (Newman and Storck 1983).

All bluegill collected at Elks Pond were measured to the nearest mm and a subsample of 10 fish from each 1-cm length group was aged. Ages were determined from scales in 1982 and 1983 and from otoliths in 1984 and 1985. Otoliths were viewed in the sagittal plane at 40x using a dissecting microscope and at 40-100x using a phase-contrast microscope. By viewing the otoliths in the sagittal plane at high magnification, the spacing patterns of daily rings could be used as an aid in discerning annular marks. Otolith-determined ages were probably more accurate than those using scales, but differences in the accuracy of the two aging methods could not have altered the conclusions drawn below. Criteria and formulae for analysis of proportional stock density (PSD) followed Novinger and Legler (1978).

RESULTS:

Elks Pond. Bluegill PSD in Elks Pond was very poor in 1982 and did not improve in the 3 years following the introduction of tiger muskellunge (Table 3). Also, the electrofishing catch rate of

Table 3. Age structure (%), PSD, RSD_{200}, and electrofishing catch rates of bluegill collected in fall electrofishing samples at Elks Pond 1982-85. Mean lengths at capture in parentheses.

Year	Age group I	II	III	IV	V	PSD	RSD_{200}	Catch of stock-size fish/ electrofishing minute
1982	82(89)	15(119)	2(130)	1(145)	--	0.5	0	3.3
1983	42(95)	10 (98)	7(122)	32(136)	9(144)	3.2	0	1.5
1984	88(93)	6(121)	2(135)	3(157)	--	4.0	0	2.5
1985	87(91)	13(139)	0	0	--	0.0	0	2.9

stock-size fish (>75 mm) remained relatively constant over the 4 study years. Growth of all age groups of bluegill was slow in all years. Mean lengths at capture of age groups I-IV in the fall were consistently below an Illinois average of 102, 134, 158, and 162 mm, respectively, for the same age groups (Carlander 1977). However, poor survival to age II, rather than slow growth or inadequate recruitment to age I, was responsible for the poor population size structure of bluegill (Table 3).

Bluegill recruitment in Elks Pond was apparently adequate because age-I fish made up a large fraction of the population in all years. Reasons for the subsequent decline in abundance of age-II fish were not identified, but high predation pressure was an unlikely cause because electrofishing catch rates indicated that stock-size largemouth bass were not abundant. Further, survival of stocked tiger muskellunge was apparently very low in Elks Pond because only two individuals were collected in the three fall electrofishing censuses. The ability of tiger muskellunge to influence bluegill density, and hence their growth rate, could not be evaluated at Elks Pond because tiger muskellunge survival was low and because overpopulation by age II and older bluegill was not responsible for the poor population size structure.

Ridge Lake. The analysis of the Ridge Lake data is incorporated into Job 11.

Job 3. Tiger muskellunge impact on largemouth bass.

OBJECTIVE: To determine the impact of tiger muskellunge on the standing crop of largemouth bass in Ridge Lake.

RESULTS: The findings of this job are incorporated into Job 11.

Job 4. Tiger muskellunge food habits.

OBJECTIVE: To determine the food habits of tiger muskellunge in centrarchid-dominated impoundments.

INTRODUCTION: The management potential of the tiger muskellunge depends as much on its impact on other fish species as on its contribution to the sport fish harvest. To obtain the desired management objective of controlling panfish populations without compromising the harvest potential of largemouth bass, the tiger muskellunge must consume bluegill in preference to largemouth bass. This job examined the food habits of the tiger muskellunge in Allerton Lake, where bass, bluegill, and crappie were the principal potential prey species, and in Lake of the Woods, where bass, bluegill, redear sunfish, and gizzard shad were the principal prey choices.

RESULTS:

Allerton Lake. Only 18 of 40 tiger muskellunge collected at Allerton Lake during 1982-1985 contained food. In 1985, only four hybrids were captured in the electrofishing collections and none contained food. The number of tiger muskellunge sampled declined in successive years, reflecting a reduction in abundance and a size-dependent decrease in vulnerability of larger fish to electrofishing gear.

Yearling and older bluegill and crappie were the principal prey items in the diet of tiger muskellunge in Allerton Lake in 1983 and 1984 (Table 4). Only two age-0 largemouth bass were eaten, both in 1983 when the tiger muskellunge were 1 year olds.

Table 4. Stomach contents of tiger muskellunge collected at Allterton Lake and Lake of the Woods at monthly intervals from March through October, 1983-1985. V = percent volume; F = percent frequency; N = number of tiger muskellunge containing food.

	Allerton Lake						Lake of the Woods					
	1983		1984		1985		1983		1984		1985	
Food items	V	F	V	F	V	F	V	F	V	F	V	F
Fish												
Bluegill	33	21	18	25	--	--	--	--	--	--	--	--
Lepomis spp.	3	7	--	--	--	--	--	--	--	--	--	--
Largemouth bass	10	14	--	--	--	--	--	--	--	--	--	--
Pomoxis spp.	32	14	79	50								
Gizzard shad	--	--	--	--	--	--	80	50	100	100	100	100
Unidentified fish	18	36	3	25	--	--	19	25	--	--	--	--
Crayfish	4	7	--	--	--	--	--	--	--	--	--	--
Insecta	<1	7	--	--	--	--	--	--	--	--	--	--
Plant matter	<1	7	--	--	--	--	1	25	--	--	--	--
N		14		4		0		4		2		1
Mean total length (mm) of tiger muskellunge		312		517		640		429		604		659

Lake of the Woods. Only seven of 40 tiger muskellunge collected at Lake of the Woods during 1982-1985 contained food (17%). This percentage is low but probably did not reflect inadequate prey availability; captured tiger muskellunge were generally in good condition and their growth was similar to that in other impoundments. Similarly, Andrews (1983) found that only 27% of tiger muskellunge contained food (N = 59). In Lake of the Woods, 5 of the 7 tiger muskellunge containing food had eaten only shad (Table 4). Age-I tiger muskellunge ate age-0 shad while age-II and older hybrids ate adult shad. The adult shad eaten by the large hybrids were larger than those vulnerable to most adult largemouth bass (Storck 1986).

In addition to the limited food habits data available from Allerton Lake and Lake of the Woods, bluegill were regurgitated by three tiger muskellunge being held in the hooking mortality study at Ridge Lake in 1985. The predominance of gizzard shad in the diet of tiger muskellunge at Lake of the Woods and of bluegill and crappie at Allerton Lake and Ridge Lake is consistent with the findings of other researchers. Weithman and Anderson (1977*a*) found that gizzard shad were more vulnerable to predation by yearling tiger muskellunge than were either bluegill or largemouth bass. Wahl and Stein (1984) found that gizzard shad dominated the diet of yearling tiger muskellunge in an 89-ha impoundment that also contained centrarchids. Further, Andrews (1983) and Wahl and Stein (1984) found that tiger muskellunge ate mostly *Lepomis* spp. in impoundments lacking shad. Neither study reported the occurrence of largemouth bass in the diet of tiger muskellunge. Thus there was no evidence either in the current study or in published accounts to indicate that tiger muskellunge eat substantial quantities of largemouth bass.

Job 5. Prey selection of the tiger muskellunge in small ponds.[1]

OBJECTIVE: To determine the food preferences of tiger muskellunge when the choice is limited to bluegill and largemouth bass.

INTRODUCTION: Laboratory and field results indicate that although esocids prefer soft-rayed species, they will use spiny-rayed fish as forage (Mauck and Coble 1971, Weithman and Anderson 1977*a*). However, to obtain the desired reduction in bluegill density, the introduced esocid (in this case, tiger muskellunge) must consume bluegill in preference to largemouth bass. No studies have been reported that evaluate tiger muskellunge prey selection when bluegill and largemouth bass are the only forage available. This job monitored prey selection of tiger muskellunge in small ponds containing equal numbers of largemouth bass and bluegill.

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[1]No work was scheduled for this job in 1985; the results reported by Newman and Storck (1983) are reprinted here.

METHODS: Tiger muskellunge food preferences were examined in three 0.4-ha ponds (maximum depth 1.3 m) located at the Illinois Natural History Survey Field Research Laboratory, Champaign. The three ponds (A, B, and C) were drainable and were filled from the municipal water supply. To allow the chlorine to dissipate, the water was "aged" for 2 days prior to adding fish. The experiment was repeated four times from May through October 1982. Two experimental ponds and one control pond were used for each replication. Each experimental pond received equal numbers of vulnerable-size largemouth bass and bluegill and 1-2 tiger muskellunge. The control pond, which received equal numbers of bass and bluegill but no tiger muskellunge, provided an estimate of mortality caused by factors other than tiger muskellunge predation. The numbers and sizes of bass and bluegill stocked in each pond varied between replications, depending on availability. The duration of each replication ranged from 13 to 26 days, depending on season and the number of tiger muskellunge stocked in each experimental pond.

The tiger muskellunge (TL = 815-892 mm) used in this study were collected from Clinton Lake in April 1982. Bass and bluegill were collected from several impoundments in central Illinois, primarily from Lake Shelbyville. Initially, all fish were transported to Champaign in aerated water, treated with 0.5% NaCl. Beginning in June, quinaldine (1 ppm) and acriflavin (2 ppm) were also added to the water to reduce stress and subsequent mortality. Fish used in consecutive replications (*i.e.*, tiger muskellunge and largemouth bass) were held in floating live cages in an adjacent pond prior to restocking.

RESULTS: The initial experiment began 11 May when all ponds were stocked with two size groups of largemouth bass and bluegill (Table 5). Prey densities equalled 1,000/size group · ha. Pond A served as the control and ponds B and C received two tiger muskellunge each. Ponds were drained on 24 May and all surviving fish were recovered. Mortality in the control pond was very high, with the percent recovered in some categories lower than that of the experimental ponds (Table 5). Therefore, no assessment could be made of tiger muskellunge prey selection.

On 28 May the experiment was repeated but terminated on 7 June due to large numbers of dead prey observed in all ponds. A third replicate was initiated on 10 June and completed on 25 June (Table 6). Initial prey densities were 925 fish/species · ha. Only one size category was used because prey species, particularly largemouth bass, were difficult to collect. Two tiger muskellunge were stocked in one pond and one tiger muskellunge in the other experimental pond. Tiger muskellunge appeared to select bluegill in preference to bass (Table 6). Bass mortality could not be attributed to tiger muskellunge predation because fewer bass survived in the control pond than in either experimental pond. In the control pond, bluegill mortality was 5.4% (N = 2) while it

Table 5. Tiger muskellunge prey selection experiment, 11-24 May 1982.

Pond	Stocked			Number recovered	
	No. stocked	Mean TL (mm)	Range	Recovered	Lost
Pond A (control)					
Small bass	40	125	115-135	25	15
Large bass	40	173	165-185	39	1
Small bluegill	40	106	95-115	6	34
Large bluegill	40	154	140-170	22	18
Pond B[1]					
Small bass	40	125	115-135	23	17
Large bass	40	173	165-185	35	5
Small bluegill	40	106	95-115	8	32
Large bluegill	40	154	140-170	16	24
Pond C[2]					
Small bass	40	125	115-135	27	13
Large bass	40	173	165-185	37	3
Small bluegill	40	106	95-115	6	34
Large bluegill	40	154	140-170	23	17

[1] Two tiger muskellunge, TL = 832 and 825 mm
[2] Two tiger muskellunge, TL = 892 and 865 mm

was 19% (N = 9) in each experimental pond, indicating that predation mortality occurred. Further prey selection experiments were not conducted during the summer because (1) it was believed that tiger muskellunge would be thermally stressed in such small ponds and would not feed normally; (2) prey species became difficult to collect and transport; and (3) the ponds were needed as nurseries for fingerling tiger muskellunge arriving from the hatchery.

A fourth replicate was conducted from 15 September through 11 October using prey densities of 1,000 fish/species · ha. Ponds A and C were stocked with one tiger muskellunge each and Pond B was the control. Numbers of bass and bluegills recovered were lowest in the control pond; therefore, mortality in ponds A and C could not be attributed to predation (Table 7).

High mortality in the control ponds in all but the third replicate compromised the value of this job. These rates may have been caused by (1) poor condition of bass and bluegill collected during the spring (*e.g.*, fungal infections) and (2) excessive handling and confinement of prey species. The prey species used for this job were collected by electrofishing, measured, transported, held in live

Table 6. Tiger muskellunge prey selection experiment, 10-25 June 1982.

Pond	Stocked			Number recovered	
	No. stocked	Mean TL (mm)	Range	Recovered	Lost
Pond A (control)					
Bass	37	163	131-184	29	8
Bluegill	37	143	122-164	30	7
Pond B[1]					
Bass	37	159	135-195	28	9
Bluegill	37	144	125-165	35	2
Pond C[2]					
Bass	37	159	133-184	34	3
Bluegill	37	140	126-163	30	7

[1] Two tiger muskellunge, TL = 830 and 825 mm
[2] One tiger muskellunge, TL = 863 mm

Table 7. Tiger muskellunge prey selection experiment, 15 September-11 October 1982.

Pond	Stocked			Recovered		
	Number stocked	Mean TL (mm)	Range	Number Recovered	Number Lost	Mean TL(mm)
Pond A (control)						
Bass	40	203	138-232	40	0	200
Bluegill	40	139	115-159	33	7	142
Pond B[1]						
Bass	40	203	138-232	38	2	206
Bluegill	40	139	115-159	26	14	139
Pond C[2]						
Bass	40	203	138-232	37	3	194
Bluegill	40	139	115-159	32	8	145

[1] One tiger muskellunge, TL = 825 mm
[2] One tiger muskellunge, TL = 863 mm

cages, remeasured, and then stocked. Because of the small size of the experimental ponds and the difficulty in obtaining adequate numbers of healthy prey, these experiments were not repeated; food habits of tiger muskellunge were determined based on Job 4.

Job 6. Growth of tiger muskellunge.

OBJECTIVE: To measure the growth of tiger muskellunge in impoundments in which bluegill and largemouth bass are the principal fish prey species.

INTRODUCTION: Growth of tiger muskellunge has been studied in experimental tanks and in natural systems (Weithman and Anderson 1977*a*, Beyerle 1971). However, growth under natural conditions where bluegill and largemouth bass are the principal prey species has not been studied nor has the time necessary to reach legal size been determined. Tiger muskellunge may not grow well where the principal forage is a deep-bodied, spiny-rayed fish such as bluegill (Tomcko 1982, Moody *et al.* 1983). Prey vulnerability studies have demonstrated that gizzard shad, goldfish, golden shiners, and other minnows are preferred over bluegill (Weithman and Anderson 1977*a*, Gillen *et al.* 1981). The purpose of this job was to measure and evaluate the growth of tiger muskellunge in a bass-bluegill dominated fishery.

METHODS: At Ridge Lake, annual growth of tiger muskellunge was evaluated using fish caught by anglers from 8 September through 14 October, 1982-1984; by electrofishing in late September, 1982-1984; and in the draining census, 1985. Because many fin clips had regenerated completely, too few individuals from the 1982 year class could be identified and growth could not be estimated. At Lake of the Woods and Allterton Lake, tiger muskellunge growth was evaluated using fish caught with electrofishing gear in September and October; too few tiger muskellunge were collected at both lakes in 1985 to evaluate growth.

RESULTS: Growth of tiger muskellunge in Ridge Lake compared favorably to growth reported for other centrarchid-dominated impoundments (Daggett Lake, Michigan; Round and Blue lakes, Indiana; Allerton Lake, Illinois) (Table 8). Mean lengths of age-I fish in Ridge Lake were very similar in the fall of 1982 (456 mm), 1983 (460 mm), and 1985 (453 mm). However, because they were stocked at a smaller size, the 1982 year class exhibited a greater annual growth increment than did the 1981 year class.

Tiger muskellunge from the 1981 year class achieved mean lengths in the fall of the year of 586, 646, and 755 mm at ages II, III, and IV, respectively. In 1984, the largest age-III tiger

Table 8. Mean lengths and ranges (mm) and annual growth increments (mm) of age I-III tiger muskellunge. At Ridge Lake, angler catch from 8 September through 14 October and electrofishing catch from late September were pooled to estimate mean lengths. Growth estimates from Round, Blue, and Daggett lakes were from collections in August and September.

		Age I			Age-II			Age-III		
Lake	Year	N	Length (mm) Mean (range)	Annual growth inc. (mm)	N	Length (mm) Mean (range)	Annual growth inc. (mm)	N	Length (mm) Mean (range)	Annual growth inc. (mm)
Ridge L.[1] (6.1 ha)	1982	27	456(394-515)	218	--	--	--	--	--	--
	1983	14	460(403-506)	239	12	586(491-670)	130	--	--	--
	1984	--	--	--	--	--	--	19	646(510-770)	60
Allerton L. (6.1 ha)	1983	9	415(392-465)	190	--	--	--	--	--	--
	1984	--	--	--	3	539(535-546)	124	--	--	--
Lake of the Woods (10.1 ha)	1983	6	412(366-477)	219	--	--	--	--	--	--
	1984	--	--	--	7	644(419-718)	232	--	--	--
Blue L., IN[2] (97 ha)	1982	11	403	200	2	683	--	--	--	--
Round L., IN[2] (53 ha)	1982	5	371	168	5	638	--	--	--	--
Daggett L., MI[2] (6.1 ha)	1980	33	450	327	53	577	--	--	--	--

[1] In 1985, the values for age-IV tiger muskellunge in Ridge Lake were: N = 7; mean length = 755 mm; length range = 623-863 mm; and annual growth increment = 109 mm. Only fish surviving to the draining census were included in this estimate.
[2] Length at ages I and II were estimated from different year classes.

muskellunge captured by anglers was 775 mm long and only three sampled individuals had reached legal size (N = 102). At the draining census, 4 of 7 fish known to be from the 1981 year class (age IV) had reached legal size. However, only 2 of 19 individuals from that year class in the 1985 angler catch had reached legal size (mean = 705 mm). In contrast, some tiger muskellunge in Stockton Lake, Missouri, reached harvestable size in the spring of their third year (age II), with gizzard shad as the principal forage species (Goddard and Redmond 1978). At Lake Shabbona, Illinois, muskellunge, *Esox masquinongy*, attained a mean length of 686 mm at age II in the fall of the year with gizzard shad present (Sule 1986). Tiger muskellunge in Round and Blue lakes, Indiana, also achieved greater lengths at age II than did tiger muskellunge in Ridge Lake, which may be related to differences in the abundance of non-centrarchid forage. Andrews (1983) noted that lakes in which tiger muskellunge stockings were successful (Round and Blue lakes), the forage base was composed of approximately 33% non-centrarchid fishes; whereas in the two lakes in which tiger muskellunge stockings were not successful, the forage base was approximately 20% non-centrarchid species. Tiger muskellunge, stocked in combination with bluegill and cyprinids, in Daggett Lake, Michigan, attained mean lengths in the fall of 450 and 577 mm at ages I and II, respectively; these lengths are similar to those recorded at Ridge Lake.

Of six lakes for which growth estimates are available (Table 8), the best growth occurred at Lake of the Woods, Illinois. Mean length at age II (644 mm) equaled the length attained at age III in Ridge Lake, a growth difference that can be explained by a difference in the forage base at the two impoundments. In 1983, the forage base at Lake of the Woods became dominated by an expanding gizzard shad population. The comparatively small size of age-I tiger muskellunge at Lake of the Woods in 1983 reflected the absence of suitable size shad during that part of the year when tiger muskellunge growth potential was greatest. Consequently, the full forage potential of the gizzard shad was not realized until 1984 and the tiger muskellunge population in Lake of the Woods was the only one to exhibit a greater annual growth increment in the third year than in the second year of life. The largest specimen taken by our sampling effort at Lake of the Woods was 806 mm in 1985 (age III), and park personnel reported that other legal fish had been taken by anglers in 1984 (age II fish). In contrast, growth of tiger muskellunge at Allerton Lake, Illinois, was slowest of the six populations compared. Mean length at age II in the fall was 539 mm and annual growth increments for age-I and -II fish were the lowest reported. Because fishing is restricted at Allerton Lake, the electrofishing catch per unit effort and PSD of largemouth bass have been consistently high (PSD > 90%), suggesting that competition for food may be high. That, in conjunction with a heavy infestation of black spot disease, had apparently slowed the growth of tiger muskellunge at Allerton Lake.

Only 8 of the 226 tiger muskellunge stocked in Ridge Lake in 1981 and 1982 had reached legal size by the end of the study. Moreover, because only 27 hybrids from those two year classes survived to the fall draining census, it is unlikely that the harvest of legal fish would have been high in subsequent years. The slow growth of tiger muskellunge, responsible for the low harvest, probably reflected a low growth potential of the hybrid when only centrarchid forage is available. The growth potential of tiger muskellunge may also have been limited by the high density of fish stocked in 1981 and 1982. Tiger muskellunge growth was adequate in Ridge Lake to provide an excellent catch-and-release fishery for large fish, but it was inadequate to produce a good trophy fishery.

Job 7. Hook-and-line mortality of tiger muskellunge.

OBJECTIVE: To determine the mortality rate of hook-and-line caught tiger muskellunge.

INTRODUCTION: High minimum length limits on tiger muskellunge are employed principally to increase the number of large fish available for harvest. However, this protection is compromised in proportion to the number of released fish that die from the trauma incurred during the angling experience. The purpose of this job was to estimate the angling mortality rate of sublegal tiger muskellunge, and thereby quantify the protection provided by a size limit.

METHODS: All angler-caught tiger muskellunge were retrieved from fishermen as quickly as possible and transported to the laboratory. Fish were immediately measured, weighed, and placed in a holding cage. The holding cage (0.7 x 1.2 x 1.0 m) was constructed with ACE-style netting (4.7-mm mesh) and was attached to a frame of PVC pipe which floated at the lake surface. All surviving fish were released the morning following their capture.

RESULTS: In 1985, 23% of angler-caught tiger muskellunge (N = 65) died within 24 hours of capture from trauma associated with hooking and handling (Table 9). By contrast, angling mortality rates were substantially lower in the preceeding 3 years (8-10%). Angling mortality is thought to increase with water temperature (Newman and Storck 1985) and to be positively related to fish size because larger fish are more difficult to handle (Weithman and Anderson 1977*b*). Although angler-caught fish were larger in 1985 than in previous years (Table 9), angling mortality of small fish (<600 mm) and large fish (>600 mm) in 1985 did not differ ($X^2 = 2.1$, $P > 0.05$). Moreover, water temperatures were not warmer in 1985 than in previous years and few tiger muskellunge were caught during mid-summer when water temperatures were highest. Thus the cause of increased angling mortality in 1985 is not known but may have been related to increasing age of the tiger muskellunge.

Forty-seven percent of angling-caused deaths in 1985 occurred during July and August even though only 22% of the total catch occurred during that interval. Mean surface water temperature during July and August at 0800 hours (26.6°C) was substantially higher than in all other months of the fishing season (22.8°C). A similar seasonal distribution of angling mortality rate occurred in 1982-1984 (Newman and Storck 1985), suggesting that water temperature is an important variable

Table 9. Hooking mortality of sublegal tiger muskellunge and largemouth bass at Ridge Lake during the 1982-1985 fishing seasons.

Species	Year	Number Caught	Number Died	Percent mortality	Mean length (mm) Dead	Mean length (mm) Survivors
Tiger muskellunge	1982					
Age I		71	6	8.5	427	426
	1983					
Age I		22	1	4.3	317	442
Age II		124	14	11.3	564	537
Total		146	15	10.3	548	522
	1984					
<600 mm		59	5	8.5	550	555
≥600 mm		43	4	9.3	662	667
Total		102	9	8.8	600	602
	1985					
<600 mm		13	5	38.5	558	576
≥600 mm		52	10	19.2	692	680
Total		65	15	23.1	647	663
Largemouth bass	1982	163	6	3.7		292
	1983	188	2	1.1		296

influencing hooking mortality. Hooking losses probably would have been higher during all years, except that the catch of tiger muskellunge was always low during mid-summer. Weithman and Anderson (1977*b*) also reported low catch rates in mid-summer. By comparison, sublegal largemouth bass (<355 mm) handled identically exhibited a similar seasonal pattern of hooking mortality but a substantially smaller fraction died as a result of the hooking experience (Table 9).

In 1984 and 1985, 14 and 29% of the angler-caught tiger muskellunge, respectively, were caught on live bait, principally minnows. In both years, hooking mortality was lower for these fish than for fish caught on artificial bait, but differences were not significant (X^2 test, $P > 0.05$). Although mortality rates are generally thought to be higher for fish caught on live baits (Wydoski 1977), tiger muskellunge in Ridge Lake did not generally swallow them; removal of multiple hooks on artificial baits increased handling time.

Our estimates of hooking mortality must be interpreted with caution. In addition to the stress associated with angling, hooked fish were weighed and measured before being placed in a holding cage. However, most fish that died in the holding cage had already lost equilibrium by the time they were retrieved from the angler. The stress associated with the struggle to escape capture and subsequent handling to remove hooks were important factors affecting survival. Angler education in techniques for handling and releasing tiger muskellunge may help reduce hooking mortality.

Tiger muskellunge that were hooked but escaped represented another potential, but unmeasurable, source of angling-related mortality. The frequency of angler reports of escaping tiger muskellunge increased as the fish became larger. Many tiger muskellunge broke fishing lines soon after being hooked while others escaped after a protracted struggle. Some of these fish may have died subsequently from injuries or trauma sustained during the hooking and fighting period. Furthermore, it is possible that some captured tiger muskellunge died following the 24-hour observation period due to injuries or trauma sustained during angling.

During 1982-1985, 12% of angler-caught tiger muskellunge died within 24 hours (N = 384). The fraction of fish stocked in 1981 and 1982 (N = 226) that died from angling was higher (20%), because each fish was caught an average of 1.7 times. Angling mortality was determined as much by factors that influence numerical catch as by those that influence moratlity rate. Angling mortality appears to be influenced most by water temperature. Numerical catch depends on the level of fishing pressure and angler skill. Thus, numbers of tiger muskellunge surviving to legal size should be negatively related to fishing pressure, even if compliance with fishing regulations is 100%. Although fish loss from hooking mortality was probably greater than 20%, the protective size limit enhanced the catch-and-release fishery, increased potential predation on bluegill, and probably allowed some fish to reach legal size.

Job 8. Survival of tiger muskellunge.

OBJECTIVE: To compare the survival to age I, in the fall, of tiger muskellunge stocked at different sizes, and to measure the survival to age III and IV of tiger muskellunge stocked as fingerlings in 1981 and 1982.

INTRODUCTION: The management benefit provided by tiger muskellunge in small impoundments depends substantially on the initial survival of stocked fish. Survival is influenced by size at stocking (Stein *et al.* 1981, Andrews 1983), density of large predators (Stein *et al.* 1981), hatchery diet used to rear the fish (Johnson 1978, Andrews 1983), date of stocking (Stein *et al.* 1981), and availability of prey (Stein *et al.* 1981). This job compared first-year survival of different sizes of tiger muskellunge stocked in the presence of an established predator population and examined the long-term survival of fish stocked in the presence of lower predator densities.

Table 10. Survival to the 1985 draining census of tiger muskellunge stocked in Ridge Lake as young of the year in 1984.

	Date stocked		
	10 July	14 September	23 October
Size class	Small	Medium	Large
Number of fish stocked	28	28	17
Fin clip	Left pelvic	Right pelvic	Right pectoral
Mean length (mm) at stocking	113	175	219
Range	90-127	162-192	205-240
Number surviving at draining[1]	1	0	1
Mean length (mm) at draining	446	--	468
Number caught by anglers	0	1	1

[1] Three additional surviving tiger muskellunge from the 1984 year class could not be assigned to a size class because their fin clips had regenerated (lengths: 375, 480, and 495 mm).

RESULTS: Survival of each of the three size classes of tiger muskellunge stocked into Ridge Lake in 1984 was extremely low (Table 10). In addition to the three individuals identified by fin clips in the 1985 draining census, three other fish from the same year class had regenerated their fin clips. Even if all three of those fish belonged to the largest size class stocked in 1984, survival of that size class through the second summer of life was still only 24%. The poor survival experienced by the two smallest size classes stocked in 1984 was expected (Stein *et al.* 1981, Beyerle 1984) and was probably due to predation by adult largemouth bass and large tiger muskellunge. Apparently, the largest size group of tiger muskellunge stocked in 1984 were also too small to avoid predation. Given the predator population in Ridge Lake, the minimum acceptable stocking size was greater than the maximum size evaluated in this experiment.

The poor survival of the 1984 year class was reflected in their contribution to the angler catch in 1985. Only four individuals from this year class were caught by anglers (two of which had regenerated fin clips) and only one was from the largest size class (6% of the number stocked). In contrast, 47% of the 1981 year class (N = 151) and 29% of the 1982 year class (N = 75) were caught as yearlings in 1982 and 1983, respectively. Thus, the contribution to the catch of age-I fish declined for successive year classes and likely reflected declining survival. A decline in survival for repeat stockings of esocids has been reported elsewhere (Beyerle 1971, Axon 1978) and in Ridge Lake probably reflected an increase in abundance of large predators (see Job 11).

Of 226 tiger muskellunge stocked in Ridge Lake in the fall of 1981 and 1982, 27 individuals (12%) survived to the draining census in October 1985. Allowing for harvest and known hooking mortality losses, a minimum of 43 fish from these two year classes (19%) were alive at the beginning of the 1985 fishing season; this number was probably higher, considering that some natural mortality or delayed hooking mortality may have occurred during the fishing season.

Average annual mortality of tiger muskellunge stocked in 1981 and 1982 was 41%, but this mortality probably was not uniformly distributed from date of stocking to the draining census. Mortality was probably disproportionately high soon after stocking because only small individuals were vulnerable to predation from adult largemouth bass. For example, high first-year mortality was suspected for the 1982 year class, because as yearlings in 1983 they contributed substantially less to the angler catch than did the 1981 year class in 1982. Nonetheless, the total number of age-0 tiger muskellunge that escaped predation by largemouth bass was apparently large, because 385 individuals were caught by anglers during the four fishing seasons. Based on the numbers of tiger muskellunge surviving to the draining census (N = 27), the number of hooking mortality deaths (N = 44), the number escaping in the lake discharge (N = 5), the number harvested by anglers (N = 4), and the number found dead in the lake (N = 5), a minimum of 38% of the total number stocked in 1981 and 1982 survived at least to age I.

Job 9. Angler catch and harvest at Ridge Lake.

OBJECTIVE: To measure the angler effort, catch, and harvest at Ridge Lake during the 1982-1985 fishing seasons.

INTRODUCTION: A goal of sport fish management is to increase the catch rate or harvest of one or more fish species. Total creel censuses are rarely used to evaluate management practices because they are too expensive to conduct. Partial creel procedures are often employed instead, but they are subject to large random and systematic errors. This job employed a total creel census to measure the impact of the introduction of tiger muskellunge on the catch rate and harvest of fish at Ridge Lake and to evaluate the accuracy of a partial creel procedure. In contrast to most creel censuses, all angler-caught fish were measured and weighed, or counted (usually only harvested fish are creeled), to determine the size structure of each species in the catch.

METHODS: All fishing at Ridge Lake was by permit and only boat fishing was allowed. The lake was open to fishing beginning the last weekend in April and ending in mid-October in 1982-1984. In 1985, fishing was terminated on 15 September so that the lake could be drained. Fishing was permitted daily (except Mondays and Tuesdays) from 6-10 am and 3-8 pm. All fishermen were required to pass through a single entry point to gain access to the lake. Anglers were informed of fishing regulations before beginning a fishing session. Prior to fishing, each fishing party was questioned as to their species preference for that particular day. Eight rowboats, with a capacity of three persons each, were provided free of charge to the angling public. No restrictions were placed on the type of bait used. All fish caught were held in live wells (except tiger muskellunge) and returned to the laboratory at the end of each fishing session. Anglers were given flags with which to signal the catch of a tiger muskellunge. A creel clerk retrieved tiger muskellunge from fishermen as quickly as possible and transported them in a live well to the laboratory where they were measured and weighed. Immediately after measurement, tiger muskellunge were placed in a holding cage to determine hooking and handling mortality (see Job 7). Minimum length limits of 355 mm (14 inches) for largemouth bass and channel catfish and 762 mm (30 inches) for tiger muskellunge were enforced. In contrast to some previous Ridge Lake studies (Bennett *et al.* 1969, 1973), unwanted and sublegal fish were returned to the lake immediately after measurement.

In 1984, the age composition of bass and bluegill caught by anglers in September and October was inferred from the age composition of 1-cm length groups of fish collected with electrofishing gear in September and November. Fish were collected using a 230-v AC elctrofishing unit during daylight hours. All fish were measured (mm, total length) and a subsample was weighed (g).

Ages of largemouth bass were determined using scales. Scales were removed from a subsample of bass collected on 24 September by electrofishing (N = 75). Five fish, or all fish if less than 5 were available, were aged from each 1-cm length group. Impressions of scales were made on acetate slides using a roller press and viewed at 27x with a scale projector. Ages of bluegill were determined from otoliths of fish collected on 24 September and 29 November (N = 130). Otoliths were viewed in the sagittal plane in water at 40x, using a dissecting microscope and at 40-100x under oil using a phase-contrast microscope. When the location of the first annulus was in question, daily rings were exposed by grinding the otolith to form a thin section in either the sagittal or transverse plane; the spacing of daily rings was used to identify the annulus. For both species, ages were assigned to fish in each 1-cm length group in proportion to the age composition of the aged fish.

In May and June 1985, a sample of angler-caught bluegill (N = 110) and black crappie (N = 49) were aged using otoliths. For each species, 10 fish were aged from each 1-cm length interval, or all fish were aged if less than 10 were available. The remaining fish in the catch in May were assigned ages in proportion to the age composition of the subsample. The same aging procedure was followed for largemouth bass (N = 182), bluegill (N = 188), and black crappie (N = 72) in late summer (16 August-15 September) except that electrofishing samples in September were the principal source of fish for age determination of largemouth bass and bluegill.

To evaluate the exploitation rate of largemouth bass in Ridge Lake in 1984, fish collected by electrofishing in May received a size-specific dorsal spine clip (Perry and Tranquilli 1984). When recaptured by fishermen, all sublegal bass (and legal bass not wanted by anglers) were given a pelvic fin clip and released; recaptures of fish marked with pelvic clips were also recorded. Exploitation rate was computed as the number of first time captures in 1984 of marked fish divided by the number of fish marked.

RESULTS:

Fishing Effort. Annual fishing effort averaged substantially greater during this study (1982-1985) than in all earlier studies conducted at Ridge Lake. The increased fishing pressure

Table 11. Fishing effort (hours/ha), harvest, and harvest rate of all fish species during selected fishing seasons at Ridge Lake.

Year	Fishing effort	Harvest		Harvest rate		Mean weight (kg)
		No./ha	kg/ha	No./hour	kg/hour	
1958	704	892	71.0	1.27	0.10	0.08
1959	768	1,355	117.0	1.76	0.15	0.09
1962	410	610	38.8	1.49	0.10	0.06
1968	264	802	88.3	3.04	0.33	0.11
1969	252	843	96.8	3.35	0.38	0.11
1982	726	38	19.3	0.06	0.03	0.51
1983	943	218	65.0	0.30	0.07	0.30
1984	927	358	57.5	0.37	0.06	0.16
1985	1,026	638	96.4	0.61	0.10	0.15

principally reflected a longer fishing season; in most earlier studies, Ridge Lake was open only during June, July, and August. Moreover, the addition of a trophy fish to the species combination and substantial news media coverage of the Ridge Lake program may have stimulated greater interest in fishing at Ridge Lake.

In the current study, effort was lowest in the first year (1982), probably because the lake had been closed to fishing in 1981. Effort increased in subsequent years, reaching a record high level in 1985 (Table 11). Fishing pressure during the current Ridge Lake study was intermediate when compared with five other Illinois impoundments (Mick 1985) but was generally much greater than reported for numerous other impoundments by Snow (1978). Fishing pressure was also substantially greater at Ridge Lake than at most large reservoirs. Jenkins and Morais (1979), in a nationwide survey of 103 large reservoirs, reported mean fishing pressure of 76.1 hours/ha.

The largemouth bass was the species most sought by anglers in all years, but angler interest in this species declined in successive years of the study (Table 12). This decline did not follow from

Table 12. Distribution of angling effort (as percentage of total fishing effort) among species at Ridge Lake, 1983-1985.

Taxa	1983	1984	1985
Largemouth bass	54.6	44.0	34.0
Tiger muskellunge	12.7	19.0	11.0
Bluegill	11.5	9.0	9.0
Channel catfish	11.6	6.0	10.0
Black crappie	0.0	4.0	6.0
No preference	9.6	18.0	30.0

increased interest in the tiger muskellunge, which was also sought by a smaller fraction of anglers in 1985 than in 1984. An increasing percentage of anglers expressed no preference in species sought which may have reflected increasing catch rates of panfish.

Based on conversations with anglers, we believe that many more of them were fishing for tiger muskellunge than so indicated when questioned. Moreover, many anglers were fishing for largemouth bass and tiger muskellunge concurrently while stating that they were fishing only for largemouth bass.

The temporal distribution of angling effort differed among years. In 1982 and 1984, effort declined dramatically in late summer, but in 1983 and 1985 it was nearly as high in August and September as in earlier months. Also during this study, fishing effort did not closely follow catch rates.

Angler Catch. The total angling catch, and catch rates for all fish species combined, increased in successive years of the study (Table 13). These increases reflected increasing contributions from

Table 13. Total catch of all fish species at Ridge Lake, 1982-1985.

	1982	1983	1984	1985
Number	2,191	4,476	7,182	8,301
Weight (kg)	597	1,073	1,151	1,290
No./ha	361	737	1,183	1,361
kg/ha	98	177	190	210
No./hour	0.56	0.76	1.25	1.33
kg/hour	0.152	0.180	0.200	0.210
Mean weight (kg)	0.27	0.24	0.16	0.15

both the 1981 year class of bluegill and the 1982 and 1983 year classes of black crappie. Because panfish made up an increasing fraction of the total catch, the mean weight of fish caught declined in successive years (Table 13).

Bluegill. The angler catch and catch rates (number and weight per angler-hour) of bluegill increased in succesive years of the current study (Table 14) while the fraction of anglers fishing for this species remained very constant (Table 12). The catch of bluegill in 1982 was made up principally of fish stocked in 1981 and consequently the mean weight of angled fish was highest in that year. The 1981 year class became dominant in the catch in subsequent years, making up 100% of the total in 1984 and more than 75% in 1985 (Table 15). The failure of later year classes

Table 14. Total angler catch of bluegill at Ridge Lake in the current study (1982-1985), in years of stable water level (1958, 1959, 1962), and in years when fall drawdowns and supplemental feeding of bluegill (1968, 1969) were used.

Year	Growing seasons since last draining census	Hours/ ha	N	Weight (kg)	Catch		Catch rate		Mean weight (kg)
					No./ha	kg/ha	No./hour	kg/hour	
1958	2	704	4,981	327	722	47.4	1.03	0.067	0.065
1959	3	768	7,894	586	1,144	84.9	1.49	0.111	0.074
1962	3	410	2,706	109	398	16.0	0.97	0.039	0.040
1968	5	264	4,165	416	622	62.1	2.36	0.235	0.100
1969	6	252	4,880	432	728	64.5	2.89	0.256	0.089
1982	1	648	671	62	111	10.3	0.17	0.016	0.090
1983	2	964	2,693	222	444	36.5	0.46	0.040	0.080
1984	3	947	4,467	278	736	45.9	0.78	0.050	0.062
1985	4	1,026	5,445	408	897	67.3	0.86	0.063	0.075

Table 15. Relative contribution (%) of various age groups in the angler catch and harvest for bluegill and black crappie in spring (April-May) and in late summer (mid August-mid September), 1984 and 1985.

Species	Year	Season	Creel category	Age			
				I	II	III	IV
Bluegill	1984	Late summer	Catch	--	--	100	0
			Harvest	--	--	100	0
	1985	Spring	Catch	--	--	1	99
			Harvest	--	--	0	100
	1985	Late summer	Catch	1	2	28	68
			Harvest	0	0	12	88
Black crappie	1985	Spring	Catch	0	36	49	14
			Harvest	0	29	54	16
	1985	Late summer	Catch	3	84	12	1
			Harvest	3	89	8	0

to contribute substantially to the catch reflected slow growth of those groups rather than low abundance (see Job 11).

Few instructive comparisons can be made between the bluegill catch in this study and in earlier studies at Ridge Lake, because frequent draining censuses precluded the development of a normal bluegill population age structure. Catch statistics for some earlier fishing seasons, selected because they followed a draining census by at least two growing seasons, are presented in Table 14. In those earlier years, the total numbers and weights of angler-caught bluegill were generally higher and the catch rates were always higher than during the current study. When drawdowns were used in conjunction with supplemental feeding of bluegill, bluegill catch rates were about twice that in 1985; thus, those management techniques produced better bluegill fishing than did attempts at restructuring the bluegill population through tiger muskellunge predation.

Higher catch rates occurred in years of drawdown and supplemental feeding than during the tiger muskellunge study period, even though the bluegill standing crop was only one-third as large at the conclusion of the former study. Growth rates of bluegill were substantially greater in 1968 and 1969 (Table 16) and consequently they became vulnerable to angling at an earlier age.

Table 16. Lengths at capture of bluegill and largemouth bass at Ridge Lake in the fall using various management techniques.

		Bluegill				Largemouth bass				
Management plan	Year	I	II	III	IV	I	II	III	IV	V
Biennial culling[1]						262	320	348	363	424
Drawdown[1]	1955	137	170	188	--					
Stable water[1]	1958-1959	119	146	161	169					
Drawdown and feeding[1]	1967-1968	147	185	205	221	201	244	287	318	358
Stable water and supplemental predator	1984	65	87	128	--	177	232	326	406	--
	1985	70	104	127	157	192	253	299	346	428
Illinois average[2]	1967					160	229	295	343	401

[1]Bennett *et al.* (1973)
[2]Lopinot (1967)

Black Crappie. Black crappie first became important in the angler catch at Ridge Lake in 1984 and their contribution doubled in 1985 (Table 17) when they accounted for 13% of the total weight of fish caught. Catch rates were highest in the first 2 weeks of each fishing season when 25-30% of the total crappie catch occurred.

Table 17. Total angler catch by taxa for black crappie, channel catfish, and tiger muskellunge at Ridge Lake, 1982-1985.

Species	Year	Effort (hours/ha)	Number	Weight (kg)	Catch		Catch rate		Mean weight (kg)
					No./ha	kg/ha	No./hour	kg/hour	
Black crappie	1982	648	15	3.2	2.4	0.5	--	--	0.210
	1983	964	87	17.1	14.0	2.8	0.01	0.002	0.197
	1984	947	1,056	114.5	170.0	18.5	0.18	0.020	0.108
	1985	1,026	1,476	167.5	243.2	27.6	0.24	0.026	0.113
Channel catfish	1982	648	90	102.6	14.8	16.9	0.02	0.026	1.14
	1983	964	133	187.9	21.9	30.9	0.02	0.030	1.41
	1984	947	59	43.7	9.7	7.2	0.01	0.010	0.74
	1985	1,026	133	129.6	21.4	21.4	0.02	0.020	0.97
Tiger muskellunge	1982	648	87	31.5	14.3	5.2	0.020	0.008	0.36
	1983	964	134	108.8	22.0	17.9	0.023	0.018	0.81
	1984	947	100	118.2	16.5	19.5	0.020	0.020	1.18
	1985	1,026	71	115.1	11.6	19.0	0.011	0.018	1.62

An unknown number of adult and juvenile black crappie gained entry into Ridge Lake in 1981. A few of them were caught in 1982 and 1983, accounting for the high mean weight of crappie in the catch. They apparently produced only a small year class in 1981, which contributed little to the catch in subsequent years. The 1982 year class, in contrast, was relatively large; they first entered the catch late in 1983 but did not contribute substantially until 1984 when they were 2-year-olds. This year class dominated the catch in the spring of 1985 at age III, but by late summer they made up only 12% of the number caught. The 1983 year class was also relatively strong, first contributing substantially to the catch in spring 1985. By late summer of 1985 they dominated the catch, accounting for 84% of the total (Table 15).

Although crappie accounted for 13% of the weight of fish caught in 1985, only 6% of anglers claimed that they were fishing for that species (Table 12). However, the large annual increase in number of anglers expressing no preference paralleled the annual increase in the contribution of crappie to the total catch.

Largemouth Bass. The angler catch of largemouth bass was relatively constant at Ridge Lake during 1982-1985 (Table 18). A small decline in catch in 1985 relative to earlier years may have been caused as much by the decline in fishing effort directed at this species (Table 12) as by a decline in its abundance.

Table 18. Total angler catch of largemouth bass at Ridge Lake during the current study (1982-1985), during years of stable water level (1958, 1959, 1962), and during years when fall drawdowns were combined with supplemental feeding of bluegill (1968, 1969).

Year	Effort (hours/ha)	Number	Weight (kg)	No./ha	kg/ha	No./hour	kg/hour	Mean weight (kg)
1958	704	814	110	118	16	0.17	0.022	0.135
1959	768	566	104	82	15	0.11	0.019	0.184
1962	410	143	48	21	7	0.05	0.017	0.335
1968	264	828	131	123	20	0.47	0.075	0.158
1969	252	490	91	73	14	0.29	0.056	0.186
1982	648	1,343	400	221	66	0.34	0.100	0.290
1983	964	1,516	555	250	91	0.26	0.090	0.360
1984	947	1,500	596	247	98	0.26	0.100	0.400
1985	1,026	1,176	459	194	76	0.19	0.072	0.390

The 1982 bass catch (N = 1,343) was comprised mostly of yearling and older fish stocked in 1981 (78%) and by a smaller number of fish spawned in 1981 (22%). By late summer of 1984 and 1985, stocked fish accounted for only 9% and 1%, respectively, of the angler catch. By contrast, the 1981 year class dominated the catch in late summer of 1984 (53%) but contributed only 27% in late summer of 1985.

The potential for high exploitation rates of bass at Ridge Lake were demonstrated in this study. The numerical catch of age II and older bass in 1982 (N = 1,009) exceeded the number of these fish stocked in 1981 (N = 887); in 1984, 82% of age-II and older bass present in Ridge Lake at the beginning of the fishing season were caught by anglers at least once during that year (Newman and Storck 1985). Moreover the number of age-I and older largemouth bass caught and released by anglers in 1985 (N = 993) was greater than the numbers of those age groups present at the draining census (N = 887, see Job 11). Similarly high exploitation rates of bass have been reported for numerous other small impoundments (Martin 1954, Bennett *et al.* 1969, Ming 1974, Redmond 1974, Burkett *et al.* 1981, Paragamian 1982).

During the tiger muskellunge study years, the annual numbers and weight of bass caught, catch rates in kg/angler-hour, and mean weights of bass landed were all substantially greater than in earlier years at Ridge Lake (Table 18). Several different management techniques were employed in the earlier studies at Ridge Lake. In all of those years, the lake was open to fishing during only June, July, and August, and all bass caught by anglers were removed from the lake. The improvement in bass catch statistics in the present study was likely the result of both an increase in fishing pressure achieved by lengthening the fishing season and the implementation of a 355-mm length limit. Because the catch-and-release fishery for sublegal bass allowed more of them to reach a large size, the mean weight of angled fish increased; moreover, catch rates increased because multiple captures of individual fish were possible. Catch rates and total catch of bass generally increase in lakes where length limits are selected to protect size groups experiencing high angling mortality (Novinger 1984). Even though bass catch rates were very low at Ridge Lake from 1942 to 1969, it is unlikely that even those rates could have been sustained in the face of angling pressure similar to that exerted during the present study.

Few catch statistics from other impoundments are available for comparison with those from Ridge Lake; in most studies, only harvest statistics are collected. However, the statewide catch rate of largemouth bass in Iowa (0.07 fish/hour; Paragamian 1982) and the mean catch rate in six Kansas impoundments (0.03 fish/hour; Gablehouse 1980) were substantially below the mean for Ridge Lake from 1982 to 1985 (0.26 fish/hour). Moreover, the 1985 catch rate of quality size bass (>300 mm) at Ridge Lake, calculated for fishermen fishing only for bass, was higher (0.30 fish/hour) than the catch rate in Kansas bass club tournaments (0.19 fish/hour) during 1977-1984 (Willis and Hartman 1986). In contrast, Novinger (1984) reported a catch rate of about one bass per hour in Missouri for people fishing specifically for bass in impoundments with size limits. At Ridge Lake, the bass catch rate for people fishing only for bass never exceeded 0.34 fish/hour.

Tiger Muskellunge. The angler catch of tiger muskellunge at Ridge Lake increased from 1982 to 1983 as fishing pressure increased and more of the hybrids reached a size vulnerable to anglers (Table 17). Thereafter, catch and catch rates declined in response to the declining abundance of the 1981 and 1982 year classes, and perhaps also because larger fish were more difficult to catch. The mean weight of angler-caught hybrids increased in successive years of the study, reflecting growth of the 1981 and 1982 year classes. The substantial increase in their mean weight between 1984 and 1985 (Table 17) suggested that individual growth continued to the end of the study. The catch of the 1984 year class in 1985 was very low (6% of the number stocked) because survival was poor (see Job 8); in contrast, the catch of tiger muskellunge as yearlings (stocked at age-0 in 1981 and 1982) equalled 47% and 29% of the number stocked, respectively.

At least some of the tiger muskellunge in Ridge Lake were very vulnerable to angling. The 226 hybrids stocked in Ridge Lake in 1981 and 1982 were caught a total of 388 times (mean = 1.7 times each) from 1982 to 1985. Because these fish were stocked in the fall at age 0 but did not contribute to the catch until the following spring, they were exposed to winter mortality before becoming vulnerable to angling. Thus survivors were caught more than 1.7 times on average.

The catch of tiger muskellunge at Ridge Lake was generally greatest in May, June, September, and October and lowest in July and August. The low catch during July and August, when water temperature was highest, served to minimize hooking mortality losses, because the hooking mortality rate was highest during those months. The artificially shortened fishing season at Ridge Lake may have reduced substantially the potential total catch of tiger muskellunge, because catch rates were relatively high at the beginnning and end of the four fishing seasons.

Channel Catfish. During the tiger muskellunge study, channel catfish made up 5-17% of the weight but only 1-4% of the number of fish caught. A substantial decline in catch occurred in 1984 (Table 17), probably reflecting the declining abundance of fish stocked in 1981. Catch improved somewhat in 1985 following the stocking of fish in the spring of 1984 and 1985. However, these fish were smaller than those stocked in 1981, and consequently the mean weight of angler-caught catfish was smaller than in 1982 and 1983.

In all years, a small number of fishermen were responsible for a large percentage of the fishing pressure directed at channel catfish and for an even larger fraction of the total catfish catch. These fishermen fished exclusively for channel catfish using baits that precluded the capture of other species of fish.

Harvest. The total numerical harvest of all species increased but mean weight of harvested individuals decreased in successive years of the tiger muskellunge study (Table 11); both trends reflected increasing contributions of bluegill and black crappie. A decline from 1983 to 1984 in total weight of fish harvested was caused by a substantial decline in the contribution of channel catfish to the creel.

During 1982-1985, total harvest was limited by size limits on largemouth bass, channel catfish, and tiger muskellunge, and all unwanted legal-size fish were returned to the lake. In contrast, all angler-caught fish were removed from the lake in earlier fishing seasons at Ridge Lake (1942-1969) and these fish were included in harvest statistics (Bennett *et al.* 1969, 1973). Consequently, the yield during those years was generally much higher and the mean weight of harvested fish substantially smaller than during the current study. Thus, Ridge Lake harvest statistics for the interval 1942-1969 are more useful for comparison with catch statistics than with harvest statistics from the current study .

Bluegill. Bluegill harvest at Ridge Lake increased substantially in successive years of the present study (Table 19), principally reflecting recruitment to a catchable size of an increasing fraction of the 1981 year class. In 1982, the harvest was comprised almost entirely of fish stocked as adults in 1981, and consequently the bluegill creeled in that year had a higher mean weight than in subsequent years. The 1981 year class of bluegill must have first contributed substantially to the harvest in 1983, because the total number of bluegill creeled in 1982 and 1983 (N = 1,157) exceeded the number stocked in 1981 (N = 1,026). Thereafter, the 1981 year class dominated the harvest, making up 100% of the total in late summer 1984 and spring 1985 (Table 15). Despite their importance in the creel in 1984 and 1985, only 67% of survivors from the 1981 year class had reached quality size (>150 mm) by the end of the study. Moreover, only 6% of the 1982 year class had reached quality size in September 1985. Thus, the small contribution of that year class to the total bluegill harvest in 1985 (12%) can be attributed to slow growth rather than to low abundance.

The 1985 harvest statistics for bluegill at Ridge Lake compared favorably with those of other impoundments in the Midwest (Table 19). However, slow growth, variable recruitment (see Job 11), and declining mean weight of harvested bluegill in successive years of the current study (Table 19) suggested that the high 1985 level would not have been sustained in subsequent years. Also, the mean weight of harvested bluegill at Ridge Lake in 1985 was below average for a sample of Midwestern impoundments (Table 19) and was smaller than the mean weight of all bluegill caught by anglers during the drawdown years of 1968 and 1969 at Ridge Lake (Table 14). Bluegill harvest in 1985 was characterized by a large number of relatively small individuals, suggesting that tiger muskellunge predation had not had the desired effect of reducing bluegill density sufficiently to insure good population growth and structure. In contrast, both harvest rates and mean weights of bluegill were substantially higher at Ridge Lake when drawdowns were used to manipulate bluegill population structure (Table 14).

Table 19. Bluegill harvest statistics at Ridge Lake, 1982-1985, and at selected impoundments in the Midwest.

Lake	Year	Effort (h/ha)	Surface area (ha)	No./ha	kg/ha	No./h	kg/h	Mean weight (kg)	Source
Ridge, IL	1982	648	6.07	28	3.5	0.043	0.005	0.124	Current study
	1983	964	6.07	162	17.2	0.168	0.018	0.106	Current study
	1984	947	6.07	220	20.0	0.230	0.020	0.090	Current study
	1985	1,026	6.07	399	35.3	0.381	0.034	0.088	Current study
Storey, IL	1984	757	54	235	27.7	0.310	0.037	0.118	Mick (1985)
Pierce, IL	1984	1,329	66	322	21.3	0.240	0.014	0.057	Mick (1985)
Shabbona, IL	1984	1,537	129	283	32.8	0.180	0.018	0.101	Mick (1985)
Collins, IL	1984	128	791	2	0.1	0.010	0.001	0.057	Mick (1985)
Ramsey, IL	1984	783	19	1,318	131.7	1.650	0.165	0.100	Mick (1985)
Argyle, IL	1972	919	38	272	42.6	0.296	0.048	0.159	Russell (1983)
57 Kansas lakes	1974-1981	--	--	--	--	0.139	0.018	0.133	Mosher (1983)
Murphy Flow-age, WI	1955-1969	--	73	285	20.2	1.570	0.111	0.070	Snow (1978)
Goede, IA	1972-1973	--	76	381	--	0.718	--	--	Kline (1983)
Burke, VA	1974-1976	--	88	218	21.7	--	--	0.125	McHigh (1983)
Binder, MO	1973	--	42	820	93.5	1.180	0.133	0.114	Hoey and Redmond (1972)
Brown, KS	1974-1979	1,465	25	48	7.1	0.036	0.005	0.149	Gabelhouse (1980)
Cowley, KS	1973-1979	1,331	34	207	31.8	0.161	0.025	0.154	Gabelhouse (1980)
Jewel, JS	1975-1976	374	23	14	2.6	0.066	0.012	0.182	Gabelhouse (1980)
McPherson,KS	1974-1976	1,760	19	43	3.9	0.024	0.002	0.090	Gabelhouse (1980)
Nemaha, KS	1974-1977	203	100	23	2.0	0.065	0.005	0.087	Gabelhouse (1980)

Management objectives for bluegill in State-owned and -leased impoundments in Illinois call for a harvest rate of 3.0 fish/angler-trip, with an average weight of 0.18 kg (Mick 1985). Harvest rates at Ridge Lake in 1985 (1.29 fish/angler trip) and at other impoundments in Illinois fell well below this stated objective. Moreover, the mean weight of bluegill harvested at Ridge Lake in 1985 (0.088 kg) and in a majority of Midwestern impoundments (Table 19) was also well below the stated objective. When drawdowns were used as a management tool at Ridge Lake, harvest rates did meet management objectives but mean weights did not approach the desired level. It is doubtful that both objectives can be met simultaneously in any impoundment because high mean weights generally occur only when bluegill densities are very low.

Black Crappie. Although not included in the project stocking combination, crappie made up 21 and 25% of the weight of fish harvested at Ridge Lake in 1984 and 1985, respectively. Despite their large contribution to the harvest, only 6% of anglers claimed that they were fishing for crappie (Table 12). Crappie fishermen were generally more successful than others and were more likely to keep their catch. Over the 1984 and 1985 fishing seasons, 73% of angler-caught crappie, but only 37% of bluegill, were harvested. This difference reflected both a greater mean size of crappie (113 g) than of bluegill (68 g) in the catch and a preference of fishermen for crappie as a food fish.

An unknown number of adult black crappie present in Ridge Lake in spring 1981 produced a relatively weak year class that contributed little to the harvest in subsequent years. A stronger year class was produced in 1982; they first entered the creel in small numbers as age-I fish in the late summer and fall of 1983 and dominated the harvest as age-II fish in 1984 and again as age-III fish in spring 1985 (Table 15). By late summer 1985, a strong 1983 year class had become more important in the harvest. Only in 1985 did two crappie year classes contribute substantially to the harvest, resulting in a near doubling of the 1984 harvest (Table 20).

Table 20. Harvest statistics of black crappie, channel catfish, and tiger muskellunge at Ridge Lake, 1982-1985.

Species	Year	Number	Weight (kg)	No./ha	kg/ha	No./hour	kg/hour	Mean weight (kg)
Black crappie	1983	87	17	14	2.8	0.092	0.002	0.197
	1984	653	72	108	11.9	0.110	0.012	0.110
	1985	1,233	145	202	23.8	0.218	0.024	0.118
Channel catfish	1982	46	84	8	13.8	0.012	0.021	1.814
	1983	122	182	20	29.8	0.021	0.031	1.493
	1984	21	37	3	6.0	0.004	0.006	1.740
	1985	64	105	11	17.1	0.009	0.014	1.600
Tiger muskellunge	1984	2	5.8	0.33	0.95	0.0003	0.001	2.90
	1985	2	5.9	0.33	0.97	0.0003	0.001	2.95

Crappie harvest rates were highest during the first few weeks of each fishing season and, in 1985, again at the end of the season. Thus, harvest likely would have been increased substantially by lengthening the fishing season. The potential for high exploitation of crappie was indicated for Ridge Lake because a large number of crappie were harvested by only a small number of anglers and because the crappie became vulnerable at an early age.

Largemouth Bass. The numbers and mean weight of harvested largemouth bass was relatively constant at Ridge Lake during 1983-1985, but the relative contribution of both stocked fish and fish spawned naturally in the lake changed substantially in successive years. Only bass stocked in 1981 and those spawned in the lake in that same year contributed to the harvest in any year of the study. Stocked fish made up 100, 40, and 6% of the bass harvest in 1983, 1984, and 1985, respectively, while the 1981 year class contributed 0, 60, and 94% to the harvest in those years. Although dominant in the harvest in the last 2 years of the present study, the 1981 year class was only partially recruited to the harvestable population by the end of the study; only 42% of the angler catch of bass from that year class were legal size in late summer of 1985. Thus, the bass harvest rate at Ridge Lake in 1985 was determined totally by the abundance and growth of the first year class spawned in the lake following the 1980 draining census.

Largemouth bass harvest statistics at Ridge Lake (kg/ha, number/ha, kg/hour, number/hour) were intermediate when compared with those in some other impoundments in the Midwest (Table 21), while the mean weight of harvested bass was higher at Ridge Lake than at most of those impoundments. The larger mean weight presumably reflected a strictly enforced 355-mm length limit and the voluntary release by anglers of 35 and 22% of legal-sized bass in 1984 and 1985, respectively. Differences in fishing pressure and fishing regulations, no doubt, contributed to the differences in harvest statistics among impoundments. The size limit served to increase catch rates and mean length of both the fish caught and harvested at the expense of harvest and harvest rate statistics.

Davies *et al.* (1979) defined light and heavy bass harvest as less than 11 kg/ha and between 20-34 kg/ha, respectively. According to these criteria, harvest at Ridge Lake in 1984 and 1985 was moderate (19 kg/ha). Anderson (1984) believed that only a few well managed, productive lakes had the capacity for sustained yield of more than 22 kg/ha. Harvest at Ridge Lake approached this value in 1984 and 1985 but greatly exceeded it in years when all angler-caught fish were harvested (Table 18, Bennett *et al.* 1969, 1973). The high bass yields in those earlier years at Ridge Lake were achieved at a cost of lower catch rates, small mean size of bass in the creel, and probably a reduction in bluegill control potential from predation. Moreover, it is unlikely that those yields

Table 21. Largemouth bass harvest statistics at Ridge Lake, 1982-1985, and at selected impoundments in the Midwest.

Lake	Year	Effort (h/ha)	Surface area (ha)	No./ha	kg/ha	No./h	kg/h	Mean weight (kg)	Source
Ridge L., IL	1982	648	6.07	3	2.1	0.040	0.003	0.832	Current study
	1983	964	6.07	21	14.9	0.022	0.015	0.712	Current study
	1984	947	6.07	26	18.5	0.026	0.019	0.720	Current study
	1985	1,026	6.07	24	18.9	0.024	0.019	0.780	Current study
Storey, IL	1984	757	54	47	19.7	0.062	0.026	0.414	Mick (1985)
Pierce, IL	1984	1,329	66	4	2.1	0.003	0.001	0.449	Mick (1985)
Shabbona, IL	1984	1,537	129	42	25.4	0.027	0.016	0.614	Mick (1985)
Collins, IL	1984	128	791	1	1.7	0.008	0.013	1.611	Mick (1985)
Argyle, IL	1972	919	38	95	27.1	0.102	0.030	0.290	Russell (1983)
Brown, KS	1974-1979	1,465	25	12	7.5	0.008	0.005	0.642	Gabelhouse (1980)
Cowley, KS	1973-1979	1,331	34	47	49.1	0.035	0.037	1.053	Gabelhouse (1980)
Jewel, JS	1975-1976	374	23	53	22.6	0.141	0.060	0.428	Gabelhouse (1980)
McPherson,KS	1974-1976	1,760	19	9	1.6	0.005	0.001	0.180	Gabelhouse (1980)
Nemaha, KS	1974-1977	203	100	6	2.1	0.028	0.010	0.368	Gabelhouse (1980)
Montgomery, KS	1974-1976	1,440	43	78	37.5	0.054	0.026	0.482	Gabelhouse (1980)
57 Kansas lakes	1974-1981	--	--	--	--	0.036	0.018	0.472	Mosher (1983)
Murphy Flow-age, WI	1955-1969	182	82	7	3.1	0.037	0.038	0.471	Snow (1978)

could have been sustained without the additional management techniques of cullings, fall drawdowns, and supplemental feedings of bluegill that were employed in those years at Ridge Lake.

Management objectives for largemouth bass in State-owned and -leased impoundments in Illinois call for a harvest rate of 0.7 fish/angler-trip with an average weight of 0.45 kg (Mick 1985). Harvest rates at Ridge Lake (0.08 fish/angler-trip) and at five state-managed impoundments in Illinois (0.09 fish/angler-trip, Mick 1985) fell well below the stated objective. Since the yield at Ridge Lake was intermediate among Midwestern impoundments, the stated objective appears unrealistic. The mean weights of harvested bass (0.78 kg at Ridge Lake in 1985 and 0.77 kg at five other state impoundments) were substantially higher than the proposed objective. Of course, the mean weight of harvested bass depends substantially on the size limit employed, and average values are of little use.

Tiger Muskellunge. Only four tiger muskellunge were harvested at Ridge Lake during 1982-1985 (two each in 1984 and 1985). The largest of these fish was 818 mm long (32 inches) and weighed 3.08 kg (6.8 lb). Based on the size composition of the 1985 angler catch, a reduction in length limit to 710 mm (28 in) or to 737 mm (29 in) could have increased the harvest by no more than 19 and 9 fish, respectively. The actual increase in harvest would have been smaller, depending on the number of these fish that were caught more than once in 1985. It could be argued, however, that in 1985 the 762-mm size limit contributed little to the development of a trophy fishery for tiger muskellunge; only seven fish longer than 710 mm survived to the draining census (see Job 8) and at least two of these fish had not been caught by anglers in 1985. While the gain in harvest resulting from implementation of a 710-mm size limit would have been achieved without seriously harming the trophy fishery, the catch-and- release fishery would have been diminished.

Channel Catfish. The channel catfish fishery at Ridge Lake was a put-grow-and-take fishery. The harvest fluctuated annually in response to variations in the number of fish stocked in earlier years (Table 20).

Job 10. Spillway escapement.

OBJECTIVE: To measure the escapement of tiger muskellunge, largemouth bass, channel catfish, and bluegill from Ridge Lake.

INTRODUCTION: Tiger muskellunge are stocked in many impoundments to provide supplemental predation pressure on forage fish and to add diversity to the creel in the form of a trophy species. The success of the hybrid in these roles is compromised in proportion to the escapement losses in the overflow. The purpose of this job was to measure those losses for tiger muskellunge and other fish species in Ridge Lake.

METHODS: Fish can escape from Ridge Lake by two separate routes, a tower spillway system and a surface spillway. The tower spillway system, which is housed in a concrete tower near the dam, discharges water from the lake bottom. Water flows over the tower spillwall whenever lake elevation exceeds the elevation of the crest of the spillwall (181.4 m msl; 595 ft. msl). The discharge increases as the lake level rises above 181.4 m msl until a maximum discharge of 0.71

cms is reached. A concrete surface spillway (21 m long), located at the northwest corner of the lake, discharges water when the capacity of the tower spillway is exceeded. Since the elevation of the surface spillway is 181.7 m msl (0.3 m higher than the tower spillwall), water flows over it only when inflow exceeds 0.71 cms for a substantial period of time. Thus, discharges over the surface spillway are uncommon, but some water flows through the tower spillway system much of the year.

Screening structures or weirs were positioned below both the surface spillway and the tower spillway. A wolf-type weir, constructed of wire screen (1.3-cm mesh) and supported by steel frames (1.4 x 1.1 m) was placed at the outfall of the tower spillway. The surface weir was positioned diagonally on a sloping concrete apron, approximately 8 m behind the spillway wall. The weir was approximately 24 m in length, 1.1 m high, and was constructed of steel wire screen (1.3-cm mesh) supported by steel frames. The entire assembly was bolted to the concrete apron. The diagonal placement of the weir allowed the water to carry a majority of the fish to an end-point collection box.

Both weirs were inspected daily during periods of overflow. Actual counts and length (mm TL) measurements of fish were made when possible, but subsampling was sometimes necessary. Water depth, measured at the tower spillway outfall, was used as an index of discharge volume.

RESULTS:

Surface Spillway Escapement. Water flowed over the surface spillway only once during 1985 (14 April). Escapement was limited to 28 bluegill (mean TL = 101 mm) and two largemouth bass (mean = 102 mm). Based on length distributions of escaping fish, the bluegill were predominantly age II and III while both of the largemouth bass were age I (see Job 11).

During the 4 years that escapement was monitored (1982-1985), discharge over the surface spillway occurred on only nine dates. Escapement was substantial only in 1982 when the catch was comprised entirely of age-I bluegill and age-0 largemouth bass (Table 22). The escaping bluegill belonged to the strong 1981 year class and probably represented surplus production. Escapement in subsequent years was low and variable, representing a negligible fraction of any of the species populations present in Ridge Lake.

Spillway escapement is probably positively correlated with fish density and discharge volume and is greatest in the warmer months when the fish are distributed predominantly in the surface water.

Table 22. Numbers and lengths of fish escaping from Ridge Lake over the surface spillway, 1982-1985.

Species	Year	Number escaping	Length (mm) Mean	Length (mm) Range	Number of quality size[1]
Tiger muskellunge	1982	0	--	--	0
	1983	0	--	--	0
	1984	2	625	589-660	0
	1985	0	--	--	0
Largemouth bass	1982	547	34	23- 81	0
	1983	0	--	--	0
	1984	5	257	93-380	2
	1985	2	103	90-115	0
Bluegill	1982	16,704	50	34- 70	0
	1983	0	--	--	0
	1984	377	95	54-233	46
	1985	28	101	67-135	0
Black crappie	1982	0	--	--	0
	1983	0	--	--	0
	1984	4	206	185-277	2
	1985	0	--	--	0
Channel catfish	1982	0	--	--	0
	1983	0	--	--	0
	1984	3	180	130-210	0
	1985	0	--	--	0

[1]Quality size: tiger muskellunge = 762 mm, largemouth bass = 300 mm, bluegill = 150 mm, black crappie = 200 mm, channel catfish = 350 mm.

In this study too few discharge events occurred to evaluate factors influencing surface spillway escapement. Further, it was not possible to measure discharge volume because individual discharge events were of very short duration.

Only two tiger muskellunge escaped over the surface spillway during this study (Table 22). Although this loss was small, it did demonstrate that relatively large tiger muskellunge will leave a lake in the surface discharge. However, Ridge Lake did not provide a good test of the potential for escapement over a surface spillway because only a small fraction of the discharge occurred via this route.

Tower Spillway Escapement. During 1985, escapement over the tower spillway was limited to two bluegill and four channel catfish (Table 23). These small losses relative to other years are attributed to low discharge volume during much of the year and to the shortened season that resulted from draining the lake in September.

Table 23. Numbers and lengths of fish escaping over the tower spillwall at Ridge Lake, 1982-1985.

Species	Year	Number escaping	Length (mm) Mean	Length (mm) Range	Number of quality size[1]
Tiger muskellunge	1982	2	462	461-463	0
	1983	0	--	--	0
	1984	3	657	600-711	0
	1985	0	--	--	0
Largemouth bass	1982	10	218	75-306	1
	1983	0	--	--	0
	1984	0	--	--	0
	1985	0	--	--	0
Bluegill	1982	5,305	84	30-155	1
	1983	137	82	44-126	0
	1984	532	89	39-167	7
	1985	2	90	82- 98	0
Black crappie	1982	4,278	90	78-161	0
	1983	86	104	78-177	0
	1984	560	94	60-219	2
	1985	0	--	--	0
Channel catfish	1982	29	387	150-630	14
	1983	9	570	506-602	9
	1984	45	155	105-628	1
	1985	4	136	100-156	0

[1]Quality size: tiger muskellunge = 762 mm, largemouth bass = 300 mm, bluegill = 150 mm, black crappie = 200 mm, channel catfish = 350 mm.

Over the 4 years of the study, escapement of all species over the tower spillwall was generally greatest during the colder months (November- March) and was positively correlated with discharge volume. Escapement was greatest on the first day of large discharge events and decreased substantially in subsequent days, even when discharge volume remained relatively high.

Only five tiger muskellunge escaped over the tower spillwall during the 4 years of the study. This loss was small and may greatly underestimate potential escapement from impoundments where all discharge occurs over surface spillways. Substantial escapement over the surface spillway at Lake of the Woods was suspected because park personnel observed several tiger muskellunge below the spillway and the District Fisheries Biologist recovered one tiger muskellunge from the river immediately below the lake.

Bluegill escapement was greatest in 1982 (Table 23) and was comprised principally of age-I individuals. Age-0 bluegill may have escaped also but few of them were large enough to be retained in the weir. Black crappie escapement was also highest in 1982 but age-0 fish predominated. In both cases, high escapement losses probably reflected the production of strong year classes. It is unlikely that the observed escapement was detrimental to the sport fishery for those species because the 1981 bluegill year class dominated the harvest in 1983-1985 and the 1982 crappie year class dominated the 1984 harvest for that species.

Escapement losses were most significant for the channel catfish, because 15% of legal-size individuals stocked in 1981 escaped over the tower spillwall in 1982 and 1983 (Table 23). Moreover, 14% of juveniles stocked in spring 1984 escaped within 2 weeks of release. In contrast, only three channel catfish were lost over the surface spillway during the entire study. Thus, the predominance of bottom discharge at Ridge Lake may have increased channel catfish escapement relative to escapement from impoundments where all water is discharged from the surface.

Escapement of largemouth bass over the tower spillwall was negligible during this study (Table 23). Even the large numerical loss of age-0 bass over the surface spillway in June 1982 (N = 547) probably represented an insignificant fraction of the number of that age group present at that time. In contrast, a large fraction of the largemouth bass population escaped from a 28-ha lake in southern Illinois (Lewis *et al.* 1968) and moderate losses of bass were reported from a 65-ha lake in southern Illinois (Louder 1958). Water was discharged entirely over surface spillways in those lakes and escapement occurred mostly during March, April, and May. Thus escapement of largemouth bass was probably minimized at Ridge Lake because water was discharged over the surface spillway infrequently during the entire study.

Job 11. Standing crop census at Ridge Lake.

OBJECTIVE: To estimate numerical biomass standing crops of all species populations in Ridge Lake; to estimate the age- and size-structure of each centrarchid species; and to measure the size specific mortality of tiger muskellunge stocked at age 0 in 1984 and of channel catfish stocked at age 0 in 1984 and 1985.

INTRODUCTION: Data collected using a creel census and various other sampling gears can be used to evaluate management programs and to estimate the population structure and abundance of important fish species. However, since no sampling gear is free from random and systematic errors, erroneous conclusions can be drawn concerning the sampled populations. Errors in the estimation of abundance may be especially large for species that are present at low densities, as was the case for the tiger muskellunge at Ridge Lake. Thus a draining census was conducted at Ridge Lake to provide the most accurate appraisal of the management potential of this hybrid in small impoundments.

METHODS: Ridge Lake was drawn down slowly over a 2-week period, beginning 16 September 1985. Water was discharged from the lake bottom through the drain tunnel, into a wolf-type weir (1.3-cm mesh hardware cloth) located on the downstream side of the dam. By 2 October, the surface area of the lake had been reduced to approximately 1 ha but only a small number of fish had made their way into the weir. The lake was drained completely on 2 October and all fish were collected in the weir. Dip nets (6-mm mesh), placed across the back of the weir, reduced the loss of small fish through the weir mesh. All tiger muskellunge and channel catfish present in the draining census were measured (nearest mm) and weighed (nearest g). Fin clips were recorded for all channel catfish. All largemouth bass were measured but none were weighed. A subsample of black crappie were measured (N = 436) but not weighed, and the remaining crappie were assigned to one of three size classes (<130 mm, 130-189 mm, ≥190 mm) and counted. These size classes corresponded to age-0, age-I, and age-II and older fish, respectively. It was generally easy to assign crappie to the appropriate size class because few fish were near the boundary between size classes (Fig. 2). A subsample of bluegill were measured (N = 5,146). The remaining bluegill filled 95 19-liter buckets. The numbers and weight of bluegill in a subsample of these buckets was determined and the results were expanded to estimate the total number and weight.

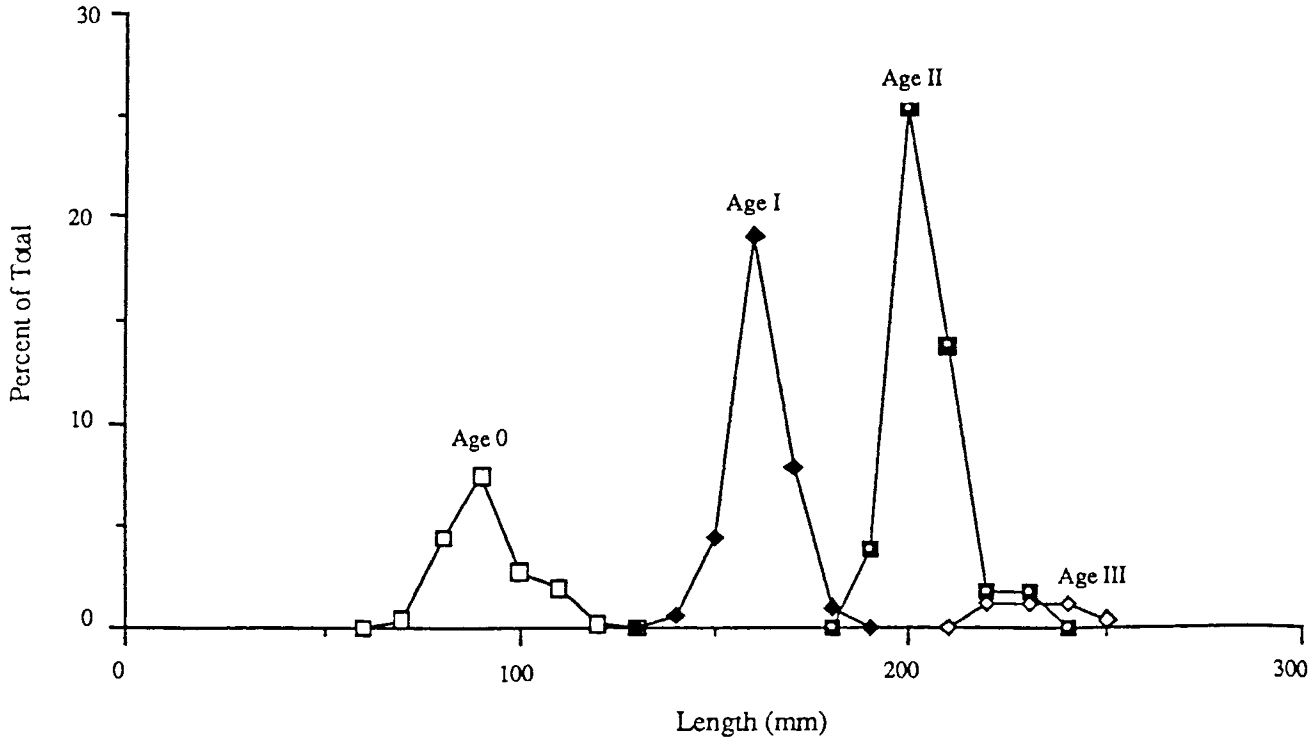

Fig. 2. Age structure of black crappie in Ridge Lake at the 1985 draining census.

Length-weight relationships and age-at-capture data for all three centrarchid species was obtained from fish collected by electrofishing and angling in September (see Job 9 methods for details). The length-weight regressions were used to estimate mean weights of 1-cm length groups in the draining census.

RESULTS: The total biomass of fish recovered from Ridge Lake in 1985 was substantially larger than in any previous draining census (Table 24; Bennett *et al.* 1969). Unusually high densities of panfish (bluegill and black crappie) were responsible for most of this increase. In contrast, the 1985 fish biomass was similar to an average for numerous other Midwestern impoundments summarized by Carlander (1955) (446 kg/ha,) and for Midwestern ponds summarized by Hackney (1978) (412 kg/ha,) but was somewhat below an average for Iowa lakes lacking shad (578 kg/ha, Hill 1984).

<u>Black Crappie</u>. Black crappie were not included in any previous studies at Ridge Lake and thus comparative standing crop data are not available. The 1985 standing crop (44.6 kg/ha) made up 10.6% of the total fish biomass in Ridge Lake in October and the 1983 year class (age-III fish)

Table 24. Percent composition, by weight, of fish species present in selected draining censuses at Ridge Lake and total standing crops.

Census year	Largemouth bass	Bluegill	Black crappie	Others	Total (kg/ha)
1959	13.0	65.0	0.0	22.0	277
1963	19.0	57.0	0.0	24.0	270
1970	17.0	35.0	0.0	48.0	218
1980	45.6	0.0	0.0	54.4	185
1985	11.0	71.2	10.6	7.2	423

made up 68% of the crappie total (Table 25). For comparison, the Ridge Lake crappie biomass was well below an average reported for many Iowa lakes (Hill 1984). Although crappie harvest increased in successive years of this study (Table 20), the age structure of surviving fish (Table 25, Fig. 2) portended substantial declines in harvest in future fishing seasons. Declines in harvest would likely have occurred because the 1984 and 1985 year classes were much smaller than those produced in 1982 and 1983. In fact, the 1983 year class was substantially more abundant in October 1985 than were either the 1984 or 1985 year class, despite the fact that only the 1983 year class had suffered substantial fishing mortality. The relatively small size of the 1984 year class was partly responsible for the high PSD of crappie in October 1985 (55%). Variations in year class strength and high exploitation rates of quality size crappie were the most important factors influencing crappie PSD in Ridge Lake. Crappie PSD did not appear to be positively correlated with bluegill PSD or with relative weight (Wr) of quality size crappie as suggested by Gablehouse (1984).

Based on their small contribution to the harvest in 1982-1985 and their absence in the draining census, the 1981 year class of crappie was comparatively small. Reasons for the limited success of this year class are not known but a numerically small spawning population may have been a major factor. In contrast, the 1982 year class was relatively strong, dominating the harvest in 1984 and in the spring of 1985. Even so, only 114 of these fish (age III in 1985) survived to the end of the study. Considering that more than 300 age-III crappie were harvested in 1985, annual exploitation of that age group was very high. Approximately 47 of them were harvested during August and September. Assuming that natural mortality was negligible during that interval, exploitation of the 1982 year class was 30% during the last 6 weeks of the 1985 fishing season. Likewise, 28% of the 1983 year class was harvested during the same interval. Exploitation at Ridge Lake could easily have been even higher because the lake was closed to fishing during

Table 25. Numbers and total weight (kg) of individual fish species recovered from Ridge Lake in the 1985 draining census. Mean total lengths (mm) for individual age groups are included for bluegill, largemouth bass, and black crappie.

	Bluegill	Largemouth bass	Black crappie	Tiger muskellunge	Channel catfish
Age 0					
Number	15,813	438	498	--	--
Weight (kg)	12	6	5	--	--
Mean total length (mm)	--	100	96	--	--
Age I					
Number	53,764	319	979	--	--
Weight (kg)	308	28	59	--	--
Mean total length (mm)	70	192	166	--	--
Age II					
Number	14,759	152	1,386	--	--
Weight (kg)	275	33	182	--	--
Mean total length (mm)	104	253	208	--	--
Age III					
Number	11,596	155	114	--	--
Weight (kg)	553	58	23	--	--
Mean total length (mm)	127	299	237	--	--
Age IV					
Number	9,488	180	0	--	--
Weight (kg)	682	107	0	--	--
Mean total length (mm)	157	346	--	--	--
Age V					
Number	--	45	0	--	--
Weight (kg)	--	52	0	--	--
Mean total length (mm)	--	428	--	--	--
Total					
Number	105,420	1,289	2,977	32	108
Weight (kg)	1,829	283	270	50	134

intervals when crappie were most vulnerable to angling. Moreover, the fishing pressure directed at black crappie was relatively low, since only 10% of anglers were fishing specifically for that species in 1985 (Table 12).

The problems most often associated with crappie populations include overcrowding, a food supply inadequate for good growth, and wide fluctuations in year class strength (Mitzner 1984). Only the latter of these three appeared to be a serious problem at Ridge Lake. It is unlikely that predation by tiger muskellunge influenced year class strength substantially in 1984 and 1985 because the hybrids were probably using larger and more abundant forage.

Bluegill. The bluegill biomass present in October 1985 was greater than in any other Ridge Lake draining census (Table 26; Bennett *et al.* 1969). In addition, bluegill made up a larger fraction of the total fish biomass in 1985 (71%) than they did in any other draining census. Bluegill biomass at Ridge Lake in 1985 was also substantially higher than in most impoundments in the Midwest (Carlander 1955, 1977; Hackney 1978, 1979; Hill 1983).

Table 26. Standing crops of bluegill in Ridge Lake at the conclusion of the tiger muskellunge study (1985), following other years of stable water level (1959, 1963), and following 7 years of fall drawdowns (1970).

Census year	Surface area (ha)	Duration (years)	Number	Weight (kg)	No./ha	kg/ha
1959	6.9	4	92,699	1,246	13,430	181
1963	6.8	3	85,600	1,051	12,588	155
1970	6.6	7	9,546	503	1,446	76
1985	6.1	5	105,420	1,829	17,367	301
1985[1]	6.1	5	73,394	1,758	11,838	284

[1]Excludes fish smaller than 64 mm, as did censuses in 1959, 1963, and 1970.

No stocked bluegill survived to the draining census and the 1981 year class (age IV in 1985) still made up a larger fraction of the bluegill biomass (37%) than did any other year class (Table 25). Considering that this year class suffered substantially more fishing mortality than other year classes and that it was exposed to more years of natural mortality, it was clearly stronger than year classes produced in 1982 and 1983.

The 1984 year class made up 51% of total bluegill numbers, demonstrating highly variable recruitment (Table 25, Fig. 3) and suggesting that the bluegill population was becoming unbalanced (Anderson 1973).

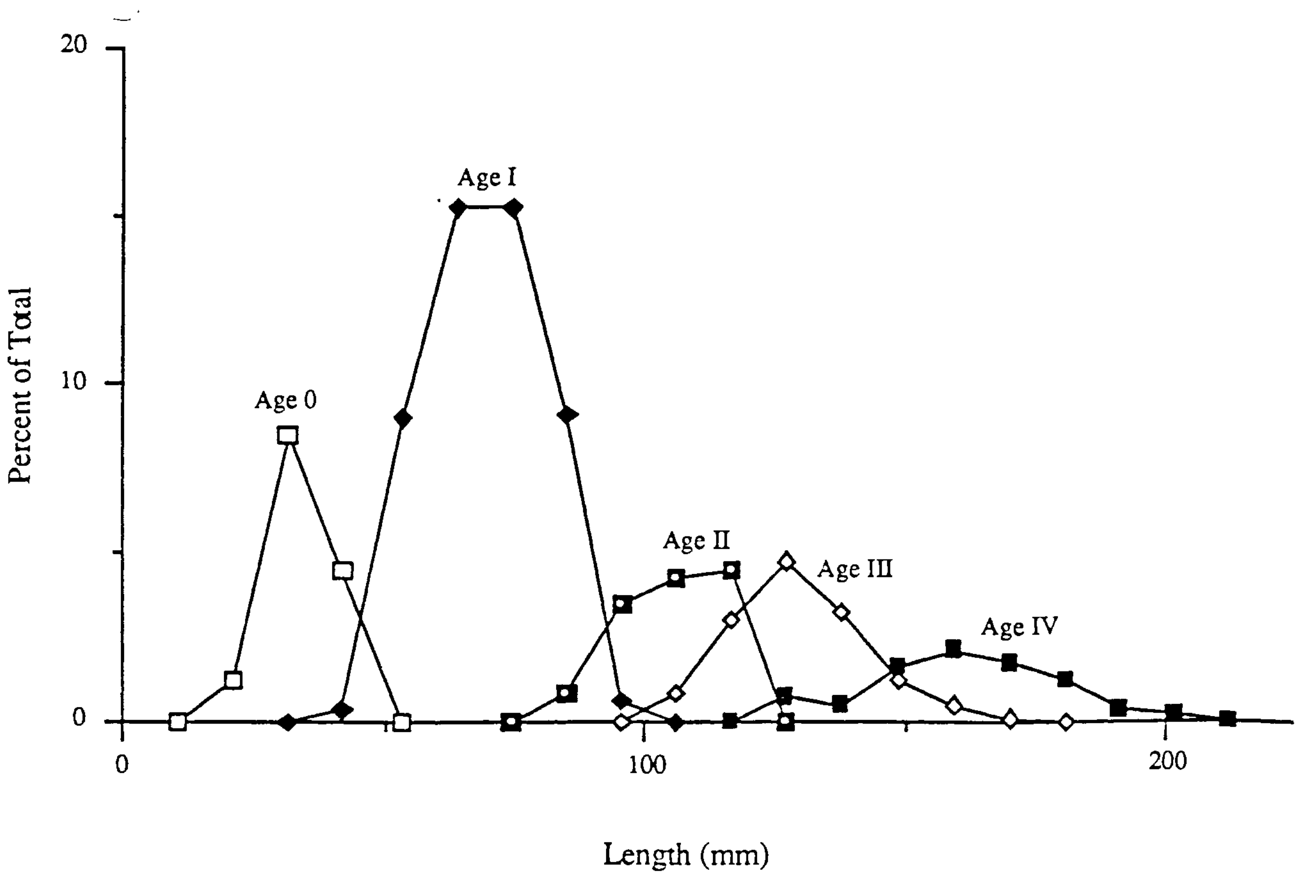

Fig. 3. Age structure of bluegill in Ridge Lake at the 1985 draining census.

The numerical and biomass standing crops of the 1985 year class (age 0) were underestimated in the draining census because some of the smallest individuals were able to escape through the 12-mm mesh hardware cloth on the floor of the weir. Also, predation on this age group may have been exacerbated by the temporary crowding of fish in a small volume of water during the lake drawdown. In support of this possibility, many black crappie examined on 2 October contained one or more small bluegill in their stomachs.

During the present study, bluegill growth was poor in comparison to growth in earlier years at Ridge Lake (Table 16) and to growth in other Illinois impoundments (Lopinot 1967). Mean lengths at capture for individual age groups in the fall of 1984 and 1985 were also generally well below calculated bluegill lengths in most Midwestern impoundments (Carlander 1977). Also, the relative weights of bluegill (Wr) in Ridge Lake in fall 1985 (Fig. 4) were below the optimum proposed for this species by Hillman (1982). Slow growth, the absence of age-V fish in the population, and variable recruitment, rather than high exploitation rates, were responsible for the low PSD (12%) and RSD_{200} (0%) values in all of the fall electrofishing censuses and in the 1985 draining census (Table 27).

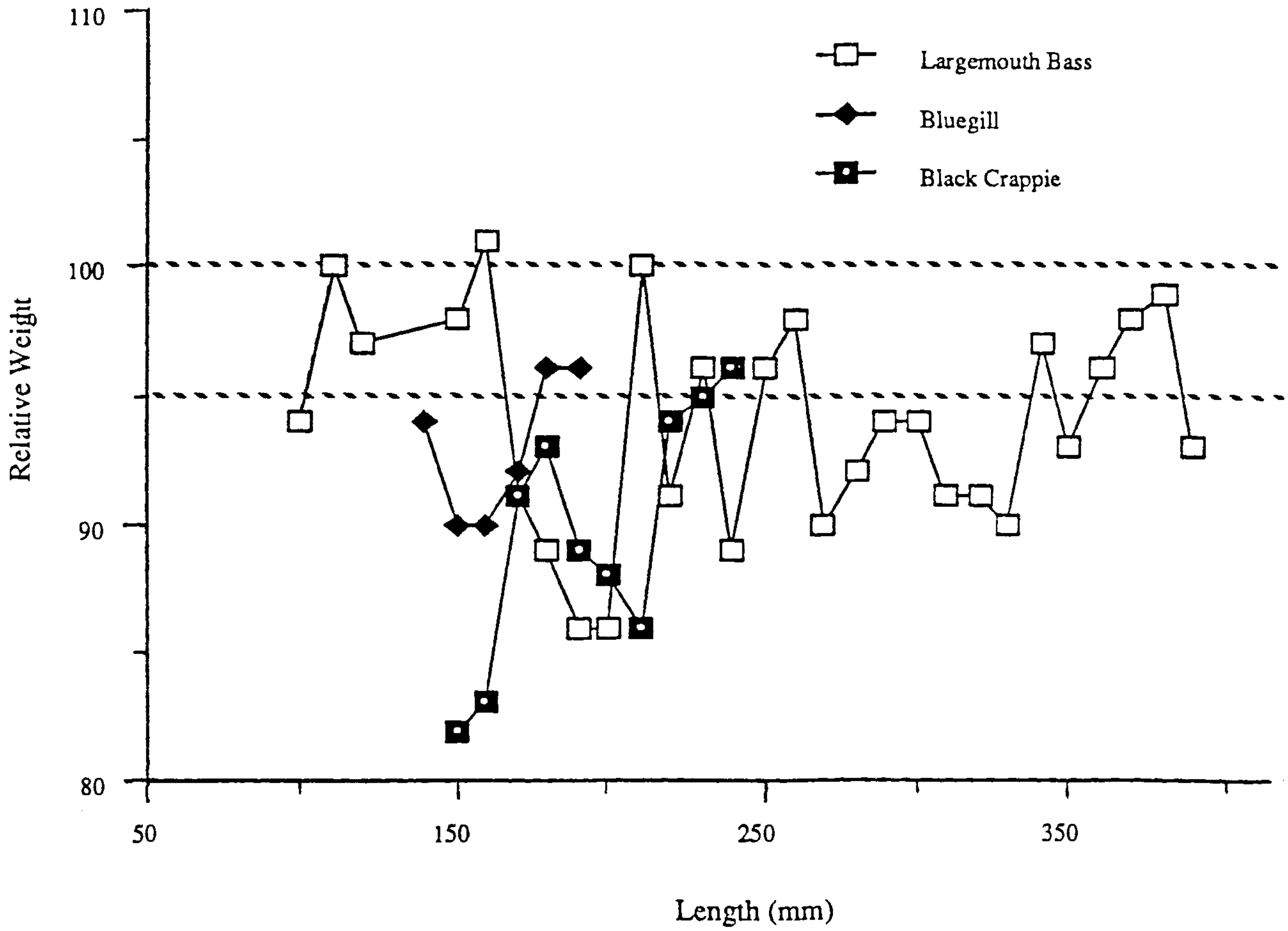

Fig. 4. Relative weight (Wr) of largemouth bass, bluegill, and black crappie at Ridge Lake in September 1985. Broken lines delimit desirable range for Wr.

Because bluegill year classes are often short lived with few survivors older than age V, they should obtain a length of at least 150 mm by age III or IV to be available for harvest for more than 1 or 2 years (Novinger and Legler 1978). In October 1985, only 6 and 67% of surviving age III and IV bluegill, respectively, had reached quality size (150 mm). Consequently, PSD was well below the 20-40% considered optimum for impoundments where fishing for both largemouth bass and bluegill is important. The poor bluegill population structure was most evident in the relatively small mean weight of harvested fish but was less apparent in the yield or harvest rate statistics (Table 19). Yield and harvest rates of bluegill were relatively high in 1985 in spite of low PSD values, because the density of quality-size bluegill (1,146/ha) was higher than in all but one previous draining census (Bennett *et al.* 1969, 1973). This was possible because the density of stock-size bluegill was also very high in 1985. Thus PSD did not accurately reflect harvest potential because fish density does not enter into its calculation.

Table 27. Length frequency indices (PSD, RSD_{355}) for largemouth bass and bluegill populations at Ridge Lake, 1982-1985. Numbers in parenthese are sample sizes. Creel values were derived from angler caught fish from last month of fishing season; electrofishing values from fall sampling; and draining values from the draining census.

	Largemouth bass		Bluegill
	PSD	RSD_{355}	PSD
1982			
Creel	51(145)	8(145)	70 (47)
Electrofishing	46 (59)	3 (59)	3 (134)
1983			
Creel	48(246)	13(246)	62 (638)
Electrofishing	52 (58)	26 (58)	5 (239)
1984			
Creel	68(182)	18(182)	61 (132)
Electrofishing	62(117)	22(117)	8 (234)
1985			
Creel	46(233)	15(233)	61 (216)
Electrofishing[1]	43 (62)	15 (62)	8 (167)
Electrofishing[2]	54 (85)	26 (85)	10 (244)
Draining	46(629)	20(629)	12(2,741)

[1]Sampling conducted on 9 September 1985; water temperature was 28°C.
[2]Sampling conducted on 17 September 1985; water temperature was 22°C.

Although two fall electrofishing samples in 1985 underestimated bluegill PSD in Ridge Lake (Table 27), both estimates were close enough to the true value to be useful in evaluating bluegill population structure. PSD values obtained from creel data greatly overestimated population PSD (Table 27), because small stock-size bluegill (75-110 mm) are not caught in proportion to their abundance (Anderson 1980). Fall electrofishing has been shown to underestimate bluegill population structure (Simpson 1978) but more accurate estimates can be obtained by sampling in late spring or early summer (Novinger and Legler 1978). Also, estimates of the relative abundance of age-0 bluegill in the Ridge Lake population were substantially underestimated in the electrofishing samples. This age group made up 15% of all bluegill in the draining census (Table 25) but only 3% of the total number collected in the fall electrofishing samples.

Based on two indices of community balance, bluegill biomass at Ridge Lake in October 1985 was more than adequate to meet the food needs of all size classes of piscivores. The Y/C ratio (Swingle

1950) was 1.65, well within the range of 1 to 3 that Swingle considered desirable for good growth. However this ratio only measures the prey available to an adult predator of average size. The AP/P ratio (Jenkins and Morais 1978) is a more comprehensive index, evaluating prey availability for all size classes of piscivores. Jenkins and Morais (1978) established a minimum desirable AP/P ratio of 1:1 for samples taken in August. In October 1985, this ratio for bluegill and bass at Ridge Lake was lowest for small predator size classes but was always well above the minimum acceptable value (Fig. 5). The addition of tiger muskellunge to the predator biomass would not have substantially reduced the ratio. The high AP/P ratios for all predator size classes in Ridge Lake indicated that the prey population could have sustained higher predator density.

One objective of stocking tiger muskellunge into centrarchid-dominated impoundments is to provide sufficient predation pressure to prevent overcrowding of bluegill. Because the additional predation pressure should reduce bluegill density and thus intraspecific competiton for food, bluegill should exhibit improved growth, leading to a population size structure consistent with

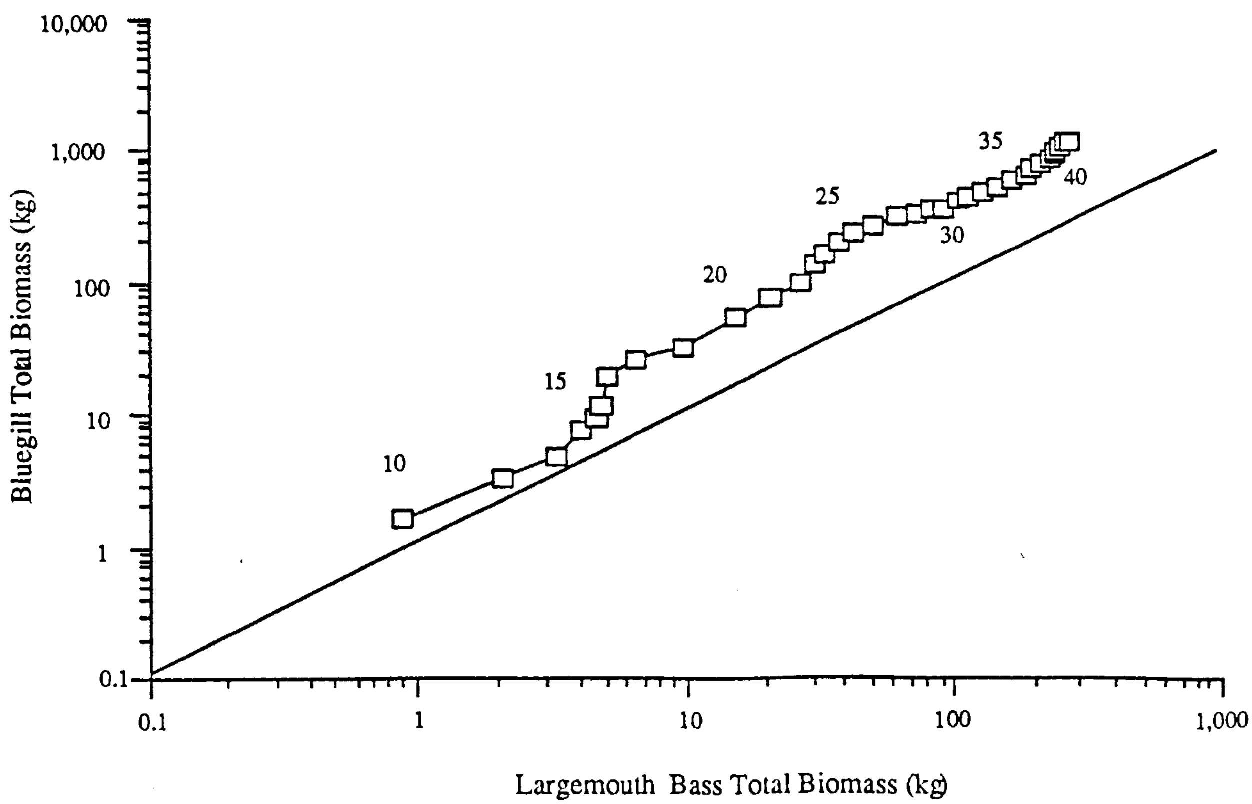

Fig. 5. Logarithmic plots of available prey (bluegill)-predator (largemouth bass) ratios at Ridge Lake in October 1985 (AP/P). Numbered points indicate cumulative biomass of largemouth bass at 5-cm length intervals beginning with 10 cm. The 45° line represents the minimum desirable AP/P ratio.

good sport fishing. The objective was not realized at Ridge Lake, because the bluegill grew slowly, developed a population size structure that was not optimum for high sport fishing success (Novinger and Legler 1978), and attained a biomass standing crop that was higher than in any other comparable census at Ridge Lake.

In contrast to the poor bluegill population control provided by tiger muskellunge, moderate and severe fall drawdowns (1951-1956) and moderate drawdowns practiced in association with supplemental feeding of bluegill (1963-1970) in Ridge Lake, resulted in low biomass standing crops of bluegill, increased growth rates, and high PSD values. Thus drawdown was a more successful technique for controlling bluegill density than was predation by tiger muskellunge.

Individual tiger muskellunge from the 1981 and 1982 year classes probably preyed on bluegill larger than those in the abundant 1984 year class, and hence would not have been expected to influence their density. However, these same tiger muskellunge did not provide an impact on older bluegill sufficient to substantially lower their density and stimulate good growth.

Largemouth Bass. The largemouth bass biomass (kg/ha) surviving to the end of the present study was about average among Ridge Lake draining censuses that followed a minimum of three growing seasons (Table 28). Bass standing crop was substantially greater only in 1980, when bluegill were not present and the biomass of all other fish species was low. In 1980, the total fish biomass at Ridge Lake was the lowest on record. Largemouth bass made up a smaller

Table 28. Standing crops of largemouth bass in Ridge Lake at the conclusion of the tiger muskellunge study (1985), following other years of stable water level (1959, 1963), following fall drawdowns (1970), and following years of a 455-mm size limit (1980).

Census year	Surface area (ha)	Duration (years)	Number	Weight (kg)	No./ha	kg/ha	Mean weight (kg)
1959	6.9	4	2,354	240	341	34.8	0.102
1963	6.8	3	6,218	360	914	52.9	0.058
1970	6.6	7	2,420	245	367	37.1	0.101
1980	6.1	5	3,729	513	613	84.1	0.140
1985	6.1	5	1,289	283	212	46.6	0.220

fraction of the total fish biomass in 1985 than in earlier draining censuses (11%, Table 24) because bluegill biomass was extremely high in 1985.

Approximately 10% of the largemouth bass stocked in 1981 at age I (N = 471) survived to the draining census (age V); they accounted for 4 and 18% of the numerical and biomass standing crops, respectively (Table 25). These stocked fish made up 36% of legal size bass (>355 mm) surviving to the draining census but only 6% of the number of bass harvested in the last month of the 1985 fishing season. Thus, they apparently were less vulnerable to angling than were the younger (and smaller) legal-size bass.

The 1981 largemouth bass year class (age IV in 1985) was stronger than the two subsequent year classes and was the only year class spawned in the lake that contributed to the harvest in any year. They made up 94% of the number of bass harvested in late summer of 1985 but only 42% of them present in the draining census were legal size (Fig. 6). No individuals from later year classes had reached legal size and only 40% of age-III bass had reached quality size.

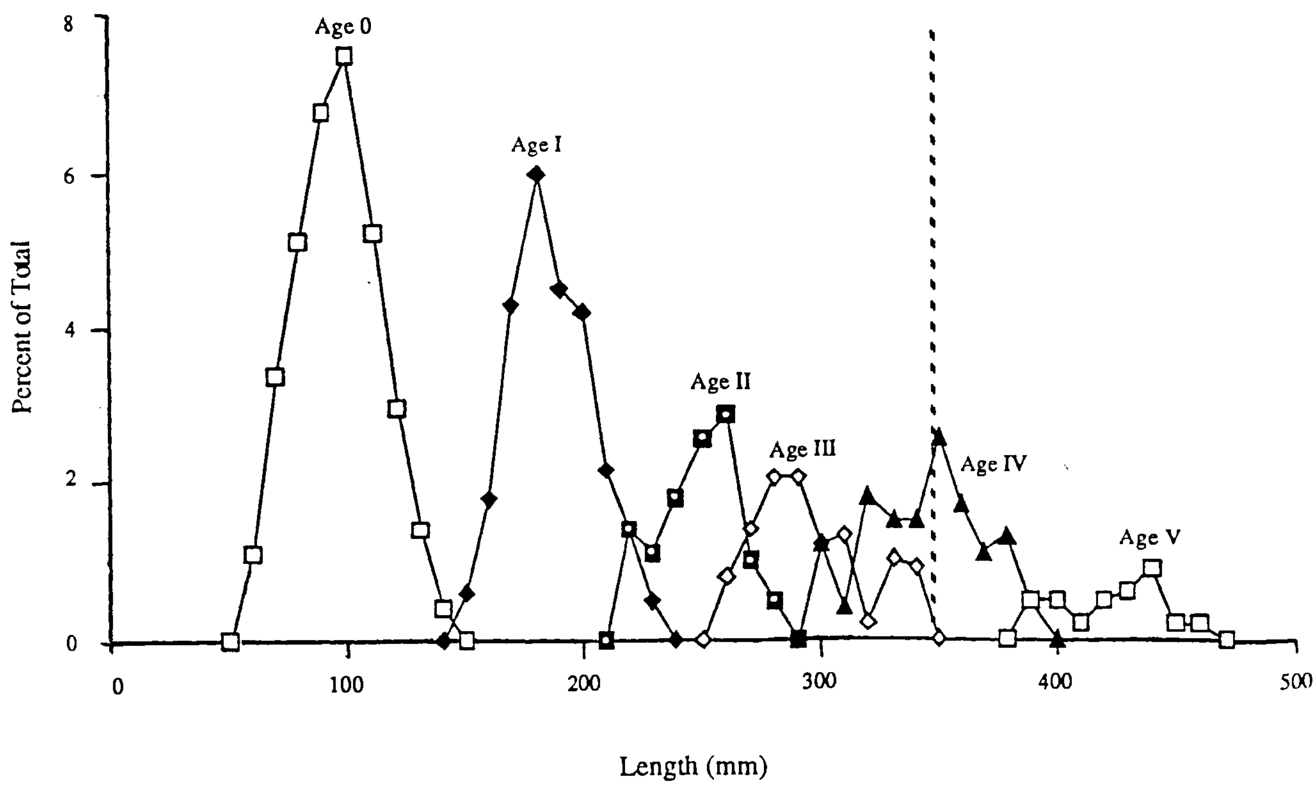

Fig. 6. Age structure of largemouth bass in Ridge Lake at the 1985 draining census. The vertical broken line represents the length limit at 355 mm.

Although the largemouth bass biomass in Ridge Lake in 1985 and in most other draining censuses were similar, the size structure of the populations were very different. The total number of surviving bass was substantially smaller and the number of quality-size bass was much larger in 1985 than in any other year (Table 28). Consequently, the mean weight of bass in the 1985 draining census was nearly twice that in other censuses (Table 28). Moreover, differences in size structure were reflected in the mean weights of angler-caught fish, which were also much larger during the present study than in earlier years (Table 28). In contrast to the liberalized fishing policy that was followed in all but one earlier study at Ridge Lake, a 355-mm size limit, enforced during 1982-1985 fishing seasons, eliminated exploitation of fish smaller than 355 mm. Although a size limit was also employed during 1977-1980, it did not produce the same effect because an overabundant 1976 year class grew slowly and did not reach quality size by the conclusion of the study. Although implementation of a 355-mm size limit during 1982-1985 fishing seasons was apparently responsible for an increase in density of quality-size fish, adult density (47 bass/acre) and total bass biomass (47 kg/ha) were only at minimum levels recommended by Reynolds and Babb (1978) for balanced bass populations in small impoundments.

While the numerical density of quality size bass was high in Ridge Lake in 1985, the density of bass <250 mm long (N = 820) was much lower than in any other draining census year (Bennett *et al.* 1969, 1973; Burkett *et al.* 1981). The reasons for lower numbers of bass in 1985 are not known, but based on abundance of bluegill forage and on the low frequency of small bass in the diet of both larger bass and tiger muskellunge, predation was not likely an important factor. While small bass were not abundant in 1985 relative to earlier Ridge Lake census years, age-I bass were more abundant in 1985 (53/ha) than in public fishing lakes (32±13/ha) and ponds (41±6/ha) in Alabama (Davies 1982).

The density of age-0 bass in October 1985 was moderate (72/ha) and survivors were relatively large (mean = 100 mm). First summer growth may be more important to recruitment than density in the fall, since recent studies have demonstrated that overwinter survival of age-0 largemouth bass is a function of length attained during the first summer (Aggus and Elliott 1975, Shelton *et al.* 1979, Adams *et al.* 1982, Anderson 1984). The largemouth bass Young-Adult Ratio (YAR) in October 1985 (1.5) was within an acceptable range (1-10) recommended by Reynolds and Babb (1978). However, given the relationship between size of age-0 bass and subsequent recruitment, the value of the YAR index for evaluating reproductive success is questionable. The low to moderate densities of age-0 and -I bass at Ridge Lake in 1985 indicated that a minimum length limit rather than a slot length limit was the appropriate management regulation.

The PSD of largemouth bass at the 1985 draining census (Table 27) indicated good population structure (Reynolds and Babb 1978). However, nearly 80% of the quality-size fish present were either stocked in 1981 as yearlings or were members of the first year class spawned in the lake. Since the first year class produced in new or renovated impoundments is likely to be numerically stronger than are subsequent year classes, the observed population structure may not reflect an equilibrium condition for Ridge Lake when tiger muskellunge are present and a 355-mm size limit is enforced on largemouth bass.

Creel and electrofishing estimates of bass PSD in late summer and fall were similar in each year of the present study (Table 27). Moreover, both creel and elctrofishing samples taken in September 1985 provided good estimates of the true population PSD. Willis and Hartman (1986) found that PSD estimates derived from angling tournaments were low relative to those derived from electrofishing samples. Differences in gear selectivity did not occur at Ridge Lake in 1985, perhaps because only creel data from late summer was used for the PSD estimate.

Relative weights (Wr) of largemouth bass in Ridge Lake in October 1985 were satisfactory (95-100%; Wege and Anderson 1978) for fish in only about 50% of the 1-cm length groups (Fig. 4); individual variability was high in most length groups. Failure of the bass population to achieve uniformly high Wr values was unexpected because bluegill forage was abundant for all size classes (Fig. 4), bass density was only moderate, and PSD was within a range that favored satisfactory Wr.

Lengths at capture in fall 1985 of the various age groups of largemouth bass were generally intermediate between those attained in years of biennial culling (1947-1949) and in years of drawdown and feeding (1967-1968) at Ridge Lake (Table 16). Moreover, lengths attained by bass in the 1985 draining census were very similar to an Illinois average (Lopinot 1967).

It is not possible to assess the impact of tiger muskellunge on the Ridge Lake largemouth bass population by comparing population rate functions and creel statistics in the current study with those from earlier years. The imposition of a size limit on largemouth bass during the current study appeared to have an impact on bass population structure sufficiently large to mask any interaction between tiger muskellunge and largemouth bass. Moreover, bass harvest in the current study was dominated by the two year classes that would not have been affected by stocked tiger muskellunge. The final largemouth bass standing crop was within the range recorded in years when tiger muskellunge were not present, and there was no evidence to suggest that the tiger muskellunge preyed substantially on largemouth bass. It was clear that the management strategy of stocking tiger muskellunge while protecting largemouth bass with a strictly enforced size limit did not result in sufficient predation pressure on bluegill to control their abundance.

Channel Catfish. The biomass and numerical standing crop of channel catfish in the 1985 draining census were made up principally of fish stocked as yearlings in 1981 (Table 20) and as age-0 fish in 1984 and 1985. Harvest and escapement losses as well as natural mortality of these year classes are reported in Study 103.

Tiger Muskellunge. Five of 32 tiger muskellunge surviving to the draining census had been stocked as age-0 fish in 1984 (Table 25). The survival of this year class was poor and is examined in Job 8. The remaining 27 fish had been stocked at age 0 in 1981 and 1982. Unfortunately, fin clip regenerations were so complete that the two year classes could not be distinguished from one another. Only 5 of these 27 fish had reached legal size by the end of the study (Fig. 7).

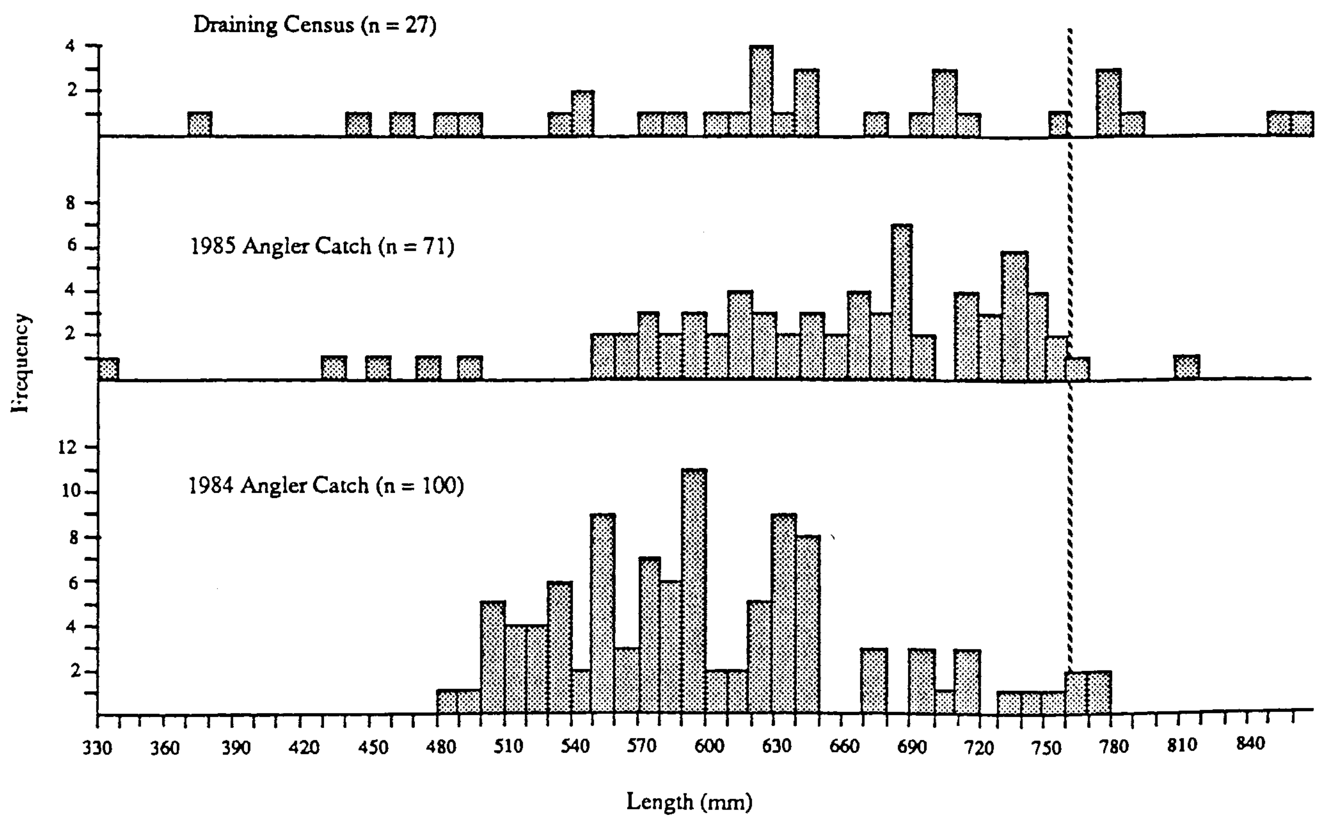

Fig. 7. Length-frequency distributions of tiger muskellunge in the angler catch in 1984 and 1985 and in the 1985 draining census at Ridge Lake.

Because 15 tiger muskellunge died from hooking mortality and two were harvested in 1985, a minimum of 49 hybrids had been present at the beginning of the fishing season. Since 71 tiger muskellunge were caught by anglers in 1985, the number present at the beginning of the fishing season was either greater than 49 or many of them were caught more than once during the 1985 fishing season.

Although the density of tiger muskellunge was reasonably high at the beginning of the 1985 fishing season, the size composition of the hybrid population in 1984 and 1985 (Fig. 7) may not have been optimum for influencing bluegill population structure. In 1985, bluegill of the abundant and slow-growing 1984 year class were probably too small to be of interest to the large tiger muskellunge from the 1981 and 1982 year classes. A more suitable tiger muskellunge size structure to control small bluegill could be achieved by annual stockings of large age-0 fish.

Job 12. Analyzing and reporting.

OBJECTIVE: To evaluate the potential of tiger muskellunge to improve the quality of fishing in small impoundments dominated by the bass-bluegill combination.

INTRODUCTION: The management potential of the tiger muskellunge in small centrarchid-dominated impoundments depends both on the hybrid's contribution to the catch and harvest and on its impact on other species populations. The purpose of this study was to collect and evaluate catch and harvest data, as well as other ecological information needed to assess the management potential of tiger muskellunge. This job summarizes the study's findings.

RESULTS: This study demonstrated that a substantial catch-and-release fishery for sublegal tiger muskellunge can be created in small centrarchid-dominated impoundments, but that the growth of the hybrid in the presence of centrarchid forage is below its potential and may be inadequate for the development of a trophy fishery. However, the estimates of growth are confounded by the high stocking density of tiger muskellunge in the study impoundment, which may have compromised its growth potential. The high angling vulnerability of tiger muskellunge in Ridge Lake indicated that a size limit is necessary to provide optimum benefit from a catch-and-release fishery; but because growth was slow, it did not greatly increase the number of fish reaching legal size. Despite the paucity of true trophy-size specimens in Ridge Lake and the small numerical catch of legal-size fish, angler satisfaction with the tiger muskellunge was high. Moreover, the mean weight of tiger muskellunge in the draining census (2.5 kg) was greater than that of age-V largemouth bass (2.1 kg). In the draining census, 18 tiger muskellunge were larger than the largest surviving largemouth bass. Thus, even a population of slow-growing tiger muskellunge is capable of supplementing the standing crop of large sportfish.

The success of catch-and-release fisheries for tiger muskellunge will vary among impoundments, depending principally on the early survival of stocked fish and upon escapement and hooking mortality losses. Unless fish are stocked at a large size, survival is likely to be poor whenever established predator populations are present. The stocked fish should be at least 250 mm long if reared on live forage and at least 300 mm long if reared on an artificial diet.

Escapement losses were insignificant at Ridge Lake but may be more important in impoundments in which all water is discharged over a surface spillway. Although cumulative hooking mortality losses of stocked tiger muskellunge can be substantial, especially when fishing pressure is high (a minimum of 20% of the fish stocked in Ridge Lake in 1981 and 1982 ultimately died from hooking mortality), the mortality rate should not preclude the development of a good catch-and-release fishery.

The impact of tiger muskellunge on largemouth bass populations could not be adequately evaluated by comparing harvest statistics and standing crops of bass in the current study with those in earlier Ridge Lake studies. The consequences of differences in fishing pressure, bass size limits, and water-level management were sufficient to mask any potential interaction between tiger muskellunge and largemouth bass. However, there was no evidence either in the current study or in published accounts to indicate that tiger muskellunge eat substantial quantities of largemouth bass. Moreover, because the catch and harvest statistics for largemouth bass in Ridge Lake were intermediate among Midwestern impoundments, there was no evidence to suggest that tiger muskellunge had a large negative impact on the bass population.

The use of tiger muskellunge as a supplemental predator to reduce bluegill density, and thereby improve bluegill growth and population structure, was unsuccessful. Bluegill grew slowly, developed a population size structure inconsistent with optimum sport fishing success, and attained a biomass standing crop that was higher than in any other comparable draining census at Ridge Lake. This population condition developed in spite of a high stocking density of tiger muskellunge and a restrictive size limit on the harvest of largemouth bass.

In summary, justification for stocking tiger muskellunge in centrarchid-dominated impoundments must rely principally on the value of the catch-and-release fishery of sublegal fish and on a very limited harvest of legal fish. Harvest can be increased modestly by small reductions in the minimum size limit but only at the expense of the catch-and-release fishery. The high vulnerability of tiger muskellunge to angling is an asset in creating a catch-and-release fishery but can only reduce the number of fish that reach legal size. It does not appear that any reasonable stocking density of tiger muskellunge will have a positive influence on bluegill population size structure.

Study 102. Accuracy of a partial creel procedure.[1]

Job 1. Evaluation of a partial creel.

OBJECTIVE: To determine the accuracy of the partial creel survey procedures used by the Illinois Department of Conservation to predict total sport fish harvest.

INTRODUCTION: The great cost and effort involved in complete creel censuses have led to the use of partial creel surveys. If properly designed, the partial creel procedure reduces costs while achieving an acceptable level of accuracy. Subsampling procedures are based on stratified random sampling. When such subsampling is distributed among days in proportion to fishing pressure, greater accuracy can be achieved than if equal effort is given to each day. However, the accuracy of partial creel projections has not been reported in the literature. This job compared partial creel projections of catch rate, harvest rate, total catch, and total harvest at Ridge Lake to the actual values measured by a complete creel census. Projections were applied to catch data as well as to harvest data to measure the precision of the estimates at two harvest levels.

METHODS: A partial creel survey of the Roving Clerk type, employed by the Illinois Department of Conservation, was used to predict fishing effort, harvest rate, catch rate, total harvest, and total catch at Ridge Lake. The fishing season was divided into 28-day blocks. Within each block, weekends and weekdays were treated as separate strata, because they received markedly different fishing pressures. Sampling probabilities assigned to these strata were approximately proportional to the anticipated amount of fishing pressure, an allocation of sampling effort designed to reduce the variance of the creel statistics. The creel day was divided into morning (0600-1000 hours) and afternoon (1500-2000 hours) sessions with equal sampling probabilities; however, sessions were not treated as strata in the computation of creel statistics. Fishing pressure was estimated from instantaneous fishermen counts made by a clerk who sampled the entire body of water. Catch per unit effort (CPE) was determined from interviews conducted by the clerk, and only complete

[1] No work was scheduled for this study in 1985; the final results reported by Newman and Storck (1984) are reprinted here.

interviews were used. Catch and harvest statistics for partial creel sampling dates were calculated as the product of fishing pressure and CPE. Projections of catch and harvest for the entire strata were derived from these estimates.

The partial creel procedure used by the Illinois Department of Conservation was modified to accomodate the regimented fishing schedule at Ridge Lake. Because Ridge Lake was closed on Mondays and Tuesdays, partial creel surveys scheduled for those days were reassigned to another weekday by means of a random numbers table. The reduction in the number of weekdays available for sampling increased the probability that a weekday would be sampled from 0.2 to 0.33. The time of day selected for instantaneous counts was also modified because Ridge Lake was often closed at the time assigned by the state creel calendar; new count times were assigned by means of a random numbers table. Also, because fishing sessions at Ridge Lake were of short duration and fishing pressure did not vary much within a particular session, only one instantaneous count was made per creel day. All other procedures followed the state lake creel survey instructions. The time interval covered by the six partial creel periods did not coincide exactly with the length of the fishing season at Ridge Lake, thus actual creel data presented here do not equal data presented in Job 9 (Study 101).

RESULTS: The partial creel projection of total annual fishing effort for 1984 (6,156 hours) was higher than the actual effort (5,592 hours) by only 10% (Table 29). However, catch and harvest statistics are derived from daily estimates of effort and catch per unit effort (CPE), which were generally less precise than the estimate of annual fishing effort. The large confidence intervals associated with estimates of monthly effort (Table 29) reflect a large day-to-day variation in fishing effort which can increase random errors in both catch and harvest estimates.

The partial creel projection of the annual number of individuals harvested differed from the actual harvest by 52% for largemouth bass, 28% for bluegill, and 23% for black crappie (Table 30). The projection of total weight harvested differed from the true value by 51% for largemouth bass, 22% for bluegill, and 24% for black crappie (Table 31). The harvest estimate for each species was formed by summing estimates for the seven individual 28-day periods. The relatively large differences between actual and estimated harvest for each species reflected low precision in the estimates of monthly harvest (Table 32), which was caused by large day-to-day variation in both fishing pressure and CPE. For most monthly estimates, differences between estimated and actual harvest could be explained by random errors. Consequently, there is no evidence to support the existence of a systematic error in the creel design.

Table 29. Actual and projected fishing effort, number of fish harvested, and 95% confidence intervals (C.I.) of projected harvest for the 1984 fishing season at Ridge Lake. Fishing effort is expressed as man-hours.

	Creel period						
	2	3	4	5	6	7	Total
Effort							
Actual	1,266	1,403	1,303	833	394	393	5,592
Projected	927	1,476	1,287	1,233	747	486	6,156
C.I.	168-1,686	711-2,241	692-1,854	612-1,854	237-1,257	80-892	
Largemouth bass							
Actual harvest	42	47	32	12	5	17	155
Projected harvest	13	19	25	4	0	14	75
C.I.	0-35	0-52	8-42	0-13	--	0-32	
Bluegill							
Actual harvest	346	739	98	129	16	9	1,337
Projected harvest	129	670	105	27	0	26	957
C.I.	0-292	15-1,325	0-297	0-64	--	0-78	
Black crappie							
Actual harvest	498	61	35	35	6	15	650
Projected harvest	601	82	12	94	0	14	803
C.I.	0-1,408	0-166	0-33	0-259	--	0-32	

The partial creel projection of annual numbers of individuals caught (regardless of whether they were harvested) differed from the actual catch by 8% for largemouth bass, 2% for bluegill, and 25% for black crappie (Table 33). The projection of total weight caught differed from the true value by 6% for largemouth bass, 5% for bluegill, and 34% for black crappie. The substantially better estimates of catch than of harvest for largemouth bass and bluegill in 1984 partly reflected lower coefficients of variation for monthly catch estimates than for monthly harvest estimates (Table 34). Because the same estimate of effort was used to calculate catch and harvest statistics, the greater precision for catch estimates resulted from lower variance in the estimate of CPE. Thus, the percent error in harvest estimates is inversely related to the magnitude of the harvest.

The non-uniform probability sampling procedure used in this study produces relatively unbiased estimates of effort, harvest rate, and harvest (Malvestuto *et al.* 1978). The estimates are most precise when sampling effort is distributed in proportion to fishing effort. Small systematic errors may result from failure of partial trip estimates of CPE to equal estimates derived from complete

Table 30. Comparison of partial creel harvest estimate to actual harvest at Ridge Lake during 1984.

	Largemouth bass	Bluegill	Black crappie
Total number			
Actual harvest	151	1,337	650
Projected harvest	75	957	803
Total weight (kg)			
Actual harvest	112	121	71
Projected harvest	54	95	88
Number/man-hour			
Actual harvest	0.027	0.240	0.116
Projected harvest	0.012	0.155	0.130
Weight (kg)/man-hour			
Actual harvest	0.020	0.022	0.013
Projected harvest	0.008	0.015	0.014
Mean weight (kg)			
Actual harvest	0.740	0.090	0.110
Projected harvest	0.720	0.100	0.110

trip interviews. However, we believe that this systematic bias, as well as any random error associated with inefficient allocation of sampling effort, is relatively unimportant to the precision and accuracy of the harvest estimates.

The precision of partial creel projections is compromised principally by variation in fishing effort and CPE. However, only variation among sampling days within strata contribute to the variance of harvest estimates, because differences between strata means do not contribute to sampling error (Snedecor and Cochran 1967). Within each sampling strata, large variations in fishing effort may occur, principally in response to changes in weather conditions. Also, CPE can vary in response to daily changes in the catchability of the fish, the skill of the anglers, and the fraction of the fishing effort directed at each species. The day-to-day variation in both average skill of interviewed anglers and in the allocation of fishing effort among species is inversely related to the number of interviews conducted. Because Ridge Lake was small and few fishermen were present at any one time, the number of interviews conducted on partial creel sample dates was always small. Consequently, angler skill and the allocation of effort among species varied greatly from

Table 32. Actual and projected fishing effort, weight (kg) of fish harvested, and 95% confidence intervals (C.I.) of projected harvest for the 1984 fishing season at Ridge Lake. Fishing effort is expressed as man-hours.

	Creel period						
	2	3	4	5	6	7	Total
Effort							
Actual	1,266	1,403	1,303	833	394	393	5,592
Projected	927	1,476	1,287	1,233	747	486	6,156
C.I.	168-1,686	711-2,241	692-1,854	612-1,854	237-1,257	80-892	
Largemouth bass							
Actual harvest	31.9	31.7	23.7	7.5	3.5	13.6	111.8
Projected harvest	9.9	12.5	17.2	2.5	0	12.3	54.3
C.I.	0.0-32.1	0.0-34.5	4.6-29.7	0.0-7.6	--	0.0-29.5	
Bluegill							
Actual harvest	31.8	71.9	6.6	8.7	1.2	1.2	121.4
Projected harvest	14.0	68.2	7.2	2.1	0	3.8	95.2
C.I.	0.0-31.2	0.0-147.2	0.0-20.2	0.0-5.6	--	0.0-11.6	
Black crappie							
Actual harvest	54.1	6.1	4.0	4.2	0.9	1.7	71.0
Projected harvest	71.6	8.6	1.3	5.0	0	1.7	88.2
C.I.	0.0-173.9	0.0-17.5	0.0-3.5	0.0-28.5	--	0.0-4.0	

day to day and the precision of the resulting estimates was poor. Thus, partial creel surveys applied to small impoundments, to impoundments receiving little pressure, or to species which are sought by only a small fraction of fishermen should generally produce estimates of low precision. The precision of harvest estimates can be increased by calculating CPE for each species using effort directed only at that particular species. This procedure will reduce the variance of the CPE statistic; the reduction will be most noticeable for species that receive little pressure.

CONCLUSIONS: The partial creel procedure employed by the Illinois Department of Conservation produces unbiased estimates of effort and harvest. The stratification and blocking procedures used are efficient, and systematic errors are probably small compared to potential random errors. The precision of estimates based on this procedure will generally be low in very small lakes, in lakes with little fishing pressure, and for species sought by only a small fraction of the anglers. Random errors associated with estimates of effort and harvest at Ridge Lake were large but would generally be much smaller at larger lakes where more interviews could be

Table 33. Actual and projected fishing effort, number of fish caught, and 95% confidence intervals (C.I.) of projected catch for the 1984 fishing season at Ridge Lake. Fishing effort is expressed as man-hours.

	Creel period						Total
	2	3	4	5	6	7	
Effort							
Actual	1,266	1,403	1,303	833	394	393	5,592
Projected	927	1,476	1,287	1,233	747	486	6,156
C.I.	168-1,686	711-2,241	692-1,854	612-1,854	237-1,257	80-892	
Largemouth bass							
Actual catch	255	438	305	175	153	145	1,471
Projected catch	190	303	279	254	448	119	1,593
C.I.	0-459	38-568	124-434	24-484	129-767	1-237	
Bluegill							
Actual catch	796	2,413	439	533	182	59	4,422
Projected catch	596	2,226	534	843	259	61	4,519
C.I.	0-1,223	842-3,610	17-1,051	195-1,491	0-711	0-134	
Black crappie							
Actual catch	748	105	51	66	39	30	1,039
Projected catch	797	152	12	248	38	53	1,300
C.I.	0--1,606	10-294	0-33	0-577	0-117	0-121	

conducted. The precision of harvest estimates can be increased by basing estimates of CPE for a species on effort expended only for that species and by maximizing the number of angler interviews.

STUDY 103. The survival of channel catfish stocked at different sizes.

Job 1. Survival of stocked fingerling channel catfish.

OBJECTIVE: To determine the relative mortality of three size classes (100, 150, and 200 mm TL) of channel catfish stocked in an impoundment containing an established largemouth bass population.

INTRODUCTION: Because recruitment of channel catfish in small impoundments is often poor to nonexistent (Marzolf 1957, Davis 1959), restocking must occur at intervals to sustain an acceptable

Table 34. Actual and projected fishing effort, weight (kg) of fish caught, and 95% confidence intervals (C.I.) of projected catch for the 1984 fishing season at Ridge Lake. Fishing effort is expressed as man-hours.

	Creel period						
	2	3	4	5	6	7	Total
Effort							
Actual	1,266	1,403	1,303	833	394	393	5,592
Projected	927	1,476	1,287	1,233	747	486	6,156
C.I.	168-1,686	711-2,241	692-1,854	612-1,854	237-1,257	80-892	
Largemouth bass							
Actual catch	103.6	167.8	126.5	66.5	63.5	58.6	586.4
Projected catch	70.2	114.9	114.3	90.1	180.3	51.5	621.3
C.I.	0.0-175.7	14.2-215.7	50.8-177.8	0.0-188.1	54.6-306.1	0.0-112.5	
Bluegill							
Actual catch	66.2	164.7	25.9	32.4	10.8	4.8	304.6
Projected catch	50.8	165.4	29.4	51.6	17.5	6.4	321.1
C.I.	0.0-102.1	43.9-286.9	1.4-57.4	13.1-90.1	0.0-48.0	0.0-14.1	
Black crappie							
Actual catch	80.5	10.6	5.6	8.3	3.7	3.7	112.3
Projected catch	92.7	15.0	1.3	31.5	4.7	6.2	151.3
C.I.	0.0-195.2	0.0-29.0	0.0-3.5	0.0-72.3	0.0-14.2	0.0-13.9	

sport fishery. However, the survival of supplementally stocked fish may also be poor when established largemouth bass populations are present (Crance and McBay 1966, Mestl 1983). Mortality of stocked channel catfish can be reduced by stocking larger fish (Krummrich and Heidinger 1973, Powell 1975, Mestl 1983), but rearing costs increase with fish size (American Fisheries Society 1982). The optimum size for stocking is determined by the relationship between rearing costs and subsequent survival. Channel catfish should be stocked at the size which provides the highest return to the creel per dollar spent. Although several studies have addressed the issue of optimum stocking size for channel catfish (Krummrich and Heidinger 1973, Powell 1975, Mestl 1983, Spinelli *et al.* 1985), none have compared survival rates of various size groups stocked concurrently into impoundments containing established centrarchid populations. This study measured survival and harvest of various sizes of channel catfish stocked into a 6.1-ha impoundment containing predator populations of largemouth bass and tiger muskellunge and prey populations of bluegill.

METHODS: In October 1981, channel catfish purchased from a private dealer, were stocked in Ridge Lake. All fish were measured to the nearest mm total length (TL); large fish (>200 mm) received a right pelvic fin clip and small fish (<200 mm) received a left pelvic fin clip (Table 35). In March 1984, three sizes of channel catfish, obtained from the Little Grassy State Fish Hatchery in Illinois, were stocked in Ridge Lake (Table 35). All fish were measured and members of each size class received the same fin clip. This stocking procedure was repeated in April 1985, except that only size-I fish were obtained from the Little Grassy Fish Hatchery. Size-II and -III fish were purchased from a commercial fish hatchery. In addition to the size-specific fin clips applied in 1984, all fish stocked in 1985 received an adipose fin clip to distinguish them from fish stocked in 1984.

Table 35. The fate during 1982-1985 of various size classes of channel catfish stocked into Ridge Lake in 1981, 1984, and 1985.

Year stocked	Size class	Total length (mm) Mean (range)	Fin clip	Number stocked	Angler Catch	Angler Harvest(%)	Escapement	Number surviving to draining (%)
1981	Small	154(106-197)	L. pelvic	275	--	37(13)	--	5 (2)
	Large	255(204-320)	R. pelvic	160	--	91(57)	--	20(12)
1984	I	117 (97-130)	L. pectoral	100	0	0 (0)	22	0 (0)
	II	159(140-171)	L. pelvic	100	15	3 (3)	12	5 (5)
	III	202(190-226)	R. pelvic	100	52	18(18)	9	7 (7)
1985	I	110(100-117)	L. pectoral	100	0	0 (0)	1	2 (2)
	II	156(140-165)	L. pelvic	100	13	0 (0)	3	15(15)
	III	202(185-220)	R. pelvic	100	35	0 (0)	0	45(45)

Escapement of channel catfish in the lake overflow was monitored daily during periods of flow. The primary overflow structure at Ridge Lake, a tower spillway, discharges water from the lake bottom over a spillwall, into a wolf-type weir located below the dam (Newman and Storck 1983). When the capacity of the tower spillway (0.71 cms) is exceeded, water is discharged over a surface spillway into a separate weir. Fin clips of escaping channel catfish were recorded for fish stocked in 1984 and 1985 but not for those stocked in 1981.

Ridge Lake was drained in October 1985 and all fish were collected in the weir located below the tower spillway. All channel catfish were measured, weighed, and their fin clips were recorded.

Also, the size structure and numerical and biomass standing crops were determined for all other fish species (see Job 12).

RESULTS: During the 1982-1985 fishing seasons, harvest of the large size class of channel catfish stocked in 1981 (57%) was substantially greater than that of the small size class (13%, Table 35) and more large fish survived to the draining census. Overall, 69% of the large fish but only 15% of the small fish either were harvested or survived to the end of the experiment.

The numerical decline of the smaller size class could not be explained by escapement from the lake, because only 24 fish stocked in 1981 were subsequently lost in the overflow. Even if all of the escaping fish were small individuals, 83% of the number stocked died in the lake from natural mortality.

The sum of survival and harvest of channel catfish stocked in 1984 and 1985 increased with size at stocking (Table 35). Twelve percent of size-I individuals escaped in the overflow, while only two individuals remaining in the lake survived to the draining census. Further, size-III fish contributed substantially more to the catch and harvest than did size-II fish and more size-III fish survived to the draining census. In both years, approximately three times as many size-III fish either were harvested or available for harvest at the conclusion of the study. Angler catch in 1984 and 1985 reasonably reflected relative survival of the three size classes (Table 35).

Although fishing pressure directed specifically at channel catfish averaged only 100 hours/ha in 1984 and 1985, anglers caught 34 and 35 sublegal size-III channel catfish from the 1984 and 1985 stockings, respectively. The high vulnerability of this size group illustrated the potential protection afforded by a size limit.

Based on survival rates of channel catfish stocked in Ridge Lake in 1984 and 1985, the greatest return to the creel should be obtained by stocking fish at least as large as size III. This size class provided a potential numerical return to anglers that was approximately three times that of size-II fish while costing only 1.5 times as much to produce (American Fisheries Society 1982). However, even size-III fish suffered substantial mortality, suggesting that further economy could be achieved by stocking larger fish. The potential for greater harvest was illustrated by the combined harvest and survival of 69% for the large fish stocked in 1981, which was substantially greater than that of size-III fish stocked in 1984 (25%) and 1985 (45%). The comparison may not be valid, however, because the density of large predators was lower in 1981 than in subsequent years.

The survival rates of channel catfish stocked in Ridge Lake in 1984 and 1985 may not be typical, even for impoundments containing established populations of centrarchid predators and prey, because size-specific survival is likely to vary, depending on the size composition and density of predator populations and on levels of factors which mediate predator success. For example, Mestl (1983) found that channel catfish survival was directly proportional to the number of potential predators. Further, Mestl (1983) and Spinelli *et al.* (1985) demonstrated that largemouth bass predation on channel catfish was influenced by the availability of alternate prey. Brown *et al.* (1970) and Mestl (1983) found a positive relationship between survival of channel catfish and physical complexity of the environment. Also, turbidity has been shown to influence the vulnerability of channel catfish to predators (Marzolf 1957, Hall and Jenkins 1952, Mestl 1983). The relative importance of these factors must be determined before an optimum stocking size for channel catfish can be predicted for individual impoundments.

The abundance of potential predators and the availability of alternate prey are likely the two most important factors influencing the survival of stocked channel catfish. Mestl (1983) estimated the maximum size of channel catfish that could be eaten by largemouth bass. By inserting glass tubes into largemouth bass stomachs, he determined the maximum food diameter that could pass through the esophagus. Because channel catfish are more rounded in cross section than are sunfish, he assumed that the pectoral girdle diameter rather than body depth, was the dimension that physically limited vulnerability of channel catfish to predators. Based on Mestl's findings, a largemouth bass should be at least 250 mm and 327 mm long, respectively, to eat a 150-mm and 200-mm channel catfish. When Ridge Lake was drained in October 1985, there were 470 largemouth bass present (76/ha) large enough to eat a 150-mm channel catfish but only 183 (30/ha) large enough to eat one 200 mm long. The difference in density of largemouth bass capable of eating the two size classes of channel catfish is consistent with the observed difference in survival of the size classes. Although the surviving age-III and -IV tiger muskellunge (N = 26) were probably large enough to eat the stocked channel catfish, their impact may have been minimal because channel catfish are less vulnerable than either bluegill or largemouth bass to predation by tiger muskellunge (Weithman and Anderson 1977*a*).

The standing crop of bluegill in Ridge Lake (295 kg/ha) was relatively high (Carlander 1977) and because growth was slow, a large percentage of them were small. Using Lawrence's (1958) estimates of the maximum size of bluegill vulnerable to various sizes of largemouth bass, the standing crops of vulnerable-sized bluegill were 43 and 79 kg/ha, respectively, for largemouth bass that were 250 and 327 mm long. Thus, even in the presence of high densities of vulnerable bluegill, mortality of stocked catfish was relatively high.

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