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Effect of Fishing Effort on the Catchability of Largemouth Bass

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Effect of fishing effort on the catchability of largemouth bass

By

Matthew Glenn Wegener

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Effect of fishing effort on the catchability of largemouth bass

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The effect of fishing on the catchability of a population receiving intense angler effort has long been debated but not measured. This study evaluated the effect of fishing effort on catchability of adult largemouth bass *Micropterus salmoides* and determined whether catchability was affected by a period of no fishing. Eight, 0.5-2.0 ha impoundments were fished once a week for 0.4 angler hours per hectare per week during two successive May-October fishing seasons to evaluate whether catch rates differed between populations fished continuously and populations with the fishing season interrupted by a 2-month period of no fishing. Mixed-model analysis indicated effort significantly decreased catch rate ($F_{4,\,298} = 16.53$; $P < 0.001$). Pair-wise comparisons indicated change in catch rate was not significantly different ($t = 1.52$; $P = 0.13$) between the first 8 weeks and the final 8 weeks of fishing for ponds that received a 2-month layoff.

DEDICATION

My thesis is dedicated to my parents, Glenn and Mary Wegener, and to the late Matthew Spickard. My father taught me the value of the great outdoors and gave me my first opening into the world of fisheries. My mother instilled in me the power and drive to finish anything I started, no matter how long it takes. Matthew Spickard opened my eyes to a world outside of fisheries management and showed me what it meant to be an aquatic biologists. We spent many hours on the water and in the classroom discussing our futures, but no one knew his would end so prematurely. Anyone that knew Matt knows that he will never be forgotten.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Numerous predator-prey combinations have been stocked in small impoundments, but the largemouth bass (*Micropterus salmoides)*-bluegill (*Lepomis macrochirus*) combination is often recommended by fisheries managers and has proven suitable to provide sustainable fishing opportunities throughout much of North America (Modde 1980; Schramm and Willis 2012). However, stable forage supply and broad size distributions of largemouth bass and bluegill are needed for greater growth rates of the predator (largemouth bass) in small impoundments. If the largemouth bass population depletes the intermediate-size bluegill (80 to 130 mm total length [TL]), largemouth bass growth slows at a less than quality size (≤ 300 mm TL). In this situation, bluegill recruitment is decreased because of intense predation by largemouth bass. Surviving bluegills grow quickly and become too large to be eaten by most largemouth bass. Bluegill spawn several times during summer; thus age-0 bluegill are plentiful and provide stable forage needed for fast growth of juvenile largemouth bass (80 to 199 mm TL). Increased survival rates and recruitment to age 1 of largemouth bass continues the cycle of overabundance of largemouth bass less than quality size (Swingle 1956). This situation is referred to as “bass crowded” and is common in small impoundments (Flickinger et al. 1999; Schramm and Willis 2012).

The management recommendation for bass-crowded ponds is to remove largemouth bass < 300 mm TL (Flickinger et al. 1999). Angler harvest is an inexpensive option for removing largemouth bass if catch rate is great. However, angling catch rates may decline because catchability (i.e., capture probability of an individual fish) of largemouth bass has been found to be inversely related to fishing effort in small impoundments (Martin 1958; Hackney and Linkous 1978; Mankin et al. 1984). Therefore, removing sufficient fish by angling to relieve the bass-crowded situation may be difficult or impossible. Anderson and Heman (1969) found catch rates of largemouth bass in experimental ponds were negatively related to fishing effort even though all fish were released unharmed after capture.

Declines in catch rate with sustained fishing effort have also been observed for other species. Lewynsky and Bjornn (1987) concluded that catchability of two salmonid species in Idaho was negatively related to fishing effort; catch rates of hatchery-raised rainbow trout *Oncorhynchus mykiss* declined with each week of fishing in an intensively fished raceway, and catchability of wild cutthroat trout *Oncorhynchus clarkii* was greater in rivers closed to angling compared to other rivers where uninterrupted fishing occurred. Young and Hayes (2004) determined that brown trout *Salmo trutta* catchability was less than in a river in New Zealand that received greater fishing effort compared to a similar river that received less effort.

Anderson and Heman (1969) concluded that previously un-angled individuals had increased catchability; thus, newly-recruited individuals may inflate catchability estimates. Studies measuring declines in catch rate during a long period of time may have catch rates influenced by recruitment of fish to the catchable population and therefore are not able to measure catchability (e.g., Anderson and Heman 1969; Young and Hayes 2004). Several studies used sufficiently brief time scales so catch rate was not affected by recruitment (e.g., Martin 1958; Hackney and Linkous 1978; Lewynsky and Bjorn 1987). However, no studies to date have used long-term catch rates to measure catchability of largemouth bass. My study is unique in that long-term catch rates were measured, but recruitment was accounted for so that catchability could be estimated during a long period of time.

Managers of public fishing lakes in Mississippi are commonly faced with bass-crowded populations that yield decreased catch rates for anglers (Larry Pugh, Mississippi Department of Wildlife, Fisheries, and Parks (MDWFP), personal communication). Information about the relationship between fishing effort and largemouth bass catch rate is important to pond owners and managers of small impoundments for recommending harvest to remedy bass-crowded conditions. If catchability is indeed negatively related to fishing effort, then closing a small impoundment to fishing for a brief period of time during the fishing season may be a technique that could increase catchability. Askey et al. (2006) found catch rate of rainbow trout increased following a 23-d period of no fishing; therefore, an interrupted fishing season may have similar effects on largemouth bass. However, they attributed the increase in catch rate to recruitment, indicating that this factor should be considered when evaluating effects of an interrupted fishing season. Closure length should also be considered when developing management strategies for bodies of water where increased catchability is desired (e.g., fee-fishing lakes, public small impoundments) because angler satisfaction may decline due to loss of fishing opportunities. No research has been done on effects of an interrupted fishing season on largemouth bass. The goal of this research is to determine if a brief period of no fishing will increase catchability.

Objectives of this study were to determine trends in largemouth bass catch rate with sustained fishing effort and to evaluate effect of interrupted fishing effort on catchability and total catch of largemouth bass in small impoundments that have established bluegill and crowded largemouth bass populations. I hypothesized that catchability of largemouth bass would be negatively related to fishing effort. If fishing effort was sustained, then catch rate would decrease as the fishing season progresses; and, if fishing effort were stopped, then catch rate would increase after a period of no fishing.

CHAPTER II

METHODS

Effect of fishing effort on catchability was evaluated by comparing catch rates of largemouth bass populations in small impoundments fished on a fixed schedule throughout the spring-through-fall (May-October) fishing season and populations with fishing season interrupted by a 2-month (July-August) period of no fishing (i.e., layoff). The premise was catch rate would decline with fishing effort in ponds fished continuously from May-October, and catch rate would increase when fishing resumed after a 2-month period of no fishing. Length of the no-fishing period was set at 2 months because this was assumed to be long enough to see an effect on catch rate and thought to be the maximum amount of time that a state lake or public pond could be closed without hindering angler relations.

Study ponds

This study was conducted in eight impoundments suspected to contain bass-crowded largemouth bass populations comprised primarily of individuals < 300 mm TL. For this study, bass crowding is defined as populations of largemouth bass comprised predominantly of small (200-300 mm), slowly-growing individuals. Metrics used in this experiment to describe populations that are bass crowded are proportional size distribution (PSD) < 40 (Gabelhouse 1984a) and annual growth < 50 mm for 200-299 mm TL fish. Proportional size distribution is the proportion of stock-length fish (≥ 200 mm TL) that are also quality length (≥ 300 mm TL; Anderson 1978).

Each study pond was fished < 2 h in April 2008, prior to initiating the study, and resulted in capture of primarily 200-250 mm TL largemouth bass, a condition suggestive of bass-crowded ponds. One pond was privately owned and located in Oktibbeha County, Mississippi. This pond was stocked with largemouth bass and bluegill in 1999 and received remedial largemouth bass harvest (40-50 $\text{fish}\cdot\text{ha}^{-1}\text{yr}^{-1}$) in years prior to this study as a preventive measure to avoid a bass-crowded situation, but no fish were harvested after January 2008. The other seven ponds were located in the MDWFP Divide Section Wildlife Management Area in Tishomingo County, Mississippi. These ponds were stocked with largemouth bass and bluegill by MDWFP in the early 1980s. The ponds have been managed with statewide harvest regulations for largemouth bass (10 bass per day, no size limit) and sunfish (50 sunfish per day, no size limit). Ponds were located in a remote area closed to vehicular traffic and have previously received little fishing effort (Jerry Hazelwood, MDWFP, personal communication). These ponds were closed to public fishing during this study (2008-2009), and appropriate signage was posted at each pond. Unauthorized fishing was also likely deterred due to distance between public parking areas and study ponds (1.6-4.0 km).

The eight ponds were 0.4-2.3 ha in surface area, and maximum water depth was < 5 m (Table 1). Habitat varied among ponds; four had aquatic macrophytes, and four contained woody cover and sparse coverage of aquatic macrophytes. Study ponds were paired based on similar surface area and aquatic habitat, then divided into two groups of four ponds with one pond from each pair. Ponds in the first group received 2.5 angler-h ha^{-1}week^{-1} of effort throughout the May-October (24-week) 2008 fishing season. This fishing effort is similar to average fishing effort on MDWFP state fishing lakes (< 3.5 angler-h ha^{-1}week^{-1}; Larry Bull, MDWFP, personal communication). The four ponds in the second group received 2.5 angler-h ha^{-1}week^{-1} for 8 weeks (May-June), then 8 weeks of no fishing (layoff) during July and August, and then 2.5 angler-h ha^{-1}week^{-1} for the final 8 weeks (September-October) during the 2008 fishing season. During the second year (2009), groups were reversed; i.e., ponds that received a layoff in 2008 were fished for a full season in 2009, and ponds fished for a full season in 2008 received layoff in 2009.

Table 1 Characteristics of northeast Mississippi study ponds in 2008-2009

Pond	Size (ha)	Maximum depth (m)	Secchi depth (m)		Habitat type	Visually-estimated coverage
			Mean	SE		30%
1	1.42	2.13	1.26	0.05	Woody cover and *Ludwigia* spp.	75%
2	1.78	6.10	1.24	0.05	Woody cover	75%
3	1.29	5.49	0.97	0.05	Woody cover	75%
4	0.93	2.20	2.13	0.07	*Potamogeton diversifolius*	75%
5	2.27	4.57	2.10	0.07	*Myriophyllum spicatum*	75%
6	0.89	1.83	1.10	0.09	*Brasenia schreberi*	90%
7	0.41	3.05	1.71	0.10	*Najas minor* and *Ludwigia* spp.	20%
8	0.49	4.57	2.42	0.16	Woody cover	10%

Habitat is type of cover prevalent in each pond. Woody cover consisted of flooded brush, fallen trees, and standing timber. Structural coverage was estimated by on-site visual survey in June 2009

Study ponds lacked boat ramps, and water access was difficult. Fishing was conducted from a small, portable boat powered by an electric trolling motor. All ponds were fished in random order weekly, ensuring that ponds received fishing effort at different times of day. Fishing direction along the shoreline of each pond (clockwise or counterclockwise) also was randomly determined each week. All fishing was conducted using lures (i.e., live bait was not used). Eleven categories of lures were selected to effectively fish the different aquatic habitats present in ponds, including standing timber, woody cover, and aquatic macrophytes (Table 2). The 11 categories of lures were compiled into a fixed-order list. During each fishing event in each pond, the first lure used was randomly selected from the list, and then each lure was fished in the order in which it appeared on the list. Ten casts were made with each lure before switching to the next lure on the list. After each lure on the list was fished, anglers were allowed to use experience gained from fishing the 11 lure types during that visit and personal judgment to select a lure or lures from those on the list for the remaining time. After the entire perimeter of the pond had been fished, anglers could choose to fish certain areas again until the time limit was reached. I fished on all trips to each pond and was accompanied by one of eight different anglers. All anglers participating in this study were skilled in using each lure on the list to avoid decreasing catch rate for reasons other than time of fishing effort applied.

Table 2 Lures used during the study on northeast Mississippi ponds in 2008-2009.

Lure Category	Product Name	Company
Texas-rigged plastic worm	6" Ribbontail	YUM Baits, Fort Smith, AR
Texas-rigged creature	6" Lizard and 5" Brushhog	Zoom Bait Company, Bogart, GA
Soft-jerkbait	5" Houdini Shad and 4" Dinger	YUM Baits, Fort Smith AR
Buzzbait	1/4 oz Buzzbait and Buzz Frog	Strike King Lure Company, Collierville, TN; Stanley Jigs Inc, Huntington TX
Topwater weedless frog	Scum Frog	Snag Proof Manufacturing, Cincinnati OH
Spinnerbait	3/16 oz Booyah Blade	Booyah Baits, Fort Smith, AR
Floating minnow lure	Rapala Original Floater F-11	Rapala-Normark Ltd., Minnetonka, MN
Crankbait	Bomber Model A	Bomber Lures, Fort Smith, AR
Lipless crankbait	¼ oz Super Spot	Cotton Cordell, Fort Smith, AR
Topwater popper	¼ oz Rebel Pop-R	Rebel Lures, Fort Smith, AR
Curl-tail grub	4" Muy Grande	YUM Baits, Fort Smith, AR

Each lure category received at least 10 casts on each fishing trip. The first lure used on each pond was randomly selected, and successive lures were fished in the order of this list

Each fish captured was measured for total length, marked by removing half of the pelvic fin to detect recaptures, and released. Left pelvic fins were clipped for fish captured in 2008 and right pelvic fins clipped for fish captured in 2009, so year of initial capture could be determined. In addition to pelvic-fin clips, recaptured fish were marked by a hole punch in the anal fin, so that up to three captures could be detected for each individual bass during the 2-year study. Number of recaptured individuals was divided by total number of captures to estimate recapture rate for each pond.

Population characteristics

To assess trends in catch rate between years and measure catchability for each fishing season, it was necessary to estimate largemouth bass population size in each study pond. If number of fish recruited to a catchable size did not change from 2008 to 2009, then change in catch rate would be due to factors other than changing population dynamics (i.e., population size, recruitment, and mortality). Population size of largemouth bass was quantified by Petersen mark-recapture population estimates (Ricker 1975) during spring 2009 and again in spring 2010. Estimates occurred during spring following the fishing season.

Population sizes were estimated on six ponds used in this study (1, 2, 3, 5, 6, and 7); two ponds were inaccessible by an electrofishing boat (ponds 4 and 8). Largemouth bass were collected using a boat-mounted 7.5 GPP Smith-Root electrofisher operated at 60 Hz pulsed DC. Marking and recapture efforts occurred during a 6-week period in March-April 2009 and April-May 2010, and length of time between marking and recapture ranged from 28-45 days to minimize recruitment and loss of marks, yet allowed sufficient time for marked fish to reintegrate into the population. Total length (mm) and weight (g) were measured for all largemouth bass captured. Largemouth bass ≥ 200 mm TL collected on the first electrofishing trip were marked by a hole punch in the soft portion of the dorsal fin. On the second electrofishing trip, captured fish ≥ 200 mm TL were checked for marks and released. The binomial distribution was used to estimate 95% confidence intervals of population estimates because number of captured individuals was < 500 and ratio of recaptured to captured individuals was > 0.10 (Ricker 1975).

The PSD was estimated from fish collected during the marking effort. PSD was also estimated from non-marked (i.e., not previously captured) individuals captured by angling during the fishing season and provided an indication of how representative angler PSD was compared to PSD estimates obtained from electrofishing samples.

Passive integrated transponder (PIT) tags were used during the second year of the study to detect multiple recaptures for instances when fin-clipping would not be sufficient to mark individuals with great recapture rates (i.e., > 4 recaptures), and to determine annual growth rates by measuring change in total length from initial to subsequent capture of fish captured approximately 1 year apart. Largemouth bass ≥ 140 mm TL captured during the spring 2009 population estimate and in angled fish during the 2009 fishing season were implanted with PIT tags subcutaneously at the base of the soft dorsal fin. Passive integrated transponder tags are commonly used to monitor growth, movement, survival, and population size in fishes (Achord et al. 1996; Armstrong et al. 1999; Hilderbrand and Kershner 2000) and have been found to have 100% retention for at least 300 days for largemouth bass (Harvey and Campbell 1989). Fish that were implanted with a PIT tag received a hole punch in the caudal fin so that tag loss could be measured.

Growth rate was estimated to assess if study ponds contained slow-growing individuals representative of a bass-crowded situation. Specimens were collected for growth estimates during the recapture period of the 2010 electrofishing sample. Largemouth bass were measured for total length, and sagittal otoliths were removed from up to 10 individuals per 50-mm size class from 200 to 300 mm TL. Due to a potential, future study on the ponds located in Tishomingo County and infrequent capture of large fish by angling and electrofishing, specimens >300 mm were released and otoliths were not removed. Largemouth bass were aged by analysis of otoliths following methods described by Taubert and Tranquilli (1982), and growth rate was estimated from back-calculated length at age for all annuli using the direct proportion method (Le Cren 1947). Growth rates estimated from otolith analysis and back calculation were compared with growth measured from PIT-tagged fish.

Otoliths were sectioned by methods of Hoyer et al. (1985) when necessary (i.e., otoliths exhibiting two or more annuli in whole view). Whole and sectioned otoliths were viewed under a dissecting microscope at 20 X magnification. Otoliths were aged independently by two readers, and age agreement was achieved by concert read for fish for which the independently assigned age did not agree. This technique resulted in 100% agreement between the two readers. Otolith radii and distances to each annulus were measured with an ocular micrometer.

Askey et al. (2006) found increased catch rate of rainbow trout after a period of no fishing was largely a result of fish recruited to the catchable population. Therefore, assessing changes in catchability with continued fishing effort for the eight largemouth bass populations in this study required accounting for recruitment. To preclude effect of recruitment, catchability was estimated by including catch of only those fish that were recruited to a catchable size. Gabelhouse and Willis (1986) reported that sub-stock (< 200 mm) largemouth bass had not fully recruited to angling gear and, therefore, had decreased catchability. Therefore, recruitment to catchable size was declared as ≥ 200 mm TL (hereafter, week-1 recruited). Individuals that were not week-1 recruited but recruited to the fishery via growth during the fishing season were excluded from catchability analysis.

It was deemed undesirable to obtain recruitment data during the fishing season because collection of largemouth bass using electrofishing or other mechanical gear could have altered catch rates. Therefore, bioenergetics modeling was used to estimate size of fish recruited to the fishery throughout the fishing season. The largemouth bass bioenergetics model has been validated (Rice and Cochran 1984; Whitledge and Hayward 1997) and used to measure growth of this species in Alabama (Irwin et al. 2003) and West Virginia (Perry et al. 1995). The Fish Bioenergetics 3.0 program and physiological parameters for largemouth bass (Hanson et al. 1997) were used to estimate growth trajectory of 200 mm TL largemouth bass for a 1-year period beginning 1 May 2009. Growth was estimated separately for each study pond by using pond-specific start and end weights. Water temperature inputs for the model were weekly surface-water temperatures of the study ponds during the fishing season (May-October; Figure 1) and mean weekly air temperature for November through April. Mean-weekly air temperatures for the study pond in Oktibbeha County, Mississippi, were obtained from the nearest weather station in Columbus, Mississippi (40 km), and from Muscle Shoals, Alabama (55 km), for study ponds located in the Tishomingo County, Mississippi. Water temperature in streams and small impoundments is significantly related to air temperature (Crisp and Howson 1982; Pilgrim et al. 1998), and the relationship improves when mean weekly temperatures are used instead of daily values (Stefan and Preud'homme 1993). Also, use of time lags only improved correlations on major rivers and improved predictions by $\leq$ 0.5°C (Stefan and Preud'homme 1993). Therefore, mean weekly air temperatures with no time lag were used in linear regression models to assess the relationship between mean weekly air temperatures and mean surface water temperatures. The relationship was significant, therefore actual mean weekly air temperatures were used as a surrogate for surface-water temperature.

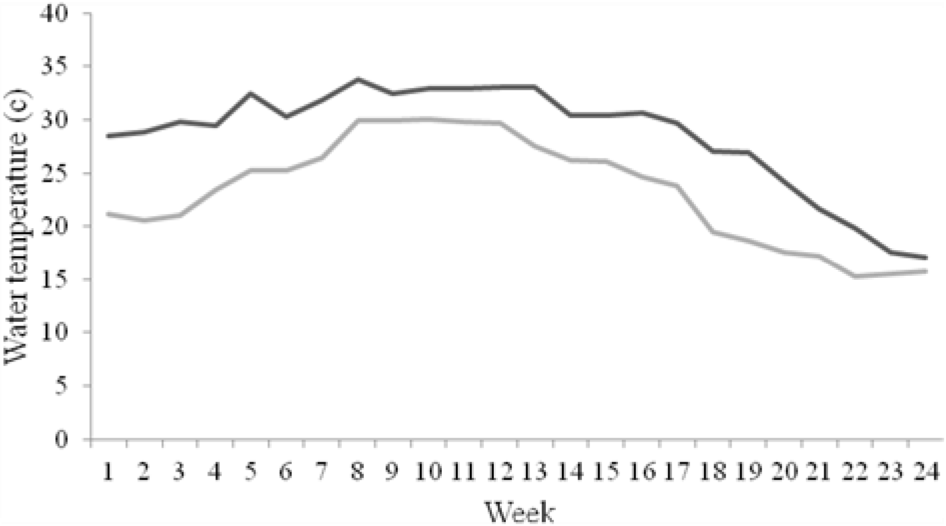

Figure 1 Weekly maximum (solid-black line) and minimum (solid-gray line) surface-water temperatures measured with a YSI meter (model 556) in eight northeast Mississippi ponds during 2008-2009.

Total length was used to define recruited size throughout the fishing season; however, the bioenergetics model estimated growth in weight. Therefore, weight-length relationships were developed to transpose weight to total length. A weight-length relationship derived from 180 to 260 mm individuals captured during the spring 2009 electrofishing sample (Table 3) was developed for each pond that was electrofished (ponds 1, 2, 3, 5, 6 and 7). Weight-length relationships in study ponds had R^2 values that exceeded 0.90, except for pond 1 ($R^2 = 0.78$). Start weight of 200 mm largemouth bass

(Table 4) was determined from the pond-specific weight-length relationship. End weight used in the bioenergetics model was estimated from largemouth bass that were PIT tagged in spring 2009 and recaptured in 2010. There were 22 individuals PIT tagged at 180 to 230 mm TL during the 2009 electrofishing sample that were recaptured during the 2010 electrofishing sample (*N* ranged from 2 to 6 fish in each pond). Mean length of recaptured PIT-tagged fish in each pond was used to estimate end length for that pond. End weight was then estimated by converting mean length of recaptured individuals to weight using the pond-specific weight-length relationship.

Table 3 Weight-length relationship of largemouth bass in northeast Mississippi ponds collected from spring 2009 electrofishing samples

Pond	Weight-length relationship	*N*	R^2	*P*
1	$\log_{10}$ weight = -4.41064 + 2.76103 $\log_{10}$ TL	52	0.78	< 0.001
2	$\log_{10}$ weight = -5.18378 + 3.08722 $\log_{10}$ TL	74	0.91	< 0.001
3	$\log_{10}$ weight = -6.28146 + 3.56464 $\log_{10}$ TL	21	0.96	< 0.001
5	$\log_{10}$ weight = -4.58205 + 2.8473 $\log_{10}$ TL	15	0.97	< 0.001
6	$\log_{10}$ weight = -5.72469 + 3.32975 $\log_{10}$ TL	13	0.98	< 0.001
7	$\log_{10}$ weight = -5.56687 + 3.25032 $\log_{10}$ TL	20	0.99	< 0.001

N is sample size; R^2 is the coefficient of determination; and *P* is the P-value

Table 4 Start and end sizes used in bioenergetics model to predict growth of largemouth bass in northeast Mississippi ponds.

Pond	Start size		End size			
	Length (mm)	Weight (g)	Mean length (mm)	Mean weight (g)	*N*	SE
1	200	88.02	249	160.10	2	5.52
2	200	82.84	240	146.31	6	8.05
3	200	82.02	248	179.35	4	9.43
4[a]	200	85.86		161.02		
5	200	94.83	245	157.11	2	7.51
6	200	86.02	239	157.11	3	7.89
7	200	81.48	241	150.34	5	10.29
8[a]	200	85.86		161.02		

Start weight was calculated as weight of 200 mm TL individuals using pond-specific weight-length relationships for 180 to 260 mm individuals collected during the spring 2009 electrofishing sample. End weight was estimated by converting mean length of recaptured PIT-tagged fish to weight using the weight-length relationship derived from fish 180-260 mm TL collected in spring of 2010. *N* for end weight represents sample size of PIT-tagged fish used to calculated mean length and SE is standard error

[a] Ponds not electrofished; therefore, start and end weights were derived from mean start and end weights of electrofished ponds

The weight-length relationship was likely not influenced by gravidity because few fish between 180 to 260 mm were large enough to be sexually mature (Heidinger 1975; Carlander 1977). Further, electrofishing samples occurred after the spawning season, as no occupied spawning nests or individuals guarding fry were observed. Change in length of week-1 recruited fish was estimated by transforming predicted weekly weight to TL using the weight-length relationship.

Ponds 4 and 8 were not electrofished, so start and end weights used in the bioenergetics model were estimated by using mean start and end lengths from electrofished ponds. Weight-length relationships from electrofished ponds that had similar mean lengths were used to transform between length and weight of largemouth bass in the non-electrofished ponds. Growth rates could not be used to determine surrogates for non-electrofished ponds, because growth estimates were analyzed from otoliths collected from electrofishing. Mean length of largemouth bass derived from angler-caught fish were used to determine which weight-length equation from electrofished ponds could be used as a surrogate for non-electrofished ponds. Pond 4 similar estimates of mean length to pond 6 (Table 5); therefore, the weigh-length relationship for pond 6 was used for pond 4. Pond 7 and pond 8 also had similar mean length estimates; therefore the weight-length relationship for pond 7 was used for pond 8.

Table 5 Population characteristics of stock-size (>200 mm TL) largemouth bass estimated in spring 2009 and 2010 in northeast Mississippi ponds.

Pond	Year	Population estimate (95% C.I.)	Density (fish/ha)	EF mean length	Angling mean length
1	2008	156 (± 71)	110	281	270
	2009[a]	164 (± 41)	116	271	275
2	2008	129 (± 38)	72	228	242
	2009[a]	185 (± 50)	103	238	239
3	2008[a]	74 (± 26)	57	226	244
	2009	53 (±16)	41	226	249
4	2008[a]				306
	2009				257
5	2008	341 (± 85)	150	299	293
	2009[a]	330 (± 93)	145	300	298
6	2008[a]	113 (± 30)	126	282	294
	2009	36 (± 12)	40	307	284
7	2008[a]	61 (± 22)	150	227	267
	2009	53 (± 14)	131	251	284
8	2008				263
	2009[a]				268

Ponds 4 and 8 were inaccessible with an electrofishing boat so population size was not estimated, and mean length was estimated from angled fish not previously angled (unmarked). C.I. is confidence interval.

[a] Fishing season was interrupted by a 2-month period of no fishing

Model inputs of prey-energy densities of bluegill (Kitchell et al. 1974) and largemouth bass (Rice et al. 1983) were the same for both species (4,186 J/g) and were assumed constant throughout the fishing season. The “fit to end weight” option was selected so Fish Bioenergetics 3.0 (Hanson et al. 1997) would generate the P-value for each study pond. The P-value is the proportion of maximum daily consumption needed for the fish to grow from the starting size to end size.

Laboratory data on annual growth patterns of largemouth bass indicate rate of growth in length of largemouth is consistent, or linear, from 10-28°C (Coutant 1975). However, condition often decreases at temperatures > 28°C (Whitledge and Hayward 1997; Neal and Noble 2006). Field experiments have also determined that energy storage is least in summer (Adams et al. 1982).

The combination of elevated water temperatures and presumed forage-deficient environment in bass-crowded ponds sampled during this study likely magnifies this decrease in energy storage and the resulting consequence on growth, and this was evidenced in the output of the bioenergetics models that predicted a decrease in weight during summer. Fish were not weighed when captured with angling gear. However, visual observation of angled fish indicated that condition declined throughout summer and began to increase in September and October. Therefore, estimating length from predicted weights would predict that fish length decreased; and, further, the decrease in length would be magnified by using weight-length models for greater-condition fish collected in spring.

However, negative growth in weight does not result in decreases in total length (length shrinkage). For example, populations of smallmouth bass *Micropterus dolmieu* exposed to water temperatures above the preferred range for growth decreased in weight but not in total length (Wrenn 1980). Because decreases in length are biologically unreasonable, TL was held constant for the time period when negative growth in weight was predicted by the bioenergetics model or when TL estimated from model-predicted weights by pond-specific weight-length equations was less than TL estimated for the previous week. When weight increased above the value at which it began to decrease, TL was again estimated from model-predicted weight.

Largemouth bass PIT tagged during the fishing season were used to assess accuracy of the bioenergetics model. Fish between 180-260 mm TL initially caught with angling gear during the 2009 fishing season and recaptured either during the same fishing season or during the spring 2010 electrofishing sample were included in the bioenergetics model to compare observed and modeled TL. Total length was converted to weight using the pond-specific weight-length equation. Predicted lengths were expected to be shorter than observed lengths because the weight-length relationship was based on greater-condition fish collected in spring. Start weight was weight of fish during initial capture and the end weight was estimated from PIT-tagged largemouth bass that were recaptured in 2010 electrofishing sample. Start and end weights were estimated from the pond-specific weight-length equation. Growth in weight was modeled from initial capture until recapture date and was then transformed to TL (i.e., predicted TL) and compared to the observed TL of each individual at recapture. Percentage difference was used to measure variation between observed and predicted lengths in the growth model using the following equation:

$$\text{Percentage difference} = [(\text{predicted TL} - \text{observed TL}) / \text{observed TL}] \times 100. \quad (1)$$

Additionally, predicted and observed lengths were modeled with a mixed model with pond as a random variable. If predicted lengths equaled observed lengths, the regression line should have a slope = 1 and an intercept = 0.

Data analysis

Repeated-measures analysis was used to assess effect of fishing effort (hours/hectare; independent variable) on catch rate (dependent variable) during the different fishing seasons (full and interrupted). Repeated-measures analysis was used because the same ponds were sampled on each trip, and data collected over time from the same sampling unit tend to be correlated. This violates the independent-error assumption of many statistical procedures and makes it difficult to accurately assess relationships between variables, leading to spurious conclusions (Gutzwiller and Riffell 2007). Conventional methods for analyzing repeated-measures data are to conduct separate analyses for each sampling period or to average across time periods, an approach that ignores the temporal component of the data (Littell et al. 1998). Traditional repeated-measures analysis of variance can be used; but this method requires that all pairs of measurements are equally correlated, regardless of amount of time elapsed between observations, and that sets of observations taken at different points in time have equal variance. Generally this is not a valid assumption for repeated-measures data because observations on the same sampling unit that are taken close together in time are often more highly correlated than observations obtained farther apart in time (Littell et al. 1998).

Mixed-model analysis (PROC MIXED; SAS 9.2; SAS Institute 2008) of repeated-measures data was used because it allows for simultaneous inferences about spatial (pond) and temporal factors (year) through use of fixed and random effects. Mixed-model analysis also allows for the correct covariance structure to be selected, based on statistical and biological perspectives (Gutzwiller and Riffell 2007). Fishing season (full season or interrupted season) and cumulative effort were included as fixed effects. Environmental characteristics in ponds may vary annually, and models with random effects consider ponds as heterogeneous units, in which each pond is represented as a block. In contrast, models with only fixed effects do not consider heterogeneity among ponds. Therefore, year and pond were included in the model as random effects to account for temporal and spatial effect these variables may have on catch rate.

Aquatic habitat varied between study ponds, so differences in catch rate were examined to determine if habitat should be included in the mixed-model analysis. Catch rate data were non-normally distributed based on visual inspection of residuals and Shapiro-Wilk test for normality (Shapiro-Wilk $W < 0.86$; $P < 0.001$); thus, a natural log transformation of the catch rate data was performed to satisfy assumptions of normality. However, after transformation catch rate data were still non-normal (Shapiro-Wilk $W < 0.98$; $P < 0.001$). Therefore, a Friedman two-way non-parametric analysis of variance (ANOVA) was used to test significant differences in catch rate between ponds containing aquatic macrophytes and woody cover using untransformed data. Catch rate data included all week-1 recruited fish (marked and unmarked individuals [i.e., recaptured fish were included]) and habitat type (aquatic macrophytes and woody cover) and fishing season (full and interrupted) were treatments. The experimental unit was the population of largemouth bass in each study pond. Habitat (woody cover and aquatic vegetation) did not significantly affect catch rate (Friedman two-way ANOVA; $F = 1.95$; df = 3; $P = 0.12$) and, therefore, was not included as a variable in further analysis.

Effects of fishing effort (trip) and layoff on catch rate (fish angler h^{-1}) were evaluated by the model: $\log_e$ (catch rate) = layoff x post layoff + trip (layoff x post layoff). The model tested if effort significantly affected catch rate during both fishing seasons using the variable “layoff” that differentiated between full and interrupted fishing seasons; and if fishing effort significantly affected catch rate following the layoff using the variable “post layoff”, which denoted trips that occurred after a 2-month period of no fishing. Pair-wise comparisons were used to contrast slopes of catch rate for time periods occurring in full and interrupted seasons of fishing. For the full and interrupted season of fishing, the first 8 weeks (weeks 1-8) were compared to the final 8 weeks (17-24) of fishing to assess differences in catch rate from beginning to end of the fishing season. The final 8 weeks for both fishing seasons were compared to determine if change in catch rate differed between full and interrupted seasons and to test if increased catch rates occurred following 2 months of no fishing.

In a bass-removal situation, captured individuals are generally harvested and therefore not available to be caught a second time. The first mixed model evaluated effect of effort on catch rate in a catch and release scenario, and then was used again with catch rate data that only included fish that were first-time captures (unmarked fish; i.e., recaptured fish were omitted from this analysis) to simulate harvest. Pair-wise comparisons were used to contrast slopes of catch rate obtained from the mixed-model analysis.

Variance components in the mixed model analysis were estimated by restricted maximum likelihood (REML) by minimizing likelihood of residuals from fitting the fixed-effects portion of the model (Littell et al. 2006). Akaike’s information criterion corrected for small sample size (AICc) allows for several co-variance structures to be tested and several models to be compared so the best supported model can be selected

(Littell et al. 1996; Wolfinger 1996). I evaluated six covariance structures by following statistical methods outlined by Littell et al. (2000): compound symmetry, heterogeneous compound symmetry, first-order autoregressive, heterogeneous autoregressive, spatial power, and unstructured. Autoregressive covariance structure was selected based on AICc scores and because fishing trips occurring closer together in time were assumed to be more highly correlated than fishing trips occurring farther apart in time (Littell et al. 2000). Model parameter estimates were generated using REML. Significance was set at $\alpha = 0.10$ to increase chance of detecting a significant relationship if one existed.

Total catch in ponds fished for a full season was compared to ponds that received an interrupted fishing season to determine effect of the 2-month period of no fishing. Total catch must be greater in ponds receiving a 2-month period of no fishing than total catch in ponds fished a full season for a no-fishing period to be an effective management tool for removing largemouth bass from bass-crowded ponds. Therefore, if a 2-month period of no fishing is effective at increasing total catch, enough fish will be caught to meet or exceed harvest recommendations of largemouth bass. Typical harvest recommendations for largemouth bass in small impoundments are 75 fish $ha^{-1}yr^{-1}$ in southern or eutrophic ponds and 50 fish $ha^{-1}yr^{-1}$ in northern or less fertile ponds, although harvest of up to 150 fish $ha^{-1}yr^{-1}$ may be needed for severely bass-crowded ponds that have great productivity (Schramm and Willis 2012). Study ponds were located in the southern USA but were not considered to be eutrophic systems. They were not fertilized and had mean Secchi depths > 0.95 m (Table 1). Therefore, total catch was considered adequate for bass-removal situations if > 50 fish $ha^{-1}yr^{-1}$ were captured, and considered substantial if total catch was > 75 fish $ha^{-1}yr^{1}$. Catch-rate values included only first-time caught (unmarked) individuals that were week-1 recruited. Total catch during the full season (Shapiro-Wilk W > 0.92; *P* > 0.43) and interrupted season (Shapiro-Wilk W > 0.94; *P* > 0.67) were normally distributed. Significant differences in total catch between continuous and interrupted fishing seasons were examined using a paired t-test.

Percentage of population captured by angling (hereafter, angled) was estimated on ponds that were electrofished by dividing total catch of non-marked largemouth bass caught during the 2009 fishing season by the 2009 population estimate.

CHAPTER III

RESULTS

Catchability was estimated from the catch rate of week-1 recruited fish throughout the fishing season. A 200-mm TL fish at the beginning of the fishing season fish grew to 219-232 mm by the end of the fishing season and had weekly growth rates of 0.0-0.8 mm/week based on growth estimated from the bioenergetics model (Figure 2) and a protocol that assumed constancy of weight during elevated summer water temperatures (≥ 28°C; Figure 1). P-values (proportion of maximum consumption) from bioenergetics model ranged from 0.38 to 0.49; consistent with P-values reported by Neal and Noble (2006) of largemouth bass in Puerto Rico (0.35 to 0.43). Total length predicted by the bioenergetics models increased from May to mid June and did not increase from July to early September. In most ponds, TL began to increase again by mid September and continued until late November, when growth became static until early March. Surface-water temperatures in pond 1 were greater than other ponds, and therefore the bioenergetics model predicted more days of negative growth in weight. This resulted in no growth in TL from mid June until early March in pond 1.

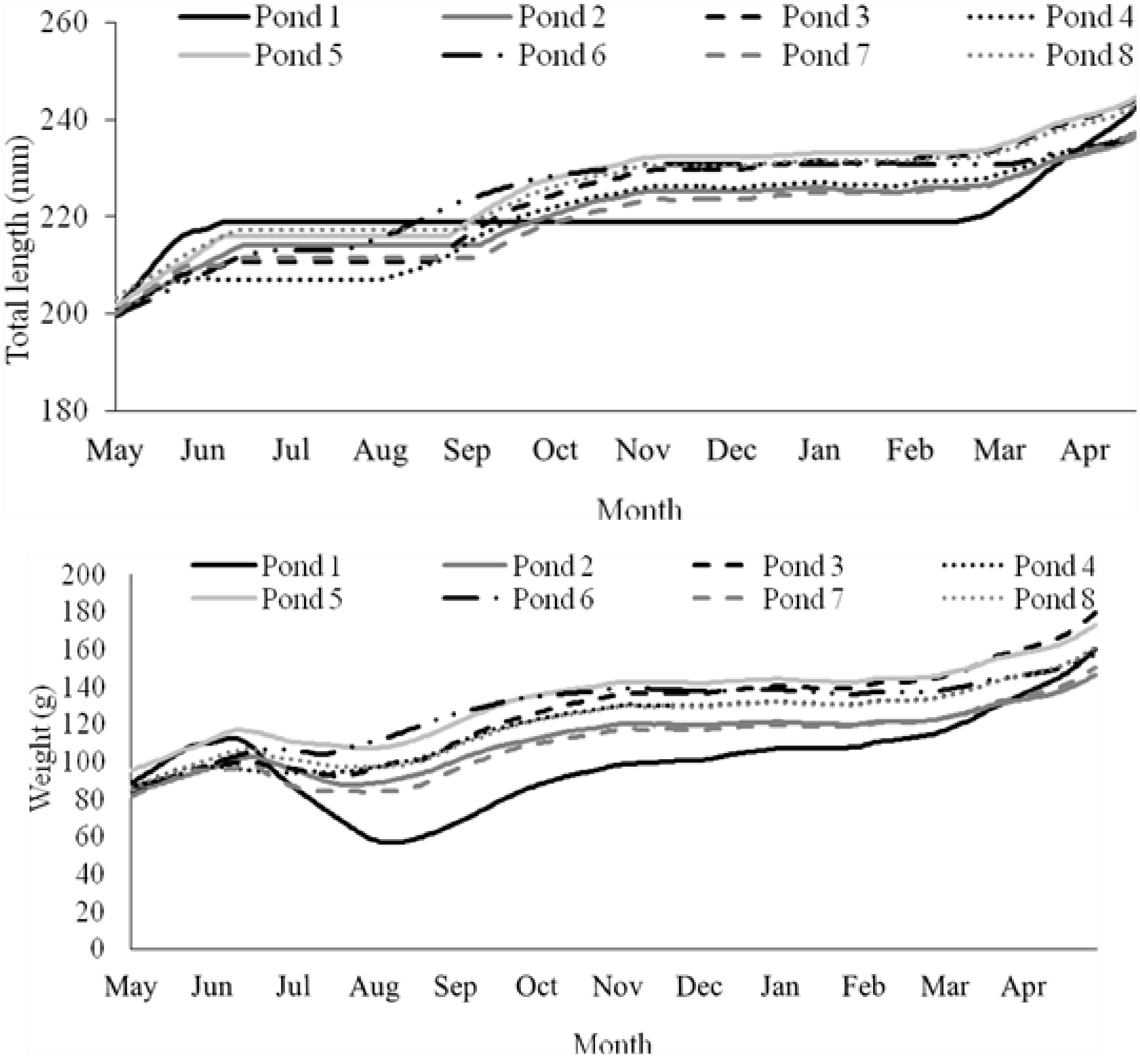

Figure 2 Predicted growth in weight (top graph) from bioenergetics model of largemouth bass in northeast Mississippi ponds in 2008-2009

The bottom graph represents growth in length estimated by converting predicted weight to length using weight-length equations and assuming no length shrinkage.

Assessment of accuracy on the bioenergetics model indicated that differences in predicted and observed TL were similar (Table 6). Although differences ranged from -11 to + 28 mm, the mean difference was 6 mm (SE 1.84) and range of percentage difference was -11.03 to 5.04. Most data pairs of observed and predicted lengths were close to a 1:1 relationship, indicating a strong relationship between observed and predicted lengths;

although the model overestimated the TL of 19 of the 25 fish (76%). Overestimation was likely caused by TL predicted from weight using a weight-length equation derived from greater-condition largemouth bass collected in the spring (Adams et al. 1982). Regression analysis of observed and predicted lengths indicated that the intercept did not differ significantly from zero and the slope did not differ significantly from one (df = 16; t = 1.66; *P* = 0.12). Therefore, change in length modeled by bioenergetics appears to provide reasonable estimates of week-1recruited largemouth bass that, in turn, can be used to estimate catchability on study ponds. Fish that were less than catchable size during the first week of fishing (subrecruited) were removed from catchability analysis. In ponds fished for a full season, 74 subrecruited-fish (< 200-mm TL) were caught and 61 subrecruited-fish were caught during fishing season that had a 2-month period of no fishing. Although non week-1 catchable fish were caught in late May, most were caught on trips in late July to October (Figure 3).

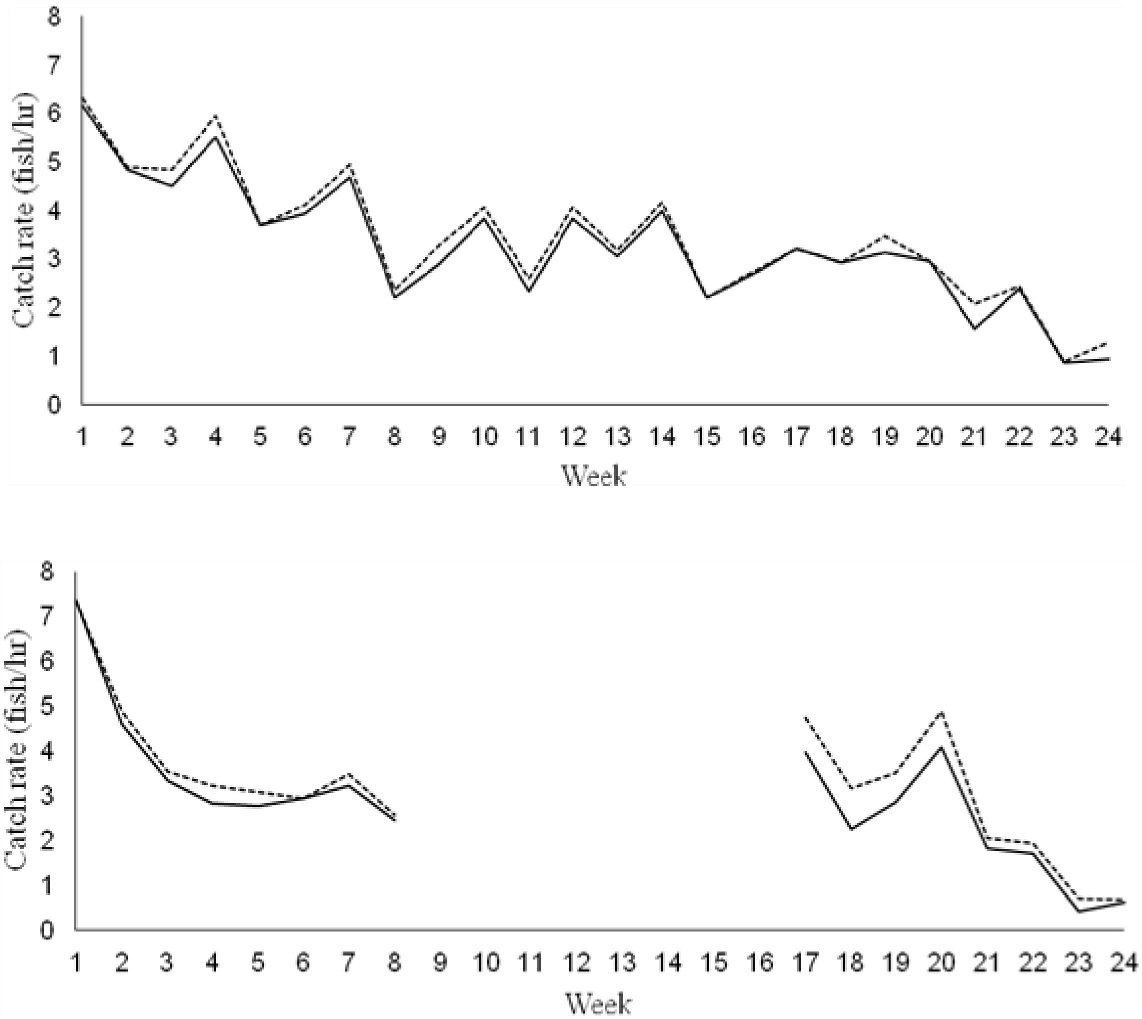

Figure 3 Mean catch rates of largemouth bass in eight northeast Mississippi ponds in 2008-2009

Solid line represents fish susceptible to angling at the beginning of the fishing season (week-1 recruited). Dotted line represents all fish angled (including fish not recruited to the catchable population at the beginning of the fishing season, but angled after they recruited to a catchable size via growth)

Table 6 Total lengths (TL) of recaptured (observed) and modeled (predicted) PIT-tagged largemouth bass using a bioenergetics model of largemouth bass in northeast Mississippi ponds in 2008-2009

PIT tag	Initial capture date	Initial TL (mm)	Recapture date	Recapture TL (mm)	Modeled TL (mm)	Average percentage difference
			Pond 1			
4A0C461F5A	01-May-09	189	26-Mar-10	238	233	-2.12
4A0D1C0036	22-May-09	203	28-Sep-09	236	211	-10.59
4A0D2E4815	12-Jun-09	202	18-Jun-09	204	206	0.99
4A0C413908	25-Jun-09	180	26-Mar-10	226	231	2.12
			Pond 2			
4A0C35770F	20-May-09	226	16-Jun-09	228	231	1.24
4A0C333C4C	10-Jun-09	241	13-Sep-09	260	231	-11.03
4A0C5A5566	16-Jun-09	221	13-Sep-09	234	221	-5.64
4A0D40255A	13-Sep-09	245	28-Oct-09	251	246	-2.07
			Pond 3			
4A0D1B3739	08-May-09	220	08-Jul-09	232	220	-5.36
4A0D3E2803	08-May-09	236	01-Oct-09	249	237	-4.66
4A0D29121F	03-Jul-09	242	25-Aug-09	244	236	-3.17
4A0C327918	03-Jul-09	233	01-May-10	251	248	-1.21
4A0C3B4B12	21-Aug-09	246	04-Oct-09	251	249	-0.64
			Pond 4			
4A0C313C2B	27-May-09	215	08-Jul-09	220	212	-3.85
4A0D36114C	27-May-09	208	06-Aug-09	224	209	-6.91
			Pond 5			
4A0C36746A	7-May-09	182	7-Apr-10	238	241	1.32
4A0C26756A	7-May-09	210	7-Apr-10	253	243	-3.98
			Pond 6			
470840190A	01-May-09	215	08-Jun-09	222	223	0.43
4A0C505B3E	8-Jul-09	224	1-May-10	245	239	-2.35
			Pond 7			
470A7F5111	01-May-09	237	09-Jun-09	246	241	-1.92
4A0D3E7A30	28-May-09	196	7-Apr-10	223	234	5.04
4A0D1D7608	28-May-09	226	7-Apr-10	243	236	-2.72
4A0D1D7608	24-Sep-09	237	7-Apr-10	243	238	-1.86
			Pond 8			
4A0C0A4721	31-Aug-09	226	04-Oct-09	244	233	-4.35
4A0C36331F	31-Aug-09	241	04-Oct-09	255	245	-3.90

Percent difference is [(predicted TL-observed TL) /observed TL] x 100

Declines in catch rate of week-1 recruited largemouth bass were observed on all ponds (Table 7). Mean catch rates of week-1 recruited fish in ponds fished for a full season decreased from 6.16 (SE = 1.53) fish/h to 2.21 (SE = 0.42) by the eighth week of fishing effort and decreased to 0.94 (SE = 0.44) fish/h after 24 successive weeks of effort (Figure 4). Mean catch rate in ponds receiving a 2-month period of no fishing was 7.35 (SE = 1.99) fish/h during the first trip. After a 2-month period of no fishing, mean catch rate increased from 2.46 (SE = 0.45) fish/h the week before the 2-month layoff to 3.97 (SE = 0.93) fish/h the week after the layoff, and then decreased to 0.63 fish/h (SE = 0.28) by 24th trip (Figure 5).

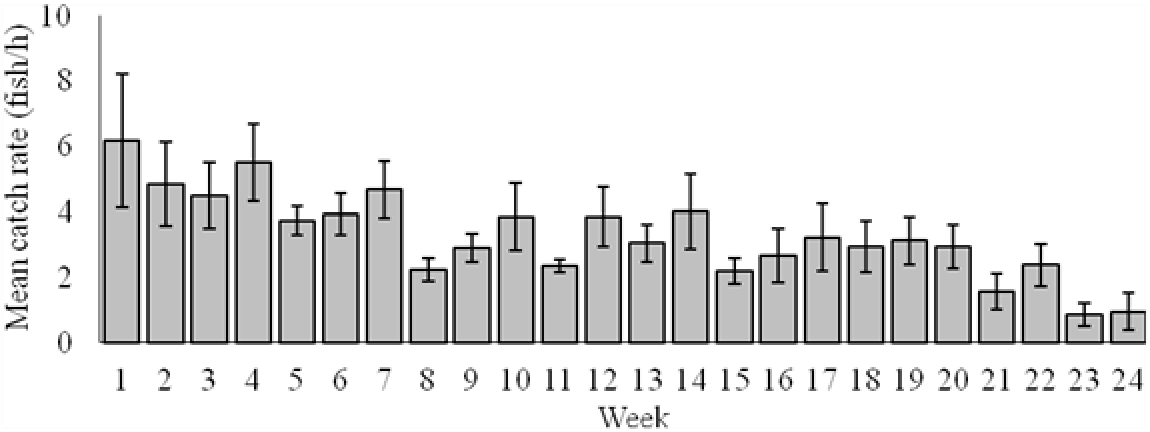

Figure 4 Mean catch rate of largemouth bass ≥_ 200 mm TL in eight northeast Mississippi ponds fished for 2.5 angler-h $ha^{-1}week^{-1}$ for 24 weeks during May-October 2008 and 2009.

Vertical bars are standard error

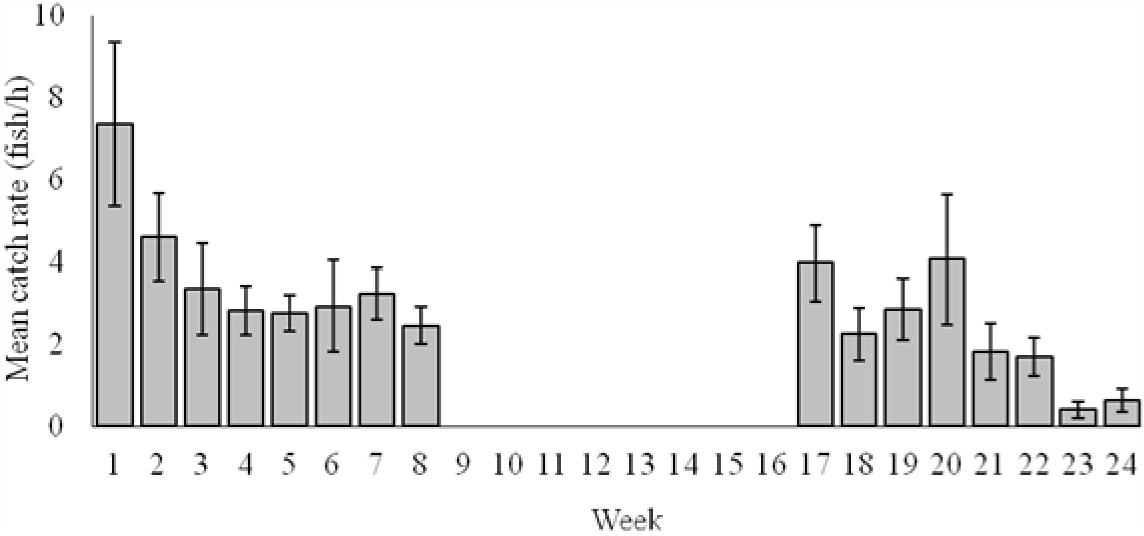

Figure 5 Mean catch rate of largemouth bass ≥ 200 mm TL in eight northeast Mississippi ponds fished 2.5 angler-h $ha^{-1}week^{-1}$ during weeks 1-8 and 17-24 of the May-October fishing seasons in 2008 and 2009

Vertical bars are standard error

Table 7 Mean catch rate of week-1 recruited largemouth bass in eight northeast Mississippi ponds in 2008-2009

Week	Full fishing season		Interrupted fishing season	
	Mean Catch Rate	SE	Mean Catch Rate	SE
1	6.16	1.53	7.35	1.99
2	4.84	1.34	4.61	1.07
3	4.49	0.89	3.34	1.10
4	5.50	1.10	2.83	0.59
5	3.71	0.75	2.77	0.44
6	3.93	0.92	2.93	1.11
7	4.67	1.14	3.22	0.62
8	2.21	0.42	2.46	0.45
9	2.89	0.83		
10	3.83	1.07		
11	2.34	0.45		
12	3.83	0.90		
13	3.04	0.78		
14	3.99	1.13		
15	2.19	0.38		
16	2.66	0.81		
17	3.22	1.01	3.97	0.93
18	2.93	0.79	2.25	0.64
19	3.12	0.68	2.84	0.75
20	2.94	0.67	4.07	1.58
21	1.55	0.42	1.83	0.69
22	2.37	0.98	1.70	0.48
23	0.85	0.34	0.41	0.21
24	0.94	0.44	0.63	0.28

Ponds were fished for 2.5 angler-h $ha^{-1}week^{-1}$ for 24 weeks during the full fishing season and 2.5 angler-h $ha^{-1}week^{-1}$ for 8 weeks (May-June), then 8 weeks of no fishing (layoff) during July and August, and then 2.5 angler-h $ha^{-1}week^{-1}$ for the final 8 weeks (September-October) during the interrupted fishing season. SE is standard error.

In 2008, 615 week-1 recruited individuals were caught 894 times. Of the 615 angled fish, 181 were recaptured one or more times during the 2008 fishing season. The exact number of times and individual was captured could be recorded in 2009 because PIT tags were used. In 2009, 560 week-1 recruited individuals were captured 708 times.

Of the 560 angled fish, 118 individuals were captured twice, and 31 were captured three times; no individuals were caught four or more times. Tag loss of PIT-tagged individuals was considered least because only one of the 560 PIT-tagged fish collected during the 2009 fishing season had a hole punch in the caudal fin but no PIT tag.

Population characteristics

Size-structure metrics were used to test the assumption that study ponds were bass crowded. The PSD was < 40 in most ponds, but ponds 5 and 6 had estimates of > 40 during both years (Table 8). Mean length in study ponds was < 300 mm TL for largemouth bass captured by electrofishing except pond 5 and 6 in 2009, which were 300 mm TL and 306 mm TL, respectively (Table 5). Mean length of angled fish was < 300 mm TL in all ponds and years except pond 4 in 2008 had a mean length of 306 mm TL. Ponds 4 and 8 had widely varying estimates of PSD and mean length between years, but these metrics were calculated from angler-caught fish rather than fish captured by electrofishing.

Table 8 Proportional size distribution (PSD) estimated from angler-caught fish and electrofishing samples in 2008-2010 in northeast Mississippi ponds.

Pond	Year	Angling			Electrofishing		
		PSD	95% CI	N	PSD	95% CI	N
1	2008	12	7-18	142	19	9-31	58
	2009	25	18-34	120	16	9-27	74
2	2008	2	1-6	134	9	2-24	33
	2009	7	3-14	89	9	4-19	74
3	2008	3	1-14	38	8	1-29	22
	2009	8	1-14	103	4	1-21	24
4	2008	60	45-74	50			
	2009	22	13-34	68			
5	2008	43	36-51	187	58	48-67	117
	2009	56	46-65	122	61	51-71	103
6	2008	37	20-56	30	45	31-61	46
	2009	55	42-68	58	57	29-82	14
7	2008	9	4-19	64	4	1-20	25
	2009	8	2-19	52	7	1-23	29
8	2008	4	1-15	47			
	2009	27	15-44	40			

N is number of stock-length fish in sample

Growth rates estimated from otoliths and measured from PIT-tagged largemouth bass indicated that fish in all study ponds were growing slowly (Table 9). Otolith analysis indicated fish age-2 and older (≥ 205 mm TL) in all ponds grew < 45 mm/yr. Average growth rates of age-2 PIT-tagged largemouth bass was 26 mm/yr (SE 3.39).

Density of recruited-size fish ranged from 40 – 145 fish/ha (Table 5). Population estimates of stock-size largemouth bass for ponds 1, 2, 3, 5, and 7 were considered similar between years because 95% confidence intervals overlapped.

Table 9	Total lengths and growth rates of largemouth bass estimated from back-calculated lengths collected in spring of 2010 in northeast Mississippi ponds

Mean back-calculated TL				Back-calculated growth rate mm/yr		Growth rate from PIT-tagged fish mm/yr		
Age	N	Mean	SE	Mean	SE	N	Mean	SE
				Pond 1				
1	32	173.8	5.7	71.3	3.1	1	49.0	
2	32	245.1	4.9	40.0	4.0	6	17.3	3.5
3	18	285.1	11.0	30.1	3.7	5	30.4	8.1
4	9	315.2	23.3	11.2	4.2	2	32.5	7.5
5	2	326.4	121.4	138.0	2.0	2	33.0	4.0
6	1	464.4	0.0	7.6				
7	1	472.0	0.0					
				Pond 2				
1	20	142.0	7.2	77.0	4.1	2	50.5	11.5
2	20	219.0	4.2	37.1	3.8	2	33.5	4.5
3	9	256.1	5.9					
				Pond 3				
1	15	140.0	6.5	71.0	4.2	6	58.2	2.6
2	15	211.0	4.8	43.2	7.3	4	32.8	3.3
3	4	254.2	10.0	4.0	0.0	1	26.0	
4	1	258.2	0.0					
				Pond 5				
1	18	129.5	3.5	99.6	2.9			
2	18	229.1	3.8	42.0	3.2			
3	6	271.1	4.9	14.3	1.1	1	25.0	
4	2	285.4	3.0					
				Pond 6				
1	9	110.4	6.8	97.8	6.6			
2	9	208.2	3.0	43.6	3.9	2	19.0	2.0
3	6	251.8	4.5	30.2	0.3			
4	2	282.0	0.3					
				Pond 7				
1	22	119.0	3.0	86.0	3.2	2	87.0	7.0
2	22	205.0	4.1	38.0	2.9	4	27.5	3.8
3	16	243.0	4.8	31.9	0.9	2	9.0	5.0
4	3	274.9	6.6					

Observed annual growth of PIT-tagged individuals was used to assess the accuracy of growth rates obtained from otolith analysis. N is sample size; SE is standard error.

The population estimate for pond 6 in 2010 (*N*= 36; 95% CI 24-66) was substantially less than the previous year's estimate and outside the confidence intervals (*N* = 113; 95% CI 83-168). The smaller population estimate in 2010 could have been due to mortality, but no significant die-off was observed. Likely, aquatic–macrophyte conditions during the second estimate led to the discrepancies between the 2009 and 2010 estimates. This pond contained a dense population of watershield *Brasenia schreberi* during both years of the study. Extensive stands of this aquatic macrophyte developed in late spring. Stems of watershield in these extensive stands entangled the propeller and limited boat movement, and the floating leaves made detection and collection of stunned fish difficult. The 2009 population estimate occurred during March and April. Because it was earlier in the growing season, macrophyte coverage was not as great as it was during the 2010 population estimate, which occurred during April and May. In 2009, the shallow (< 1 m) portions of this pond had a patchy distribution of watershield (clumps of plants surrounded by open water), which permitted access by the electrofishing-boat. Visually estimated coverage of watershield during the 2009 population estimate was 75%. However, the visually estimated coverage during the 2010 estimate had increased to > 90%, and the shallow portions of the pond were covered by an extensive stand of watershield that was impenetrable by the electrofishing boat. The only portion of the pond that could be sampled effectively during the 2010 estimate was an area of open water that occurred on the periphery of these dense beds in water depth > 1.5 m. During the 2010 estimate, 9 of 16 fish marked were recaptured, leading to a 57% recapture percentage. However, aquatic macrophytes hindered sampling of the entire water body. Therefore, it is unlikely that a representative sample was obtained. Ability to achieve a valid estimate was undermined by failure to satisfy the assumption that marked and unmarked fish were equally vulnerable to capture in the recapture period because unmarked fish in dense stands of macrophytes were not susceptible to capture with electrofishing gear. It is unknown if most of the fish captured during the marking effort remained in the open-water section of the pond, but the great recapture percentage suggests this may have occurred. However, fish inhabiting extensive stands of aquatic macrophytes were not sampled during either sample period. This resulted in a potential overrepresentation of marked fish (recaptures) in the second sample, thus leading to an underestimation of the true population number.

More individual largemouth bass were angled ($N = 103$) from pond 3 in 2009 than were estimated in the 2009 ($N = 74$; 48-130) and 2010 ($N = 38$; 37-91) population estimate. Decreased catch with electrofishing equipment affected by deep water habitat likely caused underestimation of population size. Multiple passes were made around the entire perimeter of the pond and deep water habitat, but relatively few fish were marked (< 25) and examined for marks (< 40) in this pond compared to the other ponds during the population estimates. Therefore percentage of the population angled was not estimated for this pond.

Effect of effort on catch rate

Analysis of week-1 recruited fish indicated that effort significantly decreased catch rate ($F_{4, 298} = 16.53$; $P < 0.001$). Pair-wise comparisons indicated that change in catch rate was significantly greater ($t = 2.64$; df = 298; $P = 0.009$) during the first 8 weeks compared to the last 8 weeks of the fishing season for ponds fished for a full season. Change in catch rate did not differ significantly ($t = 1.52$; df = 298; $P = 0.13$)

between the first 8 weeks and the final 8 weeks of fishing for ponds that received a 2-month layoff. Applying parametric tests to significant non-normal catch rate data increases probability of committing a Type-II error (failing to reject a false null), consequently decreasing the predictive power of the analysis (Zimmerman 1994). Change in catch rate during the final 8 weeks of the fishing season did not differ significantly ($P = 0.46$) between the ponds fished continuously and the ponds that received a layoff.

Results that included marked and unmarked fish indicated that effort significantly affected catch rate. Additionally, mixed model analysis that included only first-time captures that were week-1 recruited indicated effort had a negative effect on catch rate and was significant ($F_{4,298} = 20.43$; $P < 0.001$). Catch rate did not differ significantly between the first 8 weeks and last 8 weeks of the full fishing season ($P = 0.23$) or the interrupted fishing season ($P = 0.42$) for first-time captures. Catch rate also did not differ significantly ($P = 0.40$) between the final 8 weeks of the season for ponds with no layoff when compared to the final eight weeks of the season for ponds that received a layoff.

The effect of the 2-month period of no fishing on total catch

Results from total catch analysis indicated that the interrupted fishing season did not sufficiently increase catch of largemouth bass in my study. Total catch of non-marked individuals that were week-1 recruited was greater in ponds fished for a full season (paired t-test; n = 8; df = 9; t = 3.01; $P = 0.02$) compared to the interrupted season. Ponds fished for a full season had an average total catch of 87 (SE 17.31) individuals and ranged from 46 to 181 individuals. Total catch in ponds fished for an interrupted season averaged 60 (SE 11.49) individuals and ranged from 23 to 112 individuals. Seven ponds during the full season and four ponds during the interrupted season had total catches great enough to meet the harvest recommendation of 50 fish $ha^{-1}yr^{-1}$ (Table 10). It was apparent that the increase in catch rate observed at the beginning of the interrupted fishing season was not enough to compensate for time lost fishing during the 2 month layoff. If the same number of largemouth bass caught during the July-August period of the full fishing season were added to number of individuals caught during the entire interrupted season, then 6 ponds would have exceeded the 50 fish $ha^{-1}yr^{-1}$ harvest rate and two of those ponds would have reached the 75 fish $ha^{-1}yr^{-1}$ during the interrupted fishing season.

Percentage of the population angled during a full season of fishing was estimated in pond 6 and 7 and during an interrupted season in pond 1, 2 and 5 (Table 10). Mean percentage of the population caught at least once was 56% (SE 7.14) in these five ponds. Percentage of the population angled was > 50% in all ponds except for pond 5 (32%).

Table 10 Angling information for largemouth bass caught in northeast Mississippi ponds 2008-2009.

Pond	Year	Indiv. angled	Adequate harvest	Indiv. angled if no layoff	Indiv. recaptured	Recapture rate	Catch (fish/ha)	Percentage population angled
1	2008	140	71		89	0.64	98	
	2009[a]	100	71	143	23	0.23	70	64
2	2008	84	89		17	0.20	47	
	2009[a]	73	89	96	19	0.26	41	57
3	2008[a]	37	65	59	6	0.16	28	
	2009	85	65		18	0.21	65	
4	2008[a]	47	46	64	7	0.15	51	
	2009	55	46		14	0.25	59	
5	2008	181	113		26	0.14	80	
	2009[a]	112	113	168	19	0.17	49	32
6	2008[a]	23	44	41	1	0.04	26	
	2009	58	44		4	0.07	65	51
7	2008[a]	56	20	68	7	0.13	137	
	2009	46	20		15	0.33	112	75
8	2008	47	21		28	0.60	96	
	2009[a]	31	24	39	6	0.19	63	

Adequate harvest is how many individuals needed to be angled to reach a 50 fish $ha^{-1}yr^{-1}$ harvest rate. Individuals angled if no layoff represents how many largemouth bass would have been angled during the interrupted fishing season assuming the same number of fish caught in July-August (same time period as the 2-month layoff) of the full fishing season was caught during the interrupted fishing season. Percentage of the population angled was estimated by dividing the total individuals angled in each pond during the 2009 fishing season by the 2009 population estimate.

[a] denotes fishing season was interrupted by a 2-month period of no fishing

CHAPTER IV

DISCUSSION

Previous studies found that catch rates of largemouth bass (Martin 1958) and rainbow trout (Van Poorten and Post 2005) declined quickly after fishing began. Findings of my study support previous research. Catch rate was significantly affected by effort, and catch rates declined throughout 24 weeks of fishing. However, results did not support the prediction that a 2-month period of no fishing would increase catch rate. No significant difference in decline of catch rate was detected before and after the period of no fishing. Catch rates in my study increased immediately after a 2-month period of no fishing to rates similar to those observed during the first month of the fishing season. However, greater catch rates lasted only one month before decreasing to the least catch rates of the season and similar to catch rates observed during the full season of fishing.

Askey et al. (2006) found that catchability of rainbow trout increased following a 23-day layoff but demonstrated that elevated catch rates were from new recruits to the fishery. When I accounted for recruitment, it was evident that newly-recruited fish inflated catch rates throughout the fishing season; but the greatest impact on catch rates occurred during September to October, which also coincides with when increased catch rates were observed following a 2-month period of no fishing. Catch rate did increase following the 2-month period of no fishing, but a portion of this increase was likely from new individuals recruiting to the catchable population and not necessarily an affect of intermittent fishing effort on catch rate.

Other studies have consistently shown that catch rates of largemouth bass decline with sustained fishing effort, but the mechanisms causing this decline are undetermined. Variation in catchability among individuals in a population is a process that has been hypothesized as a reason catch rates decrease with sustained fishing effort. Martin (1958) postulated that rapidly declining catch rate was caused by a vulnerable pool of fish that were quickly angled and harvested, leaving a less vulnerable pool of fish that were difficult to catch. Lindgren and Willis (1990) supported the idea that a great percentage of the largemouth bass population can be quickly removed from a small impoundment by catching 33% of the population in only 20 hours of fishing effort. More than half of the largemouth bass population was caught in four ponds used in my study during one year of intensive angling.

Burkett et al. (1984) concluded that largemouth bass vary in vulnerabilities to angling and that some individuals within the same population are more catchable than others. Percentage of the population angled was 85% during four years of catch-and-release fishing in Ridge Lake, Illinois, but 15% of fish > 200 mm were never caught in four years of angling, indicating that segments of the population may have consisted of individuals with “high” and “low” vulnerability to angling. This suggests that a large proportion of the population can be caught quickly, but a segment of the population may never be caught, even after several years of fishing. Phillip et al. (2009), working in the same lake as studied by Burkett et al. (1984) concluded that catchability is heritable and could directly affect angling success rate. It is possible that removing the more vulnerable individuals from a population via harvest would allow the less vulnerable individuals to survive with greater success. This type of angler selection would yield a population dominated by less vulnerable fish that are not as likely to be captured by anglers, and thus decreasing the percentage of the population that could be caught. This situation was likely not a factor in my study because no fish were harvested and ponds were fished little before initializing the study. However, catchability of largemouth bass may be influenced by angler-induced selection in water bodies where greater levels of harvest occur or where catch and release mortality is substantial.

Learned lure avoidance has been hypothesized to explain the decrease in catch rates of largemouth bass (Anderson and Heman 1969; Hackney and Linkous 1978) and rainbow trout (Van Poorten and Post 2005; Askey et al. 2006). Learning is defined as changes in behavior with experience (Dill 1983), and many studies have shown that fish can learn (Brown 1937; Bull 1957; Prazdnikova 1962). Fish may learn through different processes, but researchers believe that fish learn to avoid capture by not striking lures through operant conditioning. Operant conditioning is where a fish responds to a stimulus and either receives positive or negative reinforcement (i.e., trial and error learning). Anthouard (1987) provided an example of this when he used an operant conditioning procedure to train sea bass *Dicentrarchus labrax* to press a lever for a food reward. Fish that were efficient at pushing the lever to obtain food were placed into one group and fish that responded poorly to the procedure were placed into another group. Then two groups of fish that had not been trained in this procedure (observers) were allowed visual contact with either the good lever-pushers or the poor lever-pushers. Observers that had visual contact with the good lever-pushing group learned to use the lever to obtain food more quickly than did fish exposed to the poor lever-pushing group.

Studies have shown that fish are able to not only learn, but retain this ability for a period of time. Yue et al. (2004) demonstrated that rainbow trout can learn a simple avoidance task and remember it for up to 7 d. Fish were first trained to perform a "shuttle," which consisted of swimming from one chamber of the tank through a door into another chamber. Fish that did not immediately swim through the door were guided by a dipnet. Within 2 days, most fish swam directly for the door. Then fish were trained to perform the same shuttle after being presented with an automated dip net, and subsequently an illuminated light; and immediately followed by the plunging of the automated dip net. The dipnet was a sudden and intense stimulus that the researches believed to elicit fear in mammals and birds. In the final phase of the experiment, only the light was illuminated, therefore the fish would have to associate the illumination of the light (conditioned stimulus) with the plunge of the automated dip net (unconditioned stimulus). Proportion of successful shuttles completed significantly increased over time, indicating that rainbow trout learned to associate illumination of the light with plunging of the automated dip net, and fish in the study retained this behavior for up to 7 d.

Jones (2002, page 35) reported that individual largemouth bass in tanks demonstrated avoidance behavior by not striking an artificial lure after a 5-minute exposure to the lure and retained this behavior for up to 3 months. Avoidance behavior was measured by number of times a group of six individuals struck an artificial lure during two exposure periods. Each group averaged 24 strikes (four strikes per fish) during the initial exposure, with most strikes occurring during the initial one to three minutes. After this time period, largemouth bass ignored the lure because it provided no positive food reward. After 3 months of no further testing, individuals were again exposed to the same artificial lure, but response of each group of six fish decreased to < 5 strikes during the 5-minute exposure period (K. Jones, unpublished data). Beukema (1970) concluded that catching a common carp (*Cyprinus carpio*) in experimental ponds one time decreased the individual's likelihood to take a baited hook for at least one year. Very few individuals were caught more than one time, and catch rates of carp one year after being captured were three times less than catch rates of carp not previously fished.

Conversely, Anderson and Heman (1969) concluded that learned lure avoidance was not demonstrated in all size groups of largemouth bass. Ponds containing previously fished and unfished populations of largemouth bass were drained and fish were sorted into size groups and equal numbers of each size group were stocked separately into three experimental ponds. In ponds with largemouth bass 180 to 230 mm TL, there were no significant differences in the catch rate of fish from previously unfished populations compared to previously-fished populations; however there were significant differences in catch rate in ponds containing fish > 230 mm TL.

Further, Hackney and Linkous (1978) concluded that the decline in largemouth bass catch rate using live bait was from learned lure avoidance. However, they were unable to identify learning as the reason catch rates declined in two groups of fish exposed to artificial lures. Evidence of learned lure avoidance also was not evident in populations of white-spotted char *Salvelinus leucomaenis* in a Japanese stream (Tsuboi and Morita 2004). Further, Schill et al. (1986) found that cutthroat trout in the Yellowstone River were captured 9.7 times, on average, per season, suggesting fish were not learning to avoid lures after catch and release. Askey et al. (2006) postulated that differences in catchability observed in their experiment on rainbow trout in lentic environments and behavior exhibited by white-spotted char and cutthroat trout in lotic environments may be explained by the systems they inhabit. Fish living in lotic environments may have less time to examine potential prey items, thus requiring a rapid response by the fish before the food is lost downstream.

Previous studies may have overstated the learning ability of fish by only using several lures throughout the experiment. Anglers in the study conducted by Askey et al. (2006) only used two types of flies when fishing for rainbow trout, and Anderson and Heman (1969) only used hard-plastic lures with two treble hooks to catch largemouth bass. However, anglers in the study conducted by Burkett et al. (1984) were able to choose any lure to catch largemouth bass, thereby likely leading to a greater diversity of lures used. Few fish were caught two or more times during the fishing season in my study, even though my project used a diverse selection of lures, including hard and soft-plastic lures with treble hooks, single hooks, and lures that fished the entire water column. Relatively few recaptures caught on a broad range of lures may indicate that fish are able to distinguish between a wide variety of shapes and colors of artificial lures, and learn to avoid them.

Growth rates obtained from otolith analysis suggests that largemouth bass exhibited slow growth in study ponds. Age-1 fish grew quickly, but growth rates of age-2 fish were < 40 mm/yr compared growth rates of > 70 mm/yr in lakes in Illinois and Iowa (Carlander 1977) Wisconsin (Mraz et al. 1957) Connecticut (Whitworth 1989).

Thus, the assumption that study ponds were bass-crowded was supported by size structure estimates and slow growth rates.

Mortality associated with catch-and-release fishing could alter catchability estimates by decreasing size of the largemouth bass population in study ponds. Previous studies on catch rate demonstrated that largemouth bass may be caught, released, and recaptured several times during a season (Burkett et al. 1986). Mankin et al. (1984) and Hackney and Linkous (1978) also reported no hooking mortality after recapturing largemouth bass in pond studies. Fishing mortality in my study was not estimated but was assumed to be least. I observed no dead fish; however, post-release mortality was difficult to estimate because observations on each pond occurred approximately one week apart, and dead largemouth bass likely would not have been visible.

Bacterial and fungal infections, hooking location, air exposure, and warm water temperatures have been identified as factors that can result in angler-induced mortality (Wellborn and Barkley 1973; Holbrook 1975; Pelzman 1978; Cooke and Suski 2005). However, Weathers and Newman (1997) found that proper capture and handling procedures can substantially increase fish survival, even during warm weather. Therefore, great emphasis was placed on efficient data collection to minimize potential hazards to fish health, such as injuries sustained during handling and long periods of air exposure. Largemouth bass angled during the study were lifted out of the water and into the boat with the fishing rod, or in the event of a large fish , by the lower jaw (i.e., landing nets were not used). Most fish were hooked in the mouth near the mandible or maxillary, and hooks were quickly and easily extracted without any bleeding. Eight individuals were hooked deeply in the mouth, but not in the esophagus. Hooks were removed by hand or with needle-nose pliers, and individuals swam off after release.

Cooke et al. (2003) concluded that recovery of largemouth bass following simulated exhaustive angling and air exposure was not influenced by water temperature and that largemouth bass caught in water temperatures between 13°C and 25°C and briefly exposed to air (< 30 s) were capable of surviving and recovering from this stressor. In my study, data were collected from captured fish quickly, and fish were returned to the water as soon as possible (< 30 s). In the event both anglers caught fish at the same time, the second fish hooked would be held in the water until data collection and release of the first-caught fish was complete. However, water temperatures in study ponds during 2008 (range 15.1-33.8°C; mean 25.6°C; Figure 1) and 2009 (range 14.7-33.5°C; mean 26.8) were greater than temperatures tested by Cooke et al. (2003). Because my study occurred when mortality from capture, hooking, and handling is the greatest, there is a possibility that catch rates could have been affected by mortality of angled fish.

Another factor that may have influenced angler catch rate is seasonality. Seasonal influence on angling catch rates has been recognized for decades (Lux and Smith 1960). Prey availability, predator abundance, and water temperature are biotic and abiotic factors that have been related to seasonal variation of catch rate (Lux and Smith 1960; Mills et al. 1986; Raat 1987). Catch rates may be affected by change in habitat use that occurs seasonally, such as individual largemouth bass moving out of shallow water and into deep-water areas that are less affected by temperature change (Lewis and Flickinger 1967; Coutant 1975). Because of the sustained effort used in my project, the sampling season encompassed differences in water temperature caused by seasonality. The greatest decline in water temperatures occurred during the final 4 weeks of the fishing season when surface water temperatures decreased 10ºC. Water temperatures were uniform and oxygen was > 3.5 mg/L at 3-m deep by 1 October. The entire water column was fished, but detecting bites or landing fish were challenges of fishing in deep-water areas (i.e., > 4 m). However, the same decline in catch rate was observed on all ponds, but not all ponds in my study had deep water (> 4 m). Therefore, changes in catch rate caused by the inability to properly present lures to largemouth bass seeking refuge in deep-water habitats would only be plausible in ponds 2, 3, 5, and 8. Further, Johnson and Charlton (1960) indicated the amount of food consumed by fingerling largemouth bass was between 20ºC and 27ºC. If catch rates were influenced by water temperature fluctuations caused by seasonality, then the greatest catch rates should be observed from fishing trips conducted water temperatures between 20ºC and 27ºC. Water temperature was within this range on trips 1-8, and 17-20. Great catch rates were observed on trips 1-8 but not 17-20. Therefore, it appears that fishing effort had more of an impact on catch rate than did effects of seasonality.

The study design attempted to control for catch rates being affected by reproductive behavior by not starting the fishing season until after largemouth bass had completed spawning. Mean water temperature during the first week of fishing was 26.6ºC (SE = 0.27), which was warmer than spawning temperature range of 15ºC to 24ºC for largemouth bass (Swingle 1956; Kramer and Smith 1962; Coutant 1975). Further, no occupied spawning nests or individuals guarding fry schools were observed during the fishing season. Therefore, it is unlikely that catch rate was influenced by spawning behavior of largemouth bass.

Findings from this experiment are important to managers confronted with crowded bass populations in small impoundments in the southeastern U.S. Harvest, particularly of smaller largemouth bass, is an accepted practice for correcting a bass crowded problem, but a management strategy is needed to maintain elevated catch rates. Total catch of week-1 recruited fish during the full season of fishing was adequate for harvest of 50 $ha^{-1}yr^{-1}$ on all ponds except pond 2, but was only adequate on four ponds during the interrupted fishing season. A 2-month period of no fishing increased catch rates in my study, but not to the magnitude that was needed to compensate for harvest that may have occurred during the layoff.

It is important that further research be conducted on use of interrupted fishing-seasons as a management tool for increasing catch rate of largemouth bass, specifically on length of the layoff period. If increased catch rates are observed after a shorter layoff period, then the amount of potential harvest lost during the period of no fishing could be reduced. Because many ponds were close to meeting the harvest recommendation of 50 fish $ha^{-1}yr^{-1}$ during the interrupted season, I predict that a layoff period of 1 month would allocate enough time to increase catch rate, while still allowing adequate fishing time to remove sufficient numbers of largemouth bass during a 6-month fishing season. Although change in catch rate during the final 8 weeks of fishing did not differ significantly between the full interrupted and full fishing season, a small increase in catch rate immediately following the layoff was observed. Therefore, a 1-month period of no fishing could be successful if an increase of the same magnitude is observed. This would yield a simple, yet powerful tool for small-impoundment managers to implement when faced with a bass-crowded population of largemouth bass.

In summary, effort had a significant effect on catch rates or largemouth bass; however, the exact mechanism of the decline is still undetermined. One of the strengths of this study was that it was performed on non-hatchery ponds, thus representing a more natural situation for a catchability project because it is the type of pond typically fished by anglers. However, determining the exact mechanism for declining catchability is difficult in non-hatchery ponds because stock size can change due to variation in population dynamics (i.e., recruitment and mortality). Because these ponds cannot be drained and filled throughout the study, like hatchery ponds, certain population dynamics cannot be directly measured. Population size and recruitment was estimated, but with a degree more of variability than if this study were conducted in a hatchery pond; where a known number of fish can be stocked and recruits are estimated by draining the pond, thus minimizing observation error.

Natural mortality was not estimated because of these difficulties. In a bass-crowded situation, number of recruits to number of spawning adults is thought to be a domed-shaped relation. Greatest number of recruits will be produced at an intermediate abundance of spawners. However, with a greater number of spawners, recruits will decline due to density dependence and cannibalism (Ricker 1975). Therefore, because of the bass-crowded condition and greater levels of recruitment, it is likely that natural mortality affected catch rates during the study by decreasing population size. However, the extent depends on what time of year natural mortality occurred. Fish lost from the catchable population would be replaced via recruitment of new fish to the catchable population, which was accounted for in catchability estimates. If mortality occurred during the fishing season, then catchability estimates could be affected. However, if mortality occurred outside of the fishing season, then catchability estimates would not be affected, because the same number of week-1 recruited fish that were in the population at the beginning of the fishing season would survive until the end of the fishing season.

Despite estimation of population dynamics and accounting for their possible affects on catch rate, catch rate data showed great variability between ponds and from week to week. This degree of variability made it difficult to isolate the mechanism causing the decline in catch rate. However, this study was designed to determine if a relationship between declining catchability and fishing effort existed; not to determine cause of the decline. To isolate the actual mechanism causing the decline, future researchers must understand that fishing effort is negatively related to catch rate, but absolute catch rate cannot be increased by solely removing effort for a brief period of time.

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