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[Article]

Effects of Stocking Rate, Stocking Size, and Angler Catch Inequality on Exploitation of Stocked Channel Catfish in Small Missouri Impoundments

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Abstract.—Put–grow–take fisheries for channel catfish *Ictalurus punctatus* provide popular sport fisheries in many small impoundments and lakes throughout the United States. These fisheries are costly to maintain because the fish that are stocked are usually large fingerlings (>175 mm total length). Given the substantial fiscal and human resources required, it is important that these stockings contribute to the fishery. We estimated the exploitation of stocked channel catfish by tagging fish in 14 small impoundments to determine their use. Secondly, we determined whether the stocking rate, stocking size, and angler catch inequality (proportion of tags returned) affected exploitation. Annual exploitation varied more than 10-fold among the impoundments, ranging from 0 to 0.65 for the year after the fall stockings and usually declining thereafter. Cumulative exploitation in the 3 years after stocking ranged from 0 to 0.69, indicating that there is wide variation in the use of the stocked fish. Exploitation was unrelated to the stocking rate but was affected by stocking size, larger fish being more vulnerable than smaller fish to catch and harvest. In several impoundments, one to three anglers accounted for one-third or more of all returned tags, showing that just a few anglers can markedly affect exploitation. These results suggest that exploitation can be dynamic, changing with stocking size and angling clientele. Despite this inherent variability, we found substantial differences in exploitation among lakes. Managers should focus on impoundments where channel catfish are heavily exploited, possibly by stocking more fish or implementing protective harvest restrictions. For lightly exploited lakes, reducing stockings may be necessary to improve the growth and size structure of channel catfish.

Channel catfish *Ictalurus punctatus* are commonly stocked into small lakes and impoundments (hereafter termed lakes) throughout the United States to provide for popular put–grow–take fisheries (Michaletz and Dillard 1999). Stockings of large fingerlings (>175 mm total length [TL]) are usually necessary because smaller fish, including those stemming from natural reproduction, are highly susceptible to predation by largemouth bass *Micropterus salmoides* and other predators (Marzolf 1957; Krummrich and Heidinger 1973; Spinelli et al. 1985; Storck and Newman 1988). These stockings represent a substantial investment to management agencies, making it important that they contribute significantly to the sport fisheries in these lakes.

The use of stocked channel catfish can vary greatly among lakes. Harvest has varied from 0.4 to 126 fish/ha and 0.3 to 74 kg/ha in Missouri lakes (Michaletz and Stanovick 2006) and from 1 to 768 fish/ha and 1 to 359 kg/ha in Alabama lakes (Shaner et al. 1996). Similarly, the exploitation of stocked channel catfish has been highly variable, ranging from 17% to 64% of the total number of fish stocked (reviewed by Shaner et al. 1996).

Many variables may affect the exploitation of channel catfish in small lakes, including the amount of angling effort, stocking rate, stocking size, and angler catch inequality. The amount of angling effort directed towards channel catfish affects exploitation. For example, in Missouri lakes, channel catfish harvest was positively correlated with catfish angling effort (Michaletz and Stanovick 2006). Stocking rates may also influence exploitation in at least two ways. First, at some given level of angling effort, a higher proportion of the stocked fish may be harvested when stocking rates are low than when they are high, because of a possibly greater surplus of fish at high stocking rates. Second, channel catfish may grow slowly at high stocking rates because growth is density-dependent (Hubert 1999; Mitzner 1999), and many may not grow large enough to interest anglers. Shaner et al. (1996) found that harvest was reduced in lakes stocked at high rates. The size of stocked fish may also affect exploitation because smaller fish require more time than large fish to grow to a size where they are vulnerable to harvest (Shaner et al. 1996). During this time, however, they are more susceptible to predation and other natural mortality factors (Spinelli et al. 1985; Storck and Newman 1988), and fewer may survive to

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TABLE 1.—Lake surface area, stocking rate (fingerlings $\cdot$ ha^{-1} $\cdot$ year^{-1}), and tagging information for channel catfish in the study lakes. Tags were either white (W) tags worth US$10–100 or orange (O) tags worth $50.

Lake	Area (ha)	Stocking rate	Tagging year	Tag type	Number tagged	Mean TL (range)
Belcher Branch	22	74	2004	W	500	272 (178–361)
Ben Branch	18	37	2002	W	500	317 (196–439)
Brookfield City	41	74	2001	W	500	303 (203–437)
			2001	O	100	289 (203–384)
Council Bluff	178	12	2001	W	500	251 (175–312)
			2001	O	100	253 (191–312)
Green City	23	12	2004	W	290	275 (180–409)
Lawson City	10	37	2003	W	375	270 (157–376)
Limpp Community	12	74	2002	W	500	311 (175–437)
Manito	31	12	2002	W	365	300 (175–437)
Miller	11	37	2003	W	405	270 (170–335)
Pony Express	97	37	2001	W	500	287 (203–411)
			2001	O	100	275 (211–406)
Prairie Lee	61	12	2004	W	500	222 (168–300)
Ripley	8	37	2004	W	300	232 (185–318)
Savannah City	9	74	2003	W	501	269 (180–376)
Sims Valley	15	12	2003	W	190	263 (198–371)

harvestable size. Perhaps a less obvious variable that may influence exploitation is the degree of catch inequality among anglers. In some situations, the catch (or harvest) of a few successful individuals can account for a high proportion of the total catch (or harvest) by all anglers (Smith 1990; Baccante 1995; van Poorten and Post 2005). This may be especially probable in small lakes, where relatively few anglers fish. For example, one angler was responsible for a greater than fivefold increase in exploitation of bluegill *Lepomis macrochirus* in a small private lake (Kruse 1997). Thus, the presence or absence of these few successful anglers can strongly affect exploitation.

The main objective of this study was to estimate the exploitation of stocked channel catfish in 14 small Missouri lakes that support put–grow–take fisheries. Secondly, we wanted to determine whether the stocking rate, stocking size, and catch inequality among anglers influenced exploitation. To accomplish these objectives, we tagged stocking-size channel catfish, released them into the lakes, and used tag returns to estimate exploitation. The lakes had been consistently stocked at one of three different rates for at least 3 years before this study. An understanding of factors that affect exploitation in a variety of lakes should prove useful to managers attempting to manage channel catfish populations under a wide range of conditions.

Methods

Study lakes.—The 14 study lakes ranged in size from 8 to 178 ha (Table 1) and were scattered across much of the state of Missouri. In addition to put–grow–take fisheries for channel catfish, bluegill and largemouth bass provided important sport fisheries in all of the lakes. Crappies *Pomoxis* spp., gizzard shad *Dorosoma cepedianum*, redear sunfish *Lepomis microlophus*, and common carp *Cyprinus carpio* were also common in some lakes. Channel catfish populations were regulated by a four-fish daily creel (in aggregate with blue catfish *I. furcatus* and flathead catfish *Pylodictis olivaris*) and no size limit. Anglers were restricted to using pole and line only (no trot lines, limb lines, jugs, etc.).

All of the study lakes had been consistently stocked with channel catfish fingerlings at 12, 37, or 74/ha (Table 1) annually since 1998 in late September to mid-October. Although usually 80% of the stocked fingerlings exceeded 200 mm TL (Eder et al. 1997), fingerlings can range in size from about 125 to 450 mm TL. The stocking rates used in this study represented the range of stocking rates used by the Missouri Department of Conservation (MDC).

Tagging.—Tagged channel catfish were released during one year between 2001 and 2004 in each of the 14 lakes (Table 1). These tagged fish were part or all of the normal annual stocking received by each lake in late September to mid October. Before being stocked, some fingerling channel catfish were held in raceways or catch basins at fish rearing facilities where they were tagged with Carlin dangler tags according to procedures in Wydoski and Emery (1983). Stainless steel wire was used to affix the tag to the body of the fish just below the dorsal spine. Although we did not tag fish less than 150 mm TL, they represented less than 1% of the stocked fish. These small fish were usually in poor condition and we were concerned that they would die from being tagged or from predation once they were stocked. Printed on the plastic disk of the tag was a unique number identifying the individual fish, an abbreviation (MO CONSV DEPT) indicating the agency responsible, and reward values. The standard tag was white and had reward values of US\$10–100. Reward values were randomly assigned to tag numbers: 95% of the tags were worth \$10, 4% were worth \$50, and 1% were worth \$100. Anglers were not informed about the percentage of each reward value or the actual reward value of a tag before they returned the tag. When more than 500 fingerlings were stocked, we tagged 500 of them with the standard tag for each lake; otherwise we tagged all of the stocked fish (Table 1). In 2001, in addition to fish with standard tags, 100 fish for each of three lakes were tagged with orange tags bearing a printed value of \$50 (Table 1). These high-reward tags were used to determine the degree of anglers' nonreporting of the standard tags (see below). Tagged fish were usually held in the raceway or catch basin overnight and stocked the next day.

The presence of reward-tagged fish in a lake was publicized by means of local press releases, interviews, posters at local bait shops, and signs posted at each lake. These outlets informed anglers about the study, where they should send tags, and what information they needed to provide along with the tag. Anglers were asked to state the date on which they caught the tagged fish, the length of the fish, and whether they kept or released the fish. Staff at local MDC offices, fisheries management biologists, and conservation officers were also aware of the study and provided valuable assistance to anglers inquiring about it. Rewards were not given until the angler provided the tag and the necessary information. Follow-up phone calls or letters were effective in acquiring the pertinent information in nearly all cases. Once the tag and pertinent information were received, anglers were sent a letter informing them of the reward value, the TL of the fish at tagging, and when they should expect to receive their reward.

Tagging mortality and tag loss.—Mortalities of recently tagged fish were noted in raceways or catch basins before the fish were used in stocking. Additionally, 100 fish were tagged with nonreward tags in October 2003 and stocked into a hatchery-rearing pond to determine tag loss. Because of space limitations, the remaining fish were subsequently moved to another rearing pond the following April, where they were kept until August with other fish, including a few large blue catfish and flathead catfish. In August, the remaining fish were transported to a research pond where they were kept for the remainder of that year and two additional years. The pond was drained in spring and fall of each year to assess tag loss.

Tag reporting rate.—A major source of error in estimating exploitation is the uncertainty about the reporting rate of tags by anglers (Miranda et al. 2002). To estimate the reporting rate, we compared the tag return rate of the standard \$10–100 with the \$50 (high-reward) tags. Although 5% of standard tag rewards equaled or exceeded \$50, we assumed that anglers would soon realize that most standard tag rewards were \$10. Thus, we considered that the \$50 tag was a high-reward tag relative to the standard tag. In using high-reward tags to estimate reporting of standard tags, we assumed that they are reported 100% of the time (Pollock et al. 2001). However, a reward value greater than \$50 is probably necessary to ensure 100% reporting. Nichols et al. (1991) found that a reward value of at least \$100 in 1988 was necessary for 100% reporting of duck bands. Using methods described by Henry (2003) and Crawford and Allen (2006), the reporting rate of the \$50 tags was estimated from the logistic regression presented by Nichols et al. (1991) after correcting for the difference in 1988 and 2001 dollar values. The 1988 monetary equivalent used in the equation was \$33.40 (Henry 2003). To determine whether the reporting rate of the two types of tags was different, first-year (including the year of tagging) reporting rates for each lake were compared with chi-square tests, assuming a significance level of 0.05 for these and all other tests.

Estimating exploitation.—For each lake, we calculated exploitation (u) from the tag returns for years 0 (the year of tagging), 1, 2, and 3 using maximum likelihood. The likelihood for this estimate was proportional to the product of annual cell probabilities taken to the power of the number of tags returned (Brownie et al. 1985)

$$L \propto \prod_{i=0}^{3} P(i)^{n_i},$$

where n_i is the number of tag returns in year i and the annual cell probabilities are as follows: $P(0) = r_0 u_0 \lambda$, $P(1) = r_1 S_0 u_1 \lambda$, $P(2) = r_2 S_0 S_1 u_2 \lambda$, and $P(3) = r_3 S_0 S_1 S_2 u_3 \lambda$. That is, the cell probability for each year was the product of the probabilities that a fish would retain its tag (r), survive the previous year(s) (S), be harvested (u), and have its tag reported (λ); S_i was calculated as $\exp(F_i - M)$, where F_i and M are the instantaneous rates of exploitation and natural mortality, respectively, and $F_i = -\log_e(1 - u_i)$ for year $i = 0$, 1, 2, 3. We conditioned the likelihood on the values $r_0 = r_1 = 1$, $r_2 = 0.9$, $r_3 = 0.7667$, $M = 0.1$ or 0.2, and $\lambda = 0.72$ (see Results for the estimation of r_i and λ). For year 0, the estimates of exploitation covered a period of only about 3 months; annual estimates were made for years 1, 2, and 3. Few estimates of M have been reported for channel catfish, but Gerhardt and Hubert (1991) estimated annual natural mortality to be about

21% and estimates of total annual mortality as low as 13% have been reported (review by Hubert 1999); thus, we believe that our assumed values of M are reasonable. This likelihood model was saturated (only four parameters can be estimated) but allowed the calculation of exploitation rates. We also calculated cumulative exploitation as

$$1 - \prod_{i=0}^{j}(1 - u_i)$$

for year $j = 0, 1, 2, 3$. This enabled us to examine the cumulative exploitation over the entire study period. Fish that were caught, had their tags removed, and then released by anglers were not included in the calculations of annual (less for year 0) or cumulative exploitation. Rather, the sum of all released fish throughout the study period was subtracted from the total number of tagged fish stocked into each lake.

Effects of stocking rate.—To determine whether stocking rate influenced the exploitation of channel catfish, we compared cumulative exploitation rates for year 1 and year 3 (assuming $M = 0.2$), using Kruskal–Wallis tests. This nonparametric test was used because the sample sizes were small and the data were not normally distributed.

Effects of fish size.—As the size of a tagged fish increases, its vulnerability to anglers and the probability of harvest when it is caught also increase (Storck and Newman 1988; Santucci et al. 1994; van Poorten and Post 2005; Crawford and Allen 2006). Not only did the size of the tagged channel catfish vary widely within a lake, it also varied considerably among lakes (Table 1). In particular, the tagged fish stocked into Ben Branch Lake averaged nearly 100 mm longer than those stocked into Prairie Lee Lake (Table 1). These differences in sizes of tagged fish could affect the rate of exploitation.

To account for the differences in the sizes of tagged fish, we developed adjustment factors for size-related vulnerability to capture by anglers and the probability of harvest if the fish was captured. Tag returns in years 0 and 1 were used to develop these adjustment factors, for which we assumed that no growth occurred between the time of stocking and capture. This may be a reasonable assumption because 68.7% of these tag returns were taken from fish captured before July, before most growth occurs (Michaletz, unpublished data). Also, the lengths of the captured tagged fish reported by anglers did not differ significantly from the lengths of these fish at tagging (Figure 1), suggesting that overall little growth occurred. To simplify the analysis, we combined the data from all lakes to develop the adjustment factors. Although there may be some differences among lakes, the overall pattern of increasing vulnerability to capture and harvest with increasing fish size should occur in all lakes.

To determine the relationship between capture probability and fish size, all fish and those caught during the first year were grouped into 25-mm TL classes based on their length at tagging. The smallest and largest size-classes contained a few smaller or larger fish because of the low sample sizes in those classes. The proportion of fish caught in each size-class was determined and used to fit a nonlinear regression (procedure NLIN; SAS Institute 2005), according to the formula presented by van Poorten and Post (2005):

$$\Pr(C; \mathrm{TL}) = \{1 - \exp[-\beta(\mathrm{TL})]\}^{\gamma},$$

where Pr(C; TL) is the probability of capture by anglers, TL is the total length of tagged channel catfish, and β and γ are fitted parameters. To determine the probability that a fish would be harvested after it was caught, Pr($H \mid C$; TL), we fit the following logistic regression equation (procedure LOGISTIC; SAS Institute 2005):

$$\Pr(H|C; \mathrm{TL}) = \frac{\exp[\beta_0 + \beta_1(\mathrm{TL})]}{1 + \exp[\beta_0 + \beta_1(\mathrm{TL})]},$$

where β_0 is the regression intercept and β_1 the regression coefficient. Individual fish were used to determine the relationship by coding fish that were released as 0 and those harvested as 1. The probability of harvest is

$$\Pr(H|\mathrm{TL}) = \Pr(H|C; \mathrm{TL}) \cdot \Pr(C; \mathrm{TL}),$$

which combines the probabilities of capture and harvest after capture. A curve of adjustment factors based on the size at tagging was then created by using the probability of harvest for the largest size-class (425 mm) as the standard by which the adjustments for smaller size-classes were determined, that is,

$$\text{adjustment} = \Pr(H; 425\,\text{mm})/\Pr(H; \mathrm{TL}).$$

For the largest size-class the adjustment factor was 1.

This adjustment factor was applied to each tagged fish and then a mean total adjustment factor was determined for each lake. Because we were primarily interested in comparing the lakes, each lake's mean adjustment factor was divided by the lowest of the lake mean adjustment factors (Ben Branch Lake) to standardize mean adjustment factors across lakes. For Ben Branch Lake, this standardized mean adjustment factor was equal to 1. The adjustment factor was then multiplied by the cumulative exploitation rate at year 1 to determine an adjusted exploitation rate that accounted for differences in size at tagging.

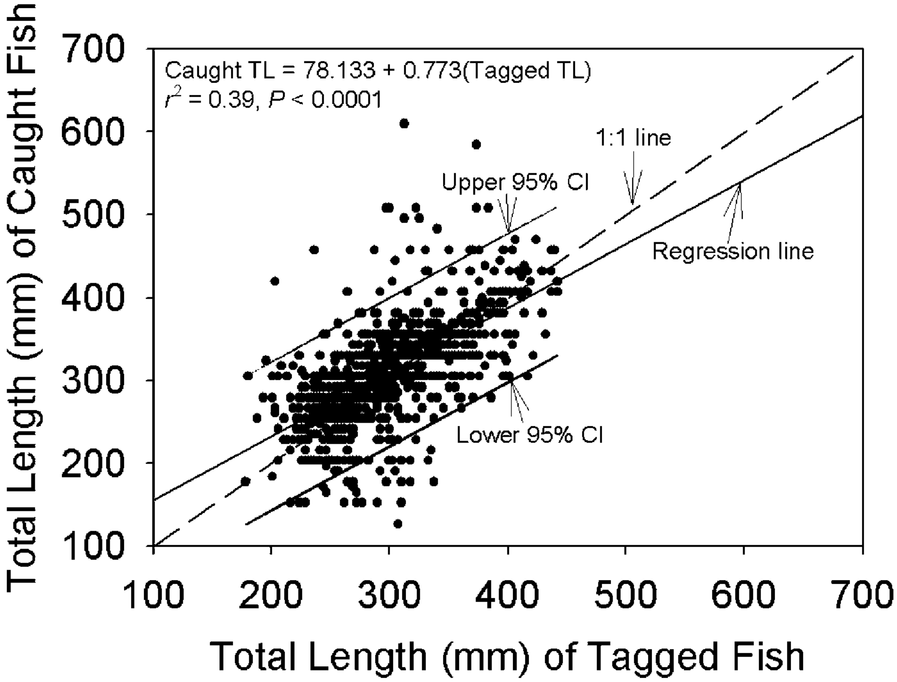

FIGURE 1.—Linear regression relating the total length (TL) of tagged channel catfish at the time of capture (as measured by anglers) to that of the fish when tagged, based on year-0 and year-1 captures. Also shown are the individual data points and the upper and lower bounds of the 95% confidence interval (CI). The 1:1 line indicates equality between length at tagging and length at capture.

Effects of catch inequality.—A small portion of anglers can account for the largest portion of the catch (Baccante 1995; van Poorten and Post 2005). Likewise, the distribution of tag returns among anglers can be highly skewed. To compare this inequality in tag returns among anglers, we plotted Lorenz curves and computed Gini coefficients (Smith 1990; Baccante 1995; van Poorten and Post 2005) for each lake based on the total tag returns over years 0 through 3. We included all tag returns (not just those from harvested fish) because all of the tagged fish could have been harvested. Lorenz curves were developed by plotting the cumulative percentage of tag returns over the cumulative percentage of anglers who returned tags. Perfect equality of tag returns among anglers would result in a 1:1 relationship; inequality would result in a departure from the 1:1 relationship. The Gini coefficient (G) was calculated to measure the degree of this departure according to the formula (Baccante 1995; van Poorten and Post 2005)

$$G = (a_1 - a_2)/a_1,$$

where a_1 is the area under the 1:1 relationship and a_2 is the area under the Lorenz curve. Gini coefficients range from 0 (perfect equality) to 1 (complete inequality). The Lorenz curves were plotted and areas determined by using SigmaPlot software (SPSS 2001).

To measure the effect of individual anglers on the tag return rate, we computed the cumulative percentage tag returns of the top three anglers (those that returned the most tags) for the years 0 through 3 at each lake. These data provide a relative measure of the importance of these anglers in estimating exploitation.

TABLE 2.—Results of the tag retention study, indicating the numbers of tagged and untagged channel catfish recovered from ponds on various dates. The fish were tagged on October 14, 2003.

Date	Number tagged	Number untagged
Oct 14, 2003	100	0
Apr 15, 2004	93	0
Aug 10, 2004	35	0
Sep 30, 2004	30	0
Apr 20, 2005	29	1
Oct 20, 2005	27	3
Apr 18, 2006	26	4
Sep 21, 2006	23	7

TABLE 3.—Exploitation rates of channel catfish for years 0 (the year of tagging) through 3 in the study lakes with instantaneous natural mortality rates (M) of 0.1 and 0.2. The estimates for year 0 cover approximately a 3-month period; those for the other years cover the entire year. The tag reporting rate was assumed to be 0.72. The tag retention rates were 1 for years 0 and 1, 0.9 for year 2, and 0.7667 for year 3.

	Year with $M = 0.1$				Year with $M = 0.2$			
Lake	0	1	2	3	0	1	2	3
Belcher Branch	0.003	0.068	0.013	0	0.003	0.075	0.016	0
Ben Branch	0.032	0.192	0.073	0.157	0.032	0.212	0.092	0.222
Brookfield City	0.041	0.173	0.135	0.019	0.041	0.191	0.169	0.028
Council Bluff	0	0.135	0.023	0.007	0	0.149	0.028	0.010
Green City	0.005	0.231	0.049	0.013	0.005	0.255	0.061	0.019
Lawson City	0	0.013	0.005	0.042	0	0.014	0.007	0.057
Limpp Community	0.037	0.096	0.026	0.021	0.037	0.106	0.032	0.029
Manito	0.037	0.038	0.018	0.008	0.037	0.041	0.022	0.011
Miller	0.020	0.237	0.198	0.057	0.020	0.262	0.250	0.086
Pony Express	0	0.043	0.042	0.023	0	0.048	0.052	0.032
Prairie Lee	0	0	0	0	0	0	0	0
Ripley	0	0.052	0	0	0	0.058	0	0
Savannah City	0	0.042	0.018	0.012	0	0.046	0.022	0.016
Sims Valley	0	0.587	0.089	0	0	0.649	0.128	0

Results

Tagging Mortality and Tag Loss

No mortalities attributable to the tagging operations were observed in the raceways and catch basins. Seven percent (7 of 100) of the tagged fish held to evaluate tag retention died over the winter (Table 2), but none died within the first day after tagging. Almost two-thirds of the remaining tag-retention fish died during the period when they were kept with other fish. These mortalities probably were not tag-induced but rather resulted from predation by large blue catfish and flathead catfish present in this pond. Once the surviving fish were transferred to a pond without large predators (sunfish *Lepomis* spp. were present), mortality was low. Because there was no evidence of tag-induced mortality, we assumed that it was zero.

Tag retention decreased over the study period. All surviving fish retained their tags throughout the first year after tagging (Table 2). During the second year, 3 of the 30 remaining fish lost their tags; another 4 fish lost their tags during the third year. Thus estimates of tag retention (r_i) were 1 for years 0 and 1, 0.9 for year 2, and 0.7667 for year 3.

Tag Reporting Rate

Based on the equation by Nichols et al. (1991), the reporting rate for a \$50 tag (when corrected for inflation) in 2001 would be 0.72. Return rates for years 0 and 1 combined were significantly higher for \$10–100 tags than for \$50 tags for Brookfield City Lake (0.25 versus 0.15; $\chi^2 = 4.66$, $P = 0.03$) and for Council Bluff Lake (0.28 versus 0.17; $\chi^2 = 5.22$, $P = 0.02$) but were nearly identical for Pony Express Lake (0.088 versus 0.09; $\chi^2 = 0.004$, $P = 0.95$). Because reporting rates were not lower for the standard tag than for the \$50 tag, we assumed the rate of tag reporting (λ) to be 0.72.

Exploitation

Estimates of annual exploitation varied more than 10-fold among the study lakes. Some exploitation occurred the year of stocking (year 0) in seven lakes, but usually the highest exploitation occurred the year after stocking (Table 3). Estimates of exploitation in year 1 (the year after stocking) ranged from 0 in Prairie Lee Lake to 0.65 in Sims Valley Lake, assuming $M = 0.2$. After year 0, nonzero exploitation estimates were slightly lower when M was assumed to equal 0.1. For brevity, we will discuss only the results for the $M = 0.2$ scenario. After year 1, estimates of exploitation usually declined, the rates ranging from 0 to 0.25 in year 2 and from 0 to 0.22 in year 3.

Cumulative exploitation rates revealed substantial differences in the use of stocked channel catfish in the study lakes. Over the entire 3-year period, the cumulative exploitation rates ranged from 0 to 0.69 (Table 4). There was no documented harvest of channel catfish in Prairie Lee Lake during the study period, but the exploitation of fish was high in Sims Valley, Miller, and Ben Branch lakes. For most lakes, cumulative exploitation was relatively low, having 3-year estimates less than 0.2.

Effects of Stocking Rate

Stocking rate appeared to have no effect on the exploitation of channel catfish. The cumulative first-year ($\chi^2 = 0.45$, $P = 0.80$) and third-year ($\chi^2 = 0.04$, $P = 0.98$) exploitation rates did not differ among channel

TABLE 4.—Cumulative exploitation rates of channel catfish for years 0–3 in the study lakes with instantaneous natural mortality rates (M) of 0.1 and 0.2. The numbers in parentheses are exploitation rates adjusted for differences in fish stocking size among the lakes (see text for details). See Table 3 for additional information.

	Year with $M = 0.1$				Year with $M = 0.2$			
Lake	0	1	2	3	0	1	2	3
Belcher Branch	0.003	0.070 (0.110)	0.083	0.083	0.003	0.077 (0.121)	0.093	0.093
Ben Branch	0.032	0.218 (0.218)	0.276	0.390	0.032	0.238 (0.238)	0.308	0.462
Brookfield City	0.041	0.207 (0.215)	0.314	0.327	0.041	0.225 (0.234)	0.355	0.373
Council Bluff	0	0.135 (0.302)	0.155	0.161	0	0.149 (0.333)	0.173	0.182
Green City	0.005	0.235 (0.436)	0.272	0.282	0.005	0.259 (0.480)	0.305	0.318
Lawson City	0	0.013 (0.024)	0.018	0.060	0	0.014 (0.026)	0.021	0.077
Limpp Community	0.037	0.129 (0.141)	0.152	0.170	0.037	0.139 (0.152)	0.167	0.191
Manito	0.037	0.073 (0.099)	0.090	0.097	0.037	0.077 (0.105)	0.097	0.107
Miller	0.020	0.252 (0.484)	0.401	0.435	0.020	0.277 (0.532)	0.458	0.504
Pony Express	0	0.043 (0.057)	0.084	0.105	0	0.048 (0.064)	0.097	0.126
Prairie Lee	0	0 (0)	0	0	0	0 (0)	0	0
Ripley	0	0.052 (0.161)	0.052	0.052	0	0.058 (0.179)	0.058	0.058
Savannah City	0	0.042 (0.077)	0.059	0.070	0	0.046 (0.084)	0.067	0.082
Sims Valley	0	0.587 (1.057)	0.624	0.624	0	0.649 (1.169)	0.694	0.694

catfish stocking rates. Exploitation was highly variable, especially within the low stocking rate, which included lakes with the lowest and highest estimates of exploitation (Figure 2).

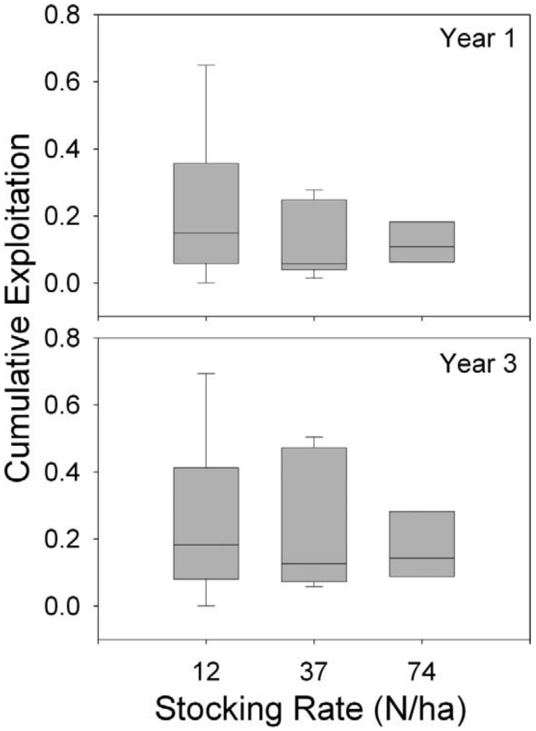

FIGURE 2.—Box plots of cumulative exploitation estimates for years 1 and 3 for the three channel catfish stocking rates. Each plot shows the median (horizontal line within the box), interquartile range (height of the box), and range (vertical lines extending from the box). The sample sizes were five for stocking rates of 12 and 37 fish/ha and four for 74 fish/ha.

Effects of Fish Size

The probabilities of capture and harvest by anglers increased with the size of the fish at tagging. The initial size distribution of all tagged fish differed significantly from the initial size distribution of those captured by anglers (Figure 3; Kolmogorov–Smirnov two-sample test, $D = 0.212$, $P < 0.0001$). The capture probabilities estimated from the nonlinear regression equation (Figure 4) ranged from 0.045 for the smallest size-class (175 mm TL) to 0.428 for the largest size-class (425 mm TL). The harvest probabilities estimated from the logistic regression equation (Figure 4) ranged from 0.121 for a 175-mm TL fish to 0.699 for a 425-mm TL fish. Thus, a 425-mm TL fish was about 55 times more likely to be harvested during the first year than a 175-mm TL fish.

The size-adjusted exploitation rates were useful for

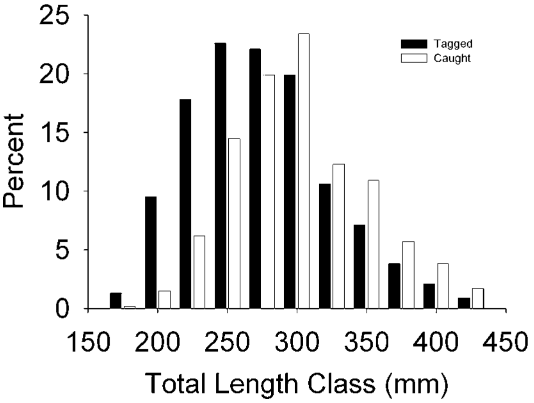

FIGURE 3.—Total length distributions at the time of tagging for all of the channel catfish in the study ($N = 5{,}918$) and those captured by anglers in the first year after release ($N = 1{,}073$).

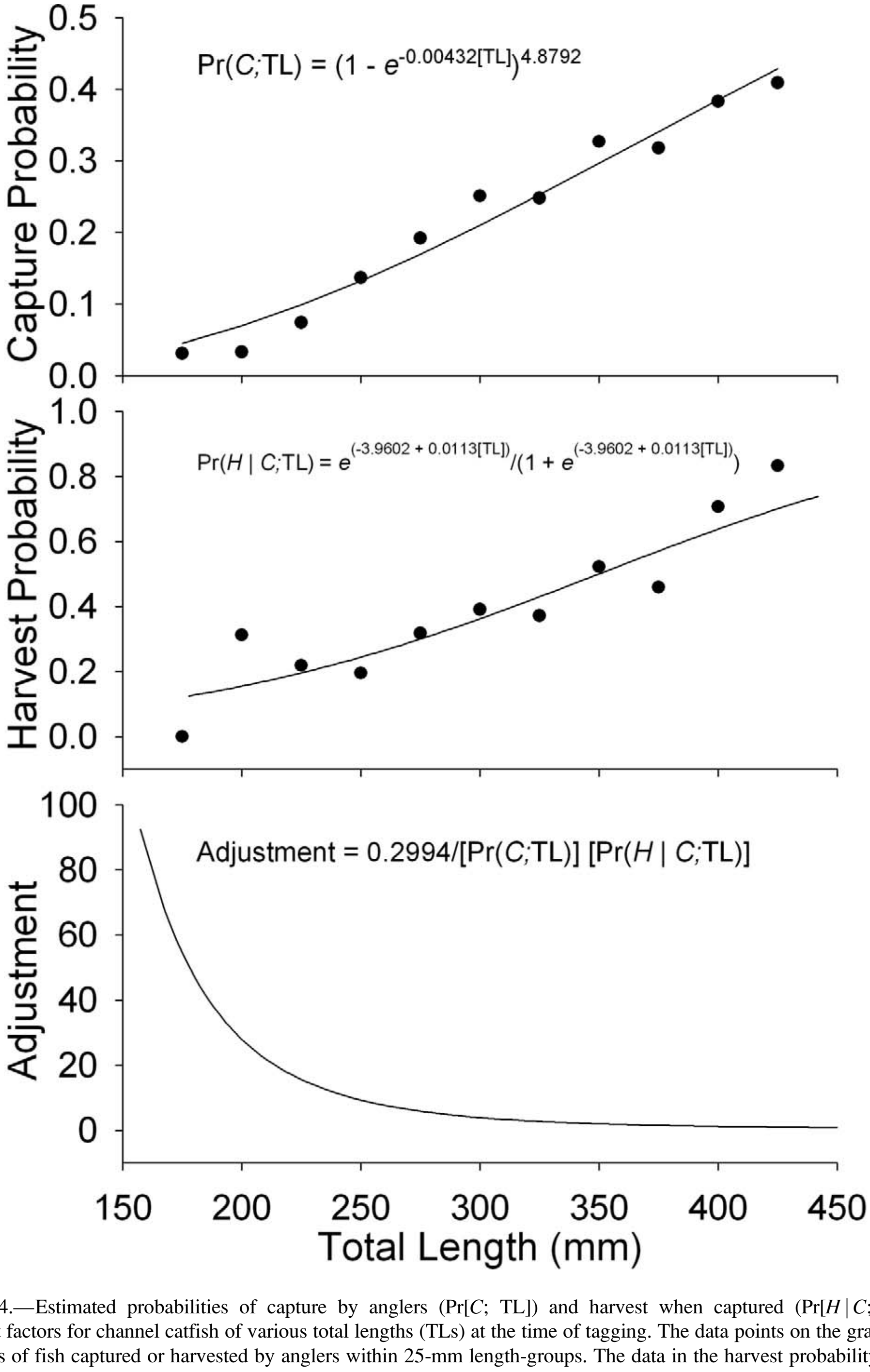

FIGURE 4.—Estimated probabilities of capture by anglers (Pr[*C*; TL]) and harvest when captured (Pr[*H* | *C*; TL]) and adjustment factors for channel catfish of various total lengths (TLs) at the time of tagging. The data points on the graphs are the proportions of fish captured or harvested by anglers within 25-mm length-groups. The data in the harvest probability graph are for comparison purposes only and were not used to estimate the logistic regression; instead, data for individual fish were used. The value 0.2994 in the adjustment equation is the probability of harvest for fish in the 425-mm size-class. See text for additional details.

TABLE 5.—Gini coefficients (G), cumulative percentages of tags returned by the top 1, 2, and 3 anglers (those that returned the most tags), and total number of anglers that returned tags (N). These data are based on all tag returns over years 0–3.

		Angler tag returns			
Lake	G	Top 1	Top 2	Top 3	N
Belcher Branch	0.36	21.9	27.4	32.9	44
Ben Branch	0.56	16.1	30.9	37.5	43
Brookfield City	0.42	8.3	14.7	18.6	99
Council Bluff	0.38	10.5	15.0	19.0	78
Green City	0.59	35.8	49.4	58.0	20
Lawson City	0.29	13.2	23.7	31.6	24
Limpp Community	0.45	13.2	24.0	31.8	55
Manito	0.15	8.7	13.1	17.4	38
Miller	0.44	8.5	16.2	21.8	62
Pony Express	0.13	4.2	8.5	11.3	54
Prairie Lee	0.00	33.3	66.7	100.0	3
Ripley	0.47	20.6	31.5	41.1	21
Savannah City	0.54	42.1	48.7	53.9	30
Sims Valley	0.47	10.9	19.4	26.4	38

comparing the relative differences in harvest if all lakes had received the same size distribution of tagged fish. Ben Branch Lake had the lowest mean adjustment value (4.95) and Prairie Lee Lake had the highest value (20.35). Once standardized to Ben Branch Lake, relative adjustment values ranged from 1 (Ben Branch Lake) to 4.11 (Prairie Lee Lake).

The estimates of exploitation adjusted for the differences in the sizes of tagged fish differed substantially from unadjusted estimates for some lakes (Table 4). Hypothetically, cumulative exploitation for year 1 could have been about two or more times higher in over one-half of the lakes if they had all received the same size fish as Ben Branch Lake did. The size-adjusted exploitation estimate for Sims Valley Lake exceeded 1, indicating that potentially all of the stocked fish could have been harvested within 1 year. However, for Prairie Lee Lake, the size-adjusted value was still 0 because no first-year harvest was reported.

Effects of Catch Inequality

For most lakes, the distribution of tag returns among anglers was highly skewed. Gini coefficients ranged from 0 to 0.59 but most exceeded 0.40 (Table 5). Excluding Prairie Lee Lake, which only had three tag returns, three individual anglers were responsible for one-third or more of the tag returns in four lakes, and one individual returned over one-third of all the tags in two lakes. It was increasingly likely that a few anglers would return a high proportion of the tags as the total number of anglers decreased (total number of anglers versus cumulative percent of top three anglers; Pearson's $r = -0.72$, $P = 0.004$). However, Gini coefficients were unrelated to the total number of anglers ($r = 0.18$, $P = 0.54$). Although these data included all tag returns (i.e., both harvested and released fish), they indicated that estimates of exploitation can be greatly affected by the tag returns from just a few individuals in these small lakes.

Discussion

Exploitation of stocked channel catfish varied widely among Missouri lakes. Our estimates of exploitation spanned the range of estimates reported by Shaner et al. (1996) and Hubert (1999), but most were lower than those reported in previous studies (Hanson 1986; Eder and McDannold 1987; Santucci et al. 1994; Shaner et al. 1996). Although channel catfish were highly exploited in a few lakes, fish were lightly exploited in most lakes, the cumulative exploitation over 3 years being less than 20%. Surprisingly, there was no reported harvest in Prairie Lee Lake, which is located in a suburb of Kansas City and for which we anticipated high exploitation. Also unexpectedly, exploitation was highest in Sims Valley and Miller lakes, which are located in the Ozark region of southern Missouri; usually, channel catfish are more popular in the northern part of the state (Michaletz and Stanovick 2006) in lakes such as Pony Express and Limpp Community lakes.

Exploitation of channel catfish in Missouri lakes appears to have declined over the past several decades. Hanson (1986) estimated that about 75–85% of stocked channel catfish would be harvested over their life span in several Missouri lakes, and Eder and McDannold (1987) reported a value of 64% for Pony Express Lake. Our cumulative 3-year estimates, although not including the entire life span, were considerably lower in most lakes. Also, Hanson (1986) reported an exploitation rate of 50% the year after stocking in Limpp Community Lake, which contrasts with our estimate of only about 10%. Eder and McDannold (1987) reported first-year exploitation rates of 9–11% in Pony Express Lake, about twice the rate that we estimated. Perhaps, angling effort directed toward channel catfish is lower now than it was in past decades.

The stocking size of channel catfish strongly influenced angler exploitation. The probability of capture and harvest of fish by anglers increased with fish size, similar to findings by Storck and Newman (1988) and Hanson and Czarnezki (1989). Santucci et al. (1994) found no difference in catch or harvest of channel catfish stocked at sizes of 200 mm and 250 mm over a 5-year period in an Illinois lake but noted that the catch of recently stocked fish was low, most being released when caught. In our study, stocking size varied considerably among lakes and even within lakes. Our stocking-size-adjusted exploitation rates suggest that exploitation of channel catfish could have been much higher in several of the study lakes if fish as large as those used for Ben Branch Lake had been stocked. Comparisons of exploitation estimates among lakes can be complicated by differences in the sizes of tagged fish used to make these estimates.

Channel catfish anglers are harvest oriented (Schramm et al. 1999; Wilde and Ditton 1999) and reportedly harvest most of the fish they catch (Eder and McDannold 1987; Michaletz and Stanovick 2006). Yet in our study, even a relatively large fish of 380 mm TL had only a 58% probability of being harvested after it was caught. In contrast, previous studies found that 74–98% of 330-mm TL and larger fish caught by anglers were harvested (Santucci et al. 1994; Eder et al. 1997). Apparently, the channel catfish anglers in our study were more selective about the fish they harvested than those in previous studies.

Fluctuations in the exploitation of channel catfish can occur within a small lake simply from small changes in angling clientele. As in other studies (Smith 1990; Baccante 1995; van Poorten and Post 2005), the distribution of catch that we computed was highly skewed among anglers. We found that one to three anglers were responsible for about one-third or more of the tag returns in over one-half of the lakes. We may even have underestimated the importance of these anglers because in several cases other family members also returned tags. If these successful anglers had not fished, their families would probably have not fished as well. The relative influence of these few successful anglers declined with increases in the total number of anglers returning tags. Thus, for lakes with few anglers wide fluctuations in exploitation are likely.

We found no effect of stocking rate on the exploitation of channel catfish, perhaps because harvest is not closely associated with the stocking rate in Missouri lakes (Michaletz and Stanovick 2006). In our study, the lowest and highest estimates of exploitation were found in lakes stocked at the lowest rate. Shaner et al. (1996) found that Alabama lakes with low channel catfish harvest tended to have higher stocking rates, which led to density-dependent reductions in fish growth, thereby reducing the vulnerability of the fish to angler harvest. Similar reductions in the growth and size structure of channel catfish in lakes with high stocking rates have occurred in Missouri (Eder et al. 1997) and Iowa (Mitzner 1999). However, stocking rates in Missouri have declined over the past few decades (Eder et al. 1997), and the highest stocking rate we used in this study was much lower than the stocking rates (some >250 fish/ha) used in the study by Shaner et al. (1996). Our inability to detect an effect of stocking rate may be due to our relatively narrow range in stocking rate. However, because of the wide variation in exploitation among lakes stocked at the same rate, a much larger sample size than used in this study will be needed to determine the effects of stocking rate.

Management Implications

Our study revealed that the exploitation of channel catfish varied widely among Missouri lakes. Therefore, lakes will have to be managed on an individual basis. Heavily exploited lakes will require the most attention from fisheries managers. It may be necessary to increase stocking rates to provide enough fish to support those fisheries. For example, population sampling of the two most heavily exploited lakes, Sims Valley and Miller lakes, produced very few fish (MDC, unpublished data), indicating that channel catfish abundance was very low. Heavily exploited lakes are also potential candidates for increased harvest restrictions such as minimum length limits. Minimum length limits could be successful at improving the size structure of channel catfish if growth rates are satisfactory and hooking mortality is low (Santucci et al. 1994). The hooking mortality of channel catfish is reportedly less than 10% (Hanson and Czarnezki 1989; Santucci et al. 1994). For lightly exploited lakes, managers may need to reduce stocking rates to maintain good growth and size structure among channel catfish populations. In lakes where channel catfish are rarely harvested, it may be appropriate to eliminate stockings entirely.

Although stocking size affected exploitation, it is probably not feasible to increase the size of fish stocked into lakes with put–grow–take fisheries. Raising fish to sizes larger than those typically stocked in Missouri is probably not cost-effective (Santucci et al. 1994; Shaner et al. 1996) and would probably require rearing them for an additional growing season.

However, managers should be aware that stocking size does influence exploitation and should consider these effects when comparing exploitation estimates among lakes.

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