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CATFISH GEAR SELECTIVITY EVALUATION

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Objectives:

1) Estimate size-selectivity of tandem hoop-net series for collecting channel catfish from river and reservoir portions of a watershed.

2) Estimate size-selectivity of low-frequency DC electrofishing for collecting blue catfish and flathead catfish from river and reservoir portions of a watershed.

3) Estimate size-selectivity of standard TPWD experimental gill nets for collecting channel catfish and blue catfish from reservoir habitat.

The attached draft manuscript "Size bias of catfish sampling gears" by David L. Buckmeier and J. Warren Schlechte resulted from this project and is submitted in fulfillment of the Federal Aid final report requirement. This manuscript addresses all segment objectives of the project.

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Size Bias of Catfish Sampling Gears

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Abstract.-- Although many gears have been used to collect catfishes, few have been evaluated for size bias. We used mark-recapture to directly estimate size bias of tandem hoop-net series for collecting channel catfish *Ictalurus punctatus* and low-frequency DC electrofishing for collecting blue catfish *I. furcatus* and flathead catfish *Pylodictis olivaris.* To examine spatial and temporal variability, size bias was estimated for river and reservoir habitat in June, July, and September 2005 (N = 6). We also estimated size bias of standard Texas Parks and Wildlife Department (TPWD) experimental gill nets for collecting channel and blue catfish from reservoir habitat by comparing size distributions to those of tandem hoop-net series and low-frequency DC electrofishing. Tandem-hoop net series collected channel catfish ≥ 250 mm total length in proportion to their abundance. Likewise, blue catfish ≥ 250 mm were fully recruited to low-frequency DC electrofishing. Flathead catfish ≥ 150 mm appeared to be fully recruited to low-frequency DC electrofishing, although sample sizes of fish ≥ 500 mm were too small to examine bias. Size when fish became fully recruited was not affected by habitat (i.e., river and reservoir) or month sampled for any gear or species. Recapture rates indicated that overall capture probability was greater for blue catfish in river habitats, and higher in July and September for low-frequency DC electrofishing. Standard TPWD experimental gill nets collected channel catfish ≥ 200 mm and blue catfish between 200 and 350 mm in proportion to their abundance, however, catch rates were lower for gill nets than for the other gears tested. The combination of tandem hoop-net series and low-frequency DC electrofishing should provide accurate size structure data for adult catfish populations from river and reservoir habitat.

Introduction

Popular sport fisheries for channel catfish *Ictalurus punctatus*, blue catfish *I. furcatus*, and flathead catfish *Pylodictis olivaris* exist in rivers and reservoirs throughout Texas. In recent surveys of Texas anglers (Anderson and Ditton 2004; Tseng et al. 2006), catfishes ranked second only to black bass *Micropterus* spp. in angler preference. According to the 2001 National Survey of Fishing, Hunting and Wildlife-Associated Recreation, 53% of all freshwater anglers in Texas fished for catfishes, whereas nationally only about 27% of anglers pursued catfishes (U.S. Department of the Interior and U.S. Department of Commerce 2001).

In recent years, Texas anglers and fisheries managers of the Texas Parks and Wildlife Department (TPWD) have become more interested in managing catfishes for specific objectives (e.g., trophy size). However, little is known about catfish populations in Texas as well as across much of their range. In a 2006 survey by the Catfish Management Technical Committee of the Southern Division of the American Fisheries Society, 61% of the biologists surveyed indicated a need for information regarding sampling gear efficiency and gear bias (Brown 2007). An additional 26% required basic population data (e.g., recruitment, mortality, and size structure; Brown 2007). These needs reflect the lack of information available regarding catfish sampling gear efficiency and bias; even though numerous methods have been used to collect catfishes (see reviews by Vokoun et al. 1997 and Vokoun and Rabeni 1999). To our knowledge, only two attempts to directly estimate size bias associated with catfish sampling gears have been published (i.e., Santucci et al. 1999 and Michaletz and Sullivan 2002). Both occurred in small impoundments and evaluated selectivity for channel catfish only.

Several commonly used sampling gears may effectively and efficiently collect catfishes with limited bias. Tandem hoop-net series (described by Sullivan and Gale 1999 and Michaletz and Sullivan 2002) and low-frequency DC electrofishing (described by Gilliland 1987; Justus 1994; and Cunningham 1995) can collect large numbers of catfishes. Both gears collect a wide size range of fish and are relatively species selective (Gilliland 1987; Michaletz and Sullivan 2002). Tandem hoop-net series tend to select for channel catfish while low-frequency DC electrofishing captures mostly blue and flathead catfish. Direct estimation of size bias for these gears has been limited. Michaletz and Sullivan (2002) found that tandem hoop-net series captured channel catfish between 250 mm and 529 mm in proportion to their abundance in a small Missouri impoundment during May, but bias for other times of the year and in different macrohabitats (i.e., rivers and large reservoirs) is unknown. Size bias of low-frequency DC electrofishing for catfishes has not been evaluated.

Experimental gill nets used by the TPWD may also provide representative samples, although catch tends to be low and substantial effort is needed to estimate population characteristics (Dumont and Schlechte 2004). Santucci et al. (1999) indicated that experimental gill nets (differing slightly from those used by TPWD) sampled fish in proportion to their actual abundance in a small Illinois impoundment; however, low sample size limited statistical power.

Capture probability (i.e., the likelihood that an individual will be captured) can vary with sampling gear, species, size, time, and habitat. For a given sampling gear and species, variation in capture probability among fish of different size (i.e., size bias) most often creates problems in fisheries assessments (e.g., Ricker 1969; Ricker 1975; Beamesderfer and Rieman 1988; Bayley and Austen 2002), although temporal and spatial effects on vulnerability must also be considered. Without knowledge of such biases, fisheries biologists cannot be confident in estimates of population parameters. The objectives of this study were to: 1) estimate size bias of tandem hoop-net series for collecting channel catfish, 2) estimate size bias of low-frequency DC electrofishing for collecting blue and flathead catfish, 3) estimate spatial (i.e., river and reservoir habitat) and temporal (i.e., June – September) variability in size bias for tandem hoop-net series and low-frequency DC electrofishing, and 4) estimate size bias of standard TPWD experimental gill nets for collecting channel and blue catfish from reservoir habitat.

Methods

Study Area

Lake Livingston is located in East Texas about 11 km west of the city of Livingston (Figure 1). The reservoir is approximately 33,590 surface ha and impounds about 39,000 km^2 of the Trinity River watershed. Combined with the Trinity River, Lake Livingston supplies water to nearly half of all Texans (about 10 million people; Trinity River Authority 2003). Lake Livingston and the Trinity River above the reservoir were selected to assess gear-specific size bias for collecting catfishes because both the reservoir and river have abundant populations of channel, blue, and flathead catfish (TPWD, unpublished data). River and reservoir habitat within the system is typical of East Texas.

Two river study sites (Upper River and Lower River) were selected in the Trinity River upstream of Riverside, Texas and two reservoir sites (Highway 190 and Kickapoo Creek) were selected in the upper portion of Lake Livingston (Figure 1). Both river sites contained shallow (< 1 m) backwater areas; however, only main channel habitats were sampled because backwater areas were frequently separated from the main channel and dissolved oxygen levels were low (< 3 mg/L). Preliminary sampling in backwater areas resulted in few catfish. The main channel at both river sites was about 100 m wide and sites were about 3 km long. Reservoir sites covered 60-70 surface ha and extended from the shoreline to just beyond the nearest river or creek channel. Depths at both reservoir and river sites ranged from 0 to 14 m and sites included preferred habitats for each of the catfish species (e.g., shallow flats for channel catfish, channel and near-channel areas for blue catfish, and large woody cover for flathead catfish; see reviews by Graham 1999, Hubert 1999, and Jackson 1999).

General Approach

We created known populations of channel, blue, and flathead catfish and recaptured fish to assess size bias (Hamley and Regier 1973; Ricker 1975; Beamesderfer and Rieman 1988) for tandem hoop-net series and low-frequency DC electrofishing. Recapture rates were used to estimate size bias and test associated assumptions. Equality of recapture rates across 50-mm size groups (total length) would suggest no size bias. Size bias of standard TPWD experimental gill nets was assessed by comparing gill net length distributions to distributions from tandem hoop-net series and low-frequency DC electrofishing.

Temporal and spatial variation in size bias was assessed by estimating bias six times from June to September 2005 at the selected sample sites. Lower River and Highway 190 sites were sampled in June and September 2005 and Upper River and Kickapoo Creek sites were sampled in July 2005. Summer months were selected because catch rates for low-frequency DC electrofishing and tandem hoop-net series are high (Cunningham 1998; Michaletz and Sullivan 2002).

Sampling Design

Known populations of marked channel, blue and flathead catfish were created for each site and month by intensively sampling for one week using several types of hoop nets, electrofishing, and setlines. Multiple gears were used to maximize the size range available for recapture. Catfish were measured and fish ≥ 150 mm were marked by punching holes into fins with a paper punch (Wydoski and Emery 1983); different combinations of hole punches distinguished sampling gear and month of sampling. Fish were released at their respective capture sites in an attempt to minimize post-tagging movements (Wendel and Kelsch 1999). Marking continued for a second week when needed to increase the numbers of marked fish. During this second week, only low-frequency DC electrofishing and tandem hoop-net series were used. Fish marked during the second week received a different mark to distinguish them from fish marked the previous week.

On maps of the sampling sites, we overlaid a geo-referenced grid with 100 m by 100 m cells, resulting in 70 – 73 sampling cells for reservoir sites and 56 – 59 cells for river sites. Sampling cells were utilized to select individual subsamples for all gears except for electrofishing at river sites. At river sites, electrofishing subsamples consisted of 15-minute transects (described below).

Over each two week period, sites were sampled multiple times with tandem hoop-net series and low-frequency DC electrofishing to examine precision of each size bias estimate. Each of these replicate samples was termed a circuit and was composed of subsamples from a number of cells or transects that represented the entire site. The number of cells or transects subsampled per circuit varied depending on catch rates, weather, and staff availability. Each circuit was conducted over a few days (1-2 d for electrofishing; 3 d for hoop nets), and cells were selected randomly (for hoop nets and setlines) or with a random starting point and then systematically (e.g., every third sample location; for reservoir electrofishing). Typically, 6 – 12 cells were sampled each circuit for tandem hoop-net series, 10 – 37 cells were sampled for reservoir low-frequency DC electrofishing, and 8 – 15 transects were sampled for river low-frequency DC electrofishing.

Fish that were recaptured with tandem hoop-net series and low-frequency DC electrofishing were recorded. Recaptured fish were measured and fish ≥ 200 mm were tagged with individually coded Floy T-bar anchor tags below the dorsal fin (similar to Buckmeier and Irwin 2000), then released. At reservoir sites, a third week of sampling was included in which standard TPWD experimental gill nets were set to collect channel and blue catfish.

Tandem hoop-net series (Table 1) were set throughout the littoral zone of each site. Areas that were anoxic or less than 2 m deep were not sampled (to avoid turtle mortality; Michaletz and Sullivan 2002). For each circuit, a subsample of cells was chosen randomly from the reference sampling grid. Two or three circuits were conducted per site (18 – 30 net series total) and effort differed by circuit because of sampling logistics. Approximately 12 series were set in circuit 1, 6 series in circuit 2, and 12 series in circuit 3. Nets were set parallel to the shore or near submerged structure and were left undisturbed for 3 d before retrieval (Michaletz and Sullivan 2002).

Low-frequency DC electrofishing (Table 1) at river sites was conducted by meandering downstream, at ambient stream velocity, between channel and bank habitats (similar to Quinn 1986). Electrofishing started at the upstream end of the site and proceeded downstream to the sites lower boundary. Every 15 minutes, fish were processed and released within the portion of the river they were collected. Between 3 and 5 circuits (40 – 102 transects total) were conducted at each river site. The number of transects needed to complete the entire 3-km site depended on flow and recapture rates.

Low-frequency DC electrofishing at reservoir sites was conducted within selected sampling cells. Electrofishing (5 minutes continuous) was relatively stationary, starting in the center of the cell and moving around within its boundaries until fish were stunned (similar to stationary methods reported by Gilliland 1987 and Cunningham 1995). Prior to beginning a circuit, the number of cells to be sampled was determined (e.g., every third cell) along with a random starting point. Between 5 and 11 circuits (241 – 244 cells total) were conducted at each reservoir site.

Sixteen to thirty standard TPWD experimental gill nets (Table 1) were set throughout each reservoir site in randomly selected cells stratified by depth. At each site, about half of the nets were set on the bottom in shallow flats to target channel catfish and half were suspended in deeper channel areas to target blue catfish. Anoxic regions were avoided. Nets were set perpendicular to the shore or channel. Nets were set during daylight hours, fished overnight, and retrieved the following day (18 – 24h).

Water quality was monitored weekly in the middle of each site during each sample. Water temperature (ºC) and dissolved oxygen (mg/L) were recorded for 1-m intervals from the surface to the bottom. Conductivity (µS/cm) was measured at the surface. Water clarity was measured using a Secchi disk.

Data Analyses

For each site and month sampled, we estimated size bias of tandem hoop-net series for channel catfish and low-frequency DC electrofishing for blue and flathead catfish. To standardize effort among circuits, catch was expressed as number of fish per 12 tandem hoop-net series or per 120 minutes of low-frequency DC electrofishing. Recapture rate was calculated for each size group by dividing the number of recaptured fish in a given circuit (adjusted for effort) by the cumulative number of marked fish from the previous circuits. We used Proc GENMOD (SAS 2003) to model recapture rates and test for equality according to the following:

$$\log_e\left(\frac{r_{ij}}{1-r_{ij}}\right) = \alpha + \beta_1 circuit_i + \beta_2 size\_group_j + \beta_{3,ij}(circuit * size\_group)_{ij} + \varepsilon_{ijk}$$

where the r_{ij} were the recapture rates for $circuit_i$ and size $group_j$ and the $\beta_n's$ were the estimated parameters of the model. We assumed a binomial distribution and used the scaled deviance to allow for over dispersion in the variance (SAS 2003). In the full model, the relation across size groups was allowed to vary by circuit. This model had main effects associated with circuit and size group, and an interaction term. Significant interaction would imply differing size bias by circuit. Non-significant interaction suggests recapture rates can be modeled solely as main effects of circuit and size group. The main effect of circuit represents the temporal component of sampling (e.g., the "day" effect). Main effects associated with size group allow the identification of size bias; similar recapture rates among size groups indicate full recruitment to the gear. Models were parameterized to compare recapture rates of size groups to the 250-mm size group because it was considered to be fully recruited after preliminary examination of the data. Tests for significant parameters were conducted using the Wald chi-square statistic ($P \leq 0.05$; SAS 2003).

Size distributions (50-mm size groups) from gill nets were compared to size distributions of fish captured with low-frequency DC electrofishing (for blue catfish) and tandem hoop-net series (for channel catfish) using Kolmogorov-Smirnov two-sample tests (Proc NPAR1WAY; SAS 2003); recapture rates of experimental gill nets were insufficient to directly estimate size bias. Size distributions for low-frequency DC electrofishing and tandem hoop-net series were limited to fish that were captured in the week prior to gill netting to increase the likelihood that population size structure was similar . Size groups that differed were identified by examining individual cell chi-square values for each size group (Proc FREQ; SAS 2003).

Assumptions

Our design required several assumptions that could affect estimates of size bias. We assumed that 1) fish marked in the previous circuit would randomly distribute themselves in the population and behave similarly to fish that had not been captured; 2) mortality of marked fish was similar across gears and size groups; and 3) emigration was not size-dependent. Each of these assumptions was evaluated to determine likelihood of effect on estimates of size bias.

Overall (all size groups pooled) recapture rates were compared across circuits (i.e., over time; Proc GENMOD; SAS 2003) to evaluate the assumption that fish marked in the previous circuit would randomly distribute themselves in the population and behave similarly to fish that had not been captured. Increasing trends in recapture rates across circuits would suggest marked fish were easier to catch than unmarked fish and decreasing trends would suggest time-at-large reduced capture probability or that previously captured fish avoided the gear. Where data were sufficient, we also compared overall recapture rates of fish that were marked in week one with those marked in week two. Similar recapture rates would suggest similar vulnerability.

We assessed mortality of channel catfish captured with tandem hoop-net series and blue catfish captured with low-frequency DC electrofishing in May and August 2005. Each month, about 50 fish of each species were collected from the Highway 190 site. Fish representing the size range captured with each gear were marked with fin punches and tagged with Floy T-bar anchor tags prior to being placed in a net enclosure (6 m diameter X 5 m deep, 13-mm square mesh) for 48 h. Water quality (i.e. temperature and dissolved oxygen) was monitored daily at the enclosure. Total mortality was calculated for each gear and size distributions were examined to detect size-specific mortality.

To address our assumption that emigration was not size dependent, we designed our study to reduce the risk of emigration and we monitored size distributions to detect changes in size structure. Risk of emigration was reduced by establishing large sample sites (3 km river sites; 60 – 70 ha reservoir sites) and limiting sampling duration to 2 – 3 weeks. We also conducted our evaluation during summer when movement of catfishes is limited (Pellet et al. 1998; Fago 1999; Wendel and Kelsch 1999; Vokoun 2003; Daugherty and Sutton 2005). Although movement of the marked population was not directly monitored, sufficient numbers of circuits were conducted to look for changes in size distributions of blue catfish captured with low-frequency DC electrofishing over each two-week period. For each circuit, we regressed catch per hour of electrofishing by size group on the circuit order. To account for unequal effort, catch per hour was weighted proportionally to the square of its effort (Zar 1984). We then tested if the slopes equaled zero, which would suggest no change in the population (Proc GLM; SAS 2003). Slopes < 0 would suggest emigration (or mortality), whereas slopes > 0 would suggest immigration (or recruitment). Because estimates of size bias were based on marked populations, evidence of immigration would not invalidate our results. To identify size-dependent emigration (or mortality) associated with channel catfish populations; we examined size-specific recapture rates of fish marked in the first circuit across subsequent circuits where data allowed. Size-dependent emigration would be evident if size distributions differed.

Results

During the study about 30,000 blue catfish, 12,000 channel catfish, and 450 flathead catfish were collected, of which nearly 2,000 were recaptures. Most channel catfish (93%) were collected with tandem hoop-net series, whereas most blue catfish (95%) and flathead catfish (88%) were collected with low-frequency DC electrofishing. Setlines were discontinued after

June because of poor efficiency (31 fish in 3,120 hook-nights). September 2005 samples (Lower River and Highway 190 sites) ended prematurely because Hurricane Rita damaged the spillway, compelling the Trinity River Authority to drop the water level by several meters. As a result, experimental gill nets were not evaluated at Highway 190 and only one week of sampling occurred at the Lower River in September.

Water temperature, clarity, and conductivity were similar from June to September 2005, while dissolved oxygen varied. Surface water temperatures ranged from 28.2 – 31.6°C. Bottom temperatures were slightly lower than surface temperatures, but were always within 2°C. All sites were turbid with Secchi disk readings of 0.25 – 0.75 m. Conductivity ranged from 437 – 732 µS/cm. Dissolved oxygen levels were ≥ 4 mg/L throughout most of the water column in June; however, July levels were < 4 mg/L below 3 m at the Kickapoo Creek site and below 1 m at the Upper River site for several days. In September, reservoir dissolved oxygen levels ranged from 4.1 – 4.9 mg/L and river values ranged from 2.2 – 3.3 mg/L across all depths.

Tandem Hoop-Net Series

Channel catfish (150 – 556 mm) dominated the catch of tandem hoop-net series (about 96% of all catfish collected in hoop-nets); however, the number of fish marked and recaptured varied substantially across sites (Table 2). Capture of large channel catfish (≥ 350 mm) was rare so we pooled fish ≥ 350 mm for analyses. Two recapture circuits were completed at each river and reservoir site in both June and July; however, only one recapture circuit was completed at each site in September because of Hurricane Rita.

Channel catfish became fully recruited to the tandem hoop-net series at 250 mm; recapture rates were equal for fish ≥ 250 mm for all 6 estimates indicating recruitment was consistent across months and habitat. Fish < 250 mm were only partially recruited as recapture rates were significantly lower than the 250-mm size group in several instances. The 200-mm size group was underrepresented in 2 estimates (Kickapoo Creek and Upper River in July), whereas the 150-mm size group was underrepresented in 3 estimates (Highway 190 in June and September, and Kickapoo Creek in July). Although differences could only be detected for reservoir sites, the 150-mm size group was likely underrepresented for all estimates because only 1 of 454 marked fish (mostly from other gears) of this size was recaptured during the entire study. Fully-recruited fish (i.e., the 250-mm size group) were recaptured at a rate of 2.6 – 9.4% in the second circuit when 6 series of nets were set ($N = 6$) and 3.8% - 6.8% in the final circuit when 12 series of nets were set ($N = 5$).

Examination of interaction terms for evidence of differing size bias by circuit suggested bias was also consistent over each 2-week sample. The only significant interaction identified was at Kickapoo Creek in July; the ≥ 350-mm size group was underrepresented in one circuit. Interaction terms were not generated for September samples because only one circuit was conducted. At the Upper River in July, we were unable to fit the full model because of insufficient data.

Low-Frequency DC Electrofishing

Blue catfish (150 – 855 mm) comprised 98% of all catfish caught with low-frequency DC electrofishing while flathead and channel catfish comprised 1.4% and 0.6%, respectively. Blue catfish were abundant at all sites (Figure 2; Table 3); however, fish ≥ 550 mm were pooled because of low sample sizes.

Blue catfish ≥ 250 mm were fully recruited to low-frequency DC electrofishing, whereas recruitment of fish < 250 mm was variable (Figure 2). Recapture rates of the 150-mm size group were equal to the 250-mm size group in 4 of 6 samples and significantly less in 2 samples.

Recapture rates of the 200-mm size group were equal to the 250-mm size group in 2 of 6 samples less in 2 samples and greater in 2 samples. With few exceptions, all other size groups, including fish ≥ 550 mm, were consistently recaptured at rates similar to the 250-mm size group across months and habitat (Figure 2).

Overall recapture rates of blue catfish were low and variable across months and habitat, but were consistent within samples (Table 4). In June, we only recaptured about 0.2% (range = 0 – 0.5%) of the blue catfish that were marked per 120 minutes of low-frequency DC electrofishing at the reservoir site; about 0.7% (range = 0.5 – 1.0%) of marked fish were recaptured at the river site (Table 4). Overall recapture rates were higher (1 – 4%) in July and September at both river and reservoir sites, with recapture rates at river sites being 3 – 4 times greater than reservoir sites (Table 4; Figure 2).

For blue catfish captured with low-frequency DC electrofishing, we had difficulties examining the interaction term for evidence of differing size bias by circuit. We were only able to fit a full model for the Upper River in July. For the other five samples, data were insufficient to examine the interaction between all circuits and size groups. At the Upper River, two significant interactions were identified; the 450-mm size group was underrepresented in one circuit and the 300-mm size group was overrepresented a different circuit. No interactions were detected for the other two circuits. For consistency, and because we found no strong evidence to support the inclusion of interaction effects, interaction terms were omitted from the final model.

Low sample size prevented us from evaluating size bias of low-frequency DC electrofishing for flathead catfish by site. Instead, size distributions were pooled among habitat (i.e., river and reservoir). Because data were pooled, circuit effects could not be examined. We limited our marked population to fish from the first week and examined the proportion of each

50-mm size group that was recaptured during the second week. During the marking week, 86% of the fish were captured using low-frequency DC electrofishing with the remainder captured using hoop nets and set lines. For the reservoir habitat (3 samples pooled), only 66 flathead catfish were marked during week one, of which 7 fish were recaptured in week two with low-frequency DC electrofishing. In the river habitat (2 samples pooled), 171 flatheads were marked and 24 fish were recaptured.

For flathead catfish, in the river, all size groups < 500 mm appeared to be fully recruited to low-frequency DC electrofishing (Figure 3). Limited recaptures of fish ≥ 500 mm at river sites precluded any evaluation of size bias for large fish. Although most (86%) recaptures in the reservoir were ≥ 650 mm, too few fish were recaptured to evaluate size bias in that habitat. Fish ≥ 500 mm were not pooled across habitat because size distributions differed, with small fish (< 400 mm) being rare in reservoir samples (Figure 3).

Experimental Gill Nets

Both channel and blue catfish were captured with standard TPWD experimental gill nets although blue catfish comprised most (87%) of the catfish catch. Length distributions indicated that the 150-mm size group was not fully recruited to the experimental gill nets for both species and this size group was omitted from further analyses (Figure 4). Kolmogorov-Smirnov tests indicated that length distributions of blue catfish captured in gill nets differed from those of low-frequency DC electrofishing at both Highway 190 and Kickapoo Creek (Figure 5). Experimental gill nets underestimated abundance of the 200-mm size group and overestimated abundance of size groups ≥ 350 mm relative to low-frequency DC electrofishing based on cell chi-square values. Length distributions of channel catfish ≥ 200 mm captured with gill nets were similar to those captured with tandem hoop-net series one week earlier (Figure 6). Thus, standard TPWD experimental gill nets also underestimated abundance of channel catfish < 250 mm, with fish ≥ 250 mm being fully recruited.

Assumptions

Tests of our assumption that channel catfish marked in the previous circuit would randomly distribute themselves in the population and behave similarly to fish that had not been captured were inconclusive. Overall recapture rate was significantly greater in the second circuit (8.5% - 14.3%) compared to the third (2.7% - 5.4%) at all four sites, suggesting capture probability decreased with time-at-large. However, at the Highway 190 site in June we were able to examine recapture rate of marked fish from different weeks within the third circuit because fish were uniquely marked. In this instance, time-at-large did not affect recapture rate since 4.0% of the week-1 fish were recaptured compared to 3.3% of the week-2 fish. Week-1 fish had been released 8 d prior to week-2 fish, which were released immediately before setting nets for the final circuit. Because circuits differed, they were not pooled for the final model that was used to examine size-group effects.

Our assumption that marked blue catfish would randomly distribute themselves in the population and behave similarly to unmarked fish appeared valid. At the Upper River and Kickapoo Creek in July, and the Lower River in September, there were no differences in overall recapture rates across circuits (Table 4). At Highway 190 in both June and September, differences were observed across circuits; however, there was no pattern of increasing or decreasing vulnerability (Table 4) suggesting differences were associated with conditions specific to those circuits. The Lower River in June was the only site that indicated overall recapture rate decreased with time; however, within a given circuit the overall recapture rate of week-1 and week-2 fish appeared similar, suggesting extrinsic factors rather than a time-at-large effect (Table 4). Overall recapture rates of week-1 and week-2 fish were also similar within circuits at other sites (Table 4). Because the overall recapture rate differed for some circuits, we did not remove circuit from the final model used to examine size-group effects.

Estimates of tagging and handling mortality associated with tandem hoop-net series and low-frequency DC electrofishing were low in May 2005 when water temperatures were between 24.7 and 27.3°C, and dissolved oxygen was between 6.6 and 13.7 mg/L at 5 m and 0 m, respectively. Only one (2%) blue catfish mortality (169 mm) was observed among the 50 blue catfish (157 – 544 mm) captured with low-frequency DC electrofishing and held for 48 h. Likewise, only one of 32 (3%; 192 mm) channel catfish captured with tandem hoop-net series (184 – 303 mm) died while in the enclosure.

In August 2005, the holding net was vandalized allowing some fish to escape; several large holes were cut in the net, but more than half of the fish were recovered. Twenty-six of the 50 blue catfish (155 – 590 mm) collected with low-frequency DC electrofishing were recovered; 3 were dead (228, 430, and 590 mm). Of the 24 that were missing, 3 were recovered alive at Highway 190 in September collections. Thirty-six of the 50 channel catfish (155 – 388 mm) collected with tandem hoop-net series were recovered; 7 were dead (155 – 243 mm). Six of the seven deaths were for fish in the 150-mm size group indicating at least 60% of the fish in this size group died within 48 h compared to 2.5% for fish ≥ 200 mm. Of the 14 channel catfish that were missing, 4 were recovered in September. Recovery of missing individuals suggests that most missing fish likely survived. Water temperatures at the holding net in August were between 30.8 and 32.4°C, and dissolved oxygen was between 0.6 and 8.6 mg/L at 5 m and 0 m, respectively.

Comparisons of catch-per-hour of blue catfish captured with low-frequency DC electrofishing and size distributions of recaptured channel catfish collected with tandem hoop-net series showed little evidence of size-dependent emigration or mortality. A single negative slope was detected at the Lower River in September for blue catfish in the 400-mm size group; electrofishing catch was 7.2, 7.1, and 5.5 fish per hour in circuits 1 – 3, respectively. Although significant, this slight decrease did not alter our estimates of size bias as recapture rates of the 400-mm size group were similar to the 250-mm size group for all circuits. For channel catfish, we were only able to compare size distributions of recaptured fish at Kickapoo Creek in July because all fish were marked on the same day. Length distributions for the two recapture events appeared similar suggesting size-dependent emigration or mortality had not occurred (Figure 7).

Discussion

Tandem hoop-net series were a viable gear for collecting channel catfish from both and river and reservoir habitat. Channel catfish were the primary species collected, although a small proportion of the catch included blue and flathead catfish as well as other species. This was expected as hoop nets are known to be selective for channel catfish (Holland and Peters 1992). With a single, 3-day set of 12 series of nets, we were able to capture more than 1,300 channel catfish at each reservoir site. River sites produced fewer fish, but samples exceeded 400 fish at all sites. Samples of at least 400 fish should be sufficient to accurately reflect length distributions (Vokoun et al. 2001; Miranda 2007).

Tandem hoop-net series underrepresented small channel catfish, but fish ≥ 250 mm were consistently recruited, regardless of month or habitat sampled. Although all size groups were collected, the 150-mm size group was rarely captured in either river or reservoir habitat and the 200-mm size group was underrepresented in two of the six samples. These results were similar to Michaletz and Sullivan (2002) who found that tandem hoop-net series captured channel catfish between 250 mm and 529 mm in proportion to their abundance in a small impoundment.

Low-frequency DC electrofishing produced large numbers of blue catfish from both river and reservoir habitats. Catch consisted almost entirely of blue catfish with few other catfishes collected. Although catch varied both temporally and spatially, we were able to capture a minimum of 120 blue catfish per hour of electrofishing at all sites. In some circuits, catch exceeded 500 fish per hour. Catch rates were similar to the range reported by Boxrucker (in press) for Oklahoma reservoirs. Using low-frequency DC electrofishing, sample sizes needed to accurately reflect length distributions (Vokoun et al. 2001; Miranda 2007) should be easily attainable.

Low-frequency DC electrofishing consistently collected all size groups ≥ 250 mm in proportion to their abundance (i.e., without significant size bias) in all months and habitats. Blue catfish in the 150- and 200-mm size groups were collected, but were underrepresented in several instances indicating they are only partially recruited. Caution should be exercised when including these size groups in size distributions. Boxrucker (in press) previously noted that young (i.e., age 1 – 3) blue catfish may be underrepresented based on catch curves. We found no evidence of size bias for large fish, but fish ≥ 600 mm comprised only 0.7% of our collections. Recapture rates of blue catfish for low-frequency DC electrofishing were very low (often < 1%); suggesting this species was very abundant. Low capture probabilities coupled with a relatively slow-growing, long-lived species such as blue catfish could also result in few collections of large fish. Boxrucker (in press) found that blue catfish in Oklahoma reservoirs typically required 9 – 16 years to attain an average length of 600 mm and that annual mortality was 21 – 32%. Assuming constant recruitment, an annual mortality of 30%, a life span of 20 years, and a mean length of 600 mm at 13 years, only 0.9% of the population would be ≥ 600 mm. Hence, low catches of these larger blue catfish likely reflects true abundance.

Although size bias was similar across habitats or months, overall recapture rates of blue catfish with low-frequency DC electrofishing were higher in river habitat, and during the months of July and September. Blue catfish may have been more vulnerable because they were forced to occupy the upper portion of the water column as dissolved oxygen levels fell in the late summer. While electrofishing, we observed that in June, sonar indicated that schools of blue catfish occupied the bottom of the river channel. In July and September, schools appeared to be suspended along the edge of the river channel and in the flats. Blue catfish also appeared at the surface faster in these samples as compared to June electrofishing samples.

Flathead and channel catfish were occasionally collected with low-frequency DC electrofishing, although most (87%) of the channel catfish were ≤ 250 mm and were collected from shallow depths. Channel catfish apparently had low vulnerability to the gear as only 167 fish were captured during the entire study, even though we electrofished the same sites where tandem hoop-net series collected > 10,000 individuals. Flathead catfish were vulnerable to low-frequency DC electrofishing; however, their abundance was apparently low. Throughout the entire study, only 454 flathead catfish were collected with all gears. More than 11% of these fish were recaptures that were collected with low-frequency DC electrofishing. Flathead catfish collected with low-frequency electrofishing ranged from 150 to 1170 mm with no indication of size bias although sample sizes of large fish (≥ 500 mm) were small.

Relative to low-frequency DC electrofishing, standard TPWD experimental gill nets were more biased for collecting blue catfish. Experimental gill nets under represented fish < 200 mm and over represented fish ≥ 350 mm. For channel catfish, the size bias associated with experimental gill nets was similar to tandem hoop-net series. Compared to other gears, experimental gill nets collected relatively few channel and blue catfish. In a total of 46 gill nets we captured 1,069 blue catfish and 166 channel catfish or 21.8 blue catfish and 3.4 channel catfish per gill net night. Our catch rates far exceeded the highest gill-net catch rates reported for blue catfish (3.3 fish/h) by Dumont and Schlechte (2004) and approached their highest catch rates of 5 fish/net reported for channel catfish. Catch of blue catfish at the same sites exceeded 120 fish/h using low-frequency DC electrofishing and catch of channel catfish was > 100 fish/tandem hoop-net series.

It is unlikely that any of our assumptions altered our estimates of size bias. Differing levels of effort across circuits for tandem hoop-net series confounded our ability to determine if channel catfish marked in the previous circuit randomly distributed themselves and behaved similarly to unmarked fish. Regardless, the lack of interaction between circuit and size group indicated size bias was similar across circuits. For blue catfish captured with low-frequency DC electrofishing, we did not observe any pattern of increasing or decreasing recapture rates across circuits. Mortality of marked fish was low and similar for tandem hoop-net series and low-frequency DC electrofishing for all size groups with one exception. Channel catfish in the 150-mm size group captured using tandem hoop-net series experienced higher mortality when water temperatures were high and dissolved oxygen levels were low. Such size-dependent mortality could have affected our estimates of size bias for tandem hoop-net series; however, this size group was underrepresented in all samples, including June when conditions were similar to May when no size-dependent mortality was observed. Finally, we found no evidence that size-dependent emigration affected our estimates of size bias. Catch-per-hour of all blue catfish size groups was constant or increased during each two-week sample, and the marked population of channel catfish also appeared stable based on data from Kickapoo Creek.

The combination of tandem hoop-net series and low-frequency DC electrofishing was a productive method of sampling populations of catfishes ≥ 250 mm in both river and reservoir habitat. Size biases associated with these gears were limited to small fish and were consistent across habitats and months sampled. Although these gears captured large numbers of adult catfishes in proportion to their abundance, samples must be distributed across the entire population to be representative. The required number of samples will depend on the spatial characteristics of the population. It is likely that channel and blue catfish have contagious distributions, and fish of similar size may school together. Until the spatial characteristics of catfish populations are determined, a random sampling design with many replicates is recommended.

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Table 1. Specifications of catfish sampling gears that were evaluated.

Gear	Description
Tandem hoop net series	Each series consisted of three hoop nets tied in tandem, attached cod end to the bridle (about 1 m apart). Each hoop net was 3.4-m long, contained 7 fiberglass hoops, and had 25-mm square mesh netting throughout. Netting was made of twine size No. 15 and each net was treated with net coat. The first hoop was about 0.8 m in diameter and the net tapered to the cod end. Nets contained two fingered crowfoot style throats attached to the second and fourth hoops. The second throat was further constricted by tying the throat strings together with a piece of twine about 15 cm from the cod end of the throat to reduce escapement. Prior to use, new nets were soaked and dried several times. Nets were baited with cheeselogs (1kg/net; Boatcycle, Inc., Henderson, Texas).
Low-frequency DC electrofisher	The unit consisted of a Smith-Root 7.5 GPP pulsating electrofisher with Smith-Root booms and 2, 6-dropper anode arrays. Droppers were made of 5-mm diameter stainless steel and were 1 m in length. The boat hull served as the cathode. Settings for the electrofisher were 15 pulses per second and 500 volts DC. Percent of current was adjusted to yield about 1 amp. Typically, two chase boats assisted with the capture of fish. All boats had a driver and 1 dipper.
Experimental gill net	Each net was 38.1 m long by 2.4 m high and made with monofilament webbing. Nets contained five 7.6-m panels of the following square mesh and twine sizes: Square mesh — Twine size 25 mm — #104 (Mono #4) 38 mm — #104 (Mono #4) 51 mm — #139 (Mono #6) 64 mm — #139 (Mono #6) 76 mm — #139 (Mono #6) Webbing was hung on a one-half basis, double knotted, and had double selvage. Top and bottom lines extended 4 feet past webbing at both ends. Nets were negatively buoyant with lead lines of 6-mm diameter braided poly leadcore and float lines of 10-mm braided poly foamcore.

Table 2. The number of channel catfish marked using all gears and recaptured using tandem hoop-net series by site and month.

Site, month	*N* marked (size groups mm)	Recapture effort *N* series of nets	*N* recaptured (size groups mm)
Lower River, June	906 (150-500)	18 (2 circuits)	56 (150-400)
Highway 190, June	1,345 (150-450)	18 (2 circuits)	89 (200-350)
Upper River, July	588 (150-500)	18 (2 circuits)	30 (200-300)
Kickapoo Creek, July	1,359 (150-450)	18 (2 circuits)	170 (200-350)
Lower River, Sept.	443 (150-450)	6 (1 circuit)	11 (200-250)
Highway 190, Sept.	1,567 (150-450)	7 (1 circuit)	106 (200-350)[1]

[1]Nets were retrieved after only 2 d due to Hurricane Rita.

Table 3. The number of blue catfish marked using all gears and recaptured using low-frequency DC electrofishing by site and month.

Site, month	*N* marked (size groups mm)	Recapture effort min. electrofishing	*N* recaptured (size groups mm)
Lower River, June	3,234 (150-750)	765 (4 circuits)	121 (150-350)
Highway 190, June	3,662 (150-800)	1,085 (10 circuits)	20 (150-500)
Upper River, July	3,006 (150-800)	735 (4 circuits)	400 (150-650)
Kickapoo Creek, July	1,273 (150-550)[1]	1,035 (7 circuits)	88 (150-550)
Lower River, Sept.	4,230 (150-850)	360 (2 circuits)	296 (150-800)
Highway 190, Sept.	7,624 (150-800)	850 (4 circuits)	388 (150-700)

[1]Fish were only marked during the first week.

Table 4. Comparison of overall recapture rate by circuit of fish marked in week 1 and week 2. Circuits with the same superscript letter were similar (Wald chi-square statistic, $P > 0.05$) when recapture rate across tag week was pooled.

Circuit	Percent Week 1 fish recaptured	Percent Week 2 fish recaptured
Lower River, June		
1^z	1.01	-
2^z	0.99	0.81
3^y	0.67	0.48
4^y	0.54	0.55
Highway 190, June		
1^z	0	-
2^z	0.33	-
3^z	0.19	-
4^z	0.18	-
5^y	0.13	-
6^y	0.13	0.32
7^y	0.13	0.26
8^y	0.06	0.25
9^z	0.39	0.47
10^z	0.19	0.07
Upper River, July		
1^z	3.53	-
2^z	4.15	-
3^z	2.97	-
4^z	2.93	4.21
Kickapoo Creek, July		
1^z	0.17	-
2^z	1.18	-
3^z	1.59	-
4^z	0.56	-
5^z	0.82	-
6^z	1.58	-
7^z	1.10	-
Highway 190, September		
1^z	1.36	-
2^y	0.76	-
3^z	1.53	-
4^z	1.16	1.87
Lower River, September		
1^z	4.06	-
2^z	4.17	-

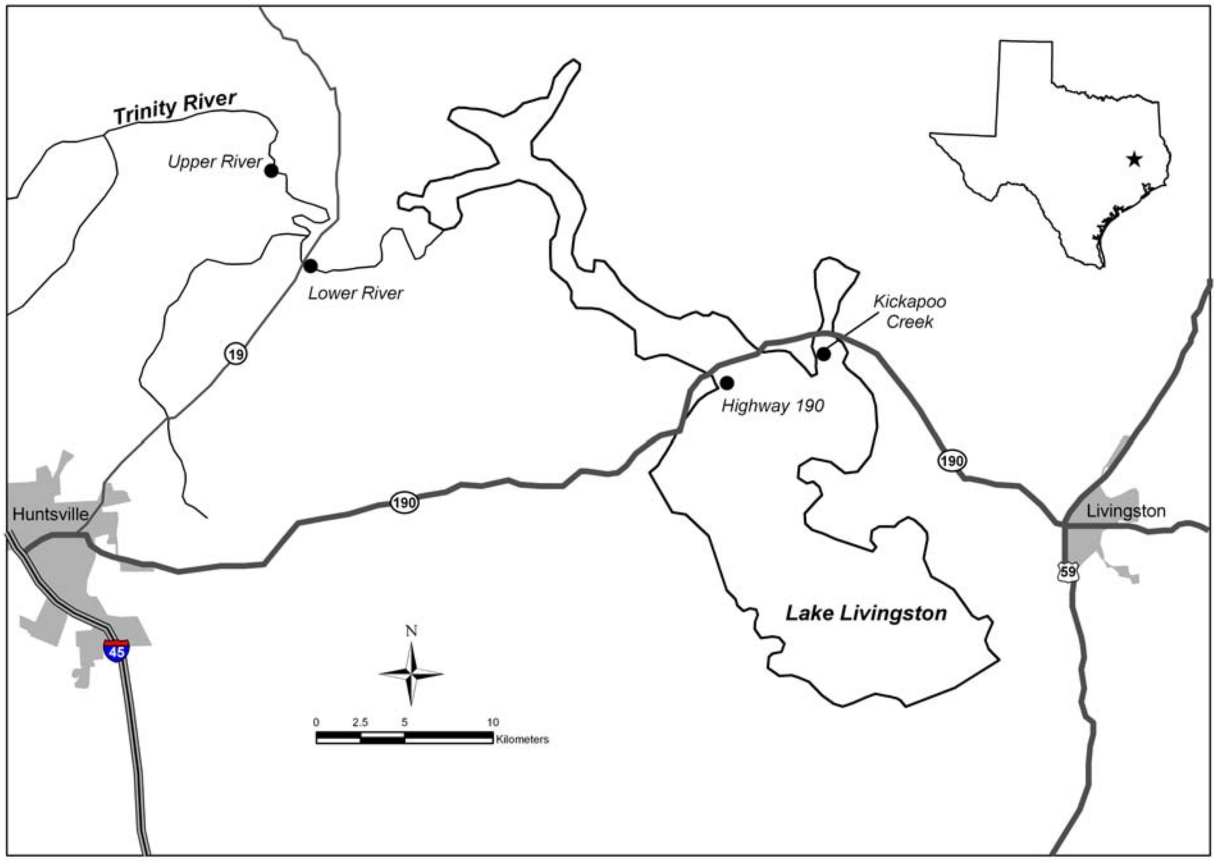


Figure 1. Map of Lake Livingston and the Trinity River study area indicating locations of river (Upper and Lower) and reservoir (Highway 190 and Kickapoo Creek) study sites.

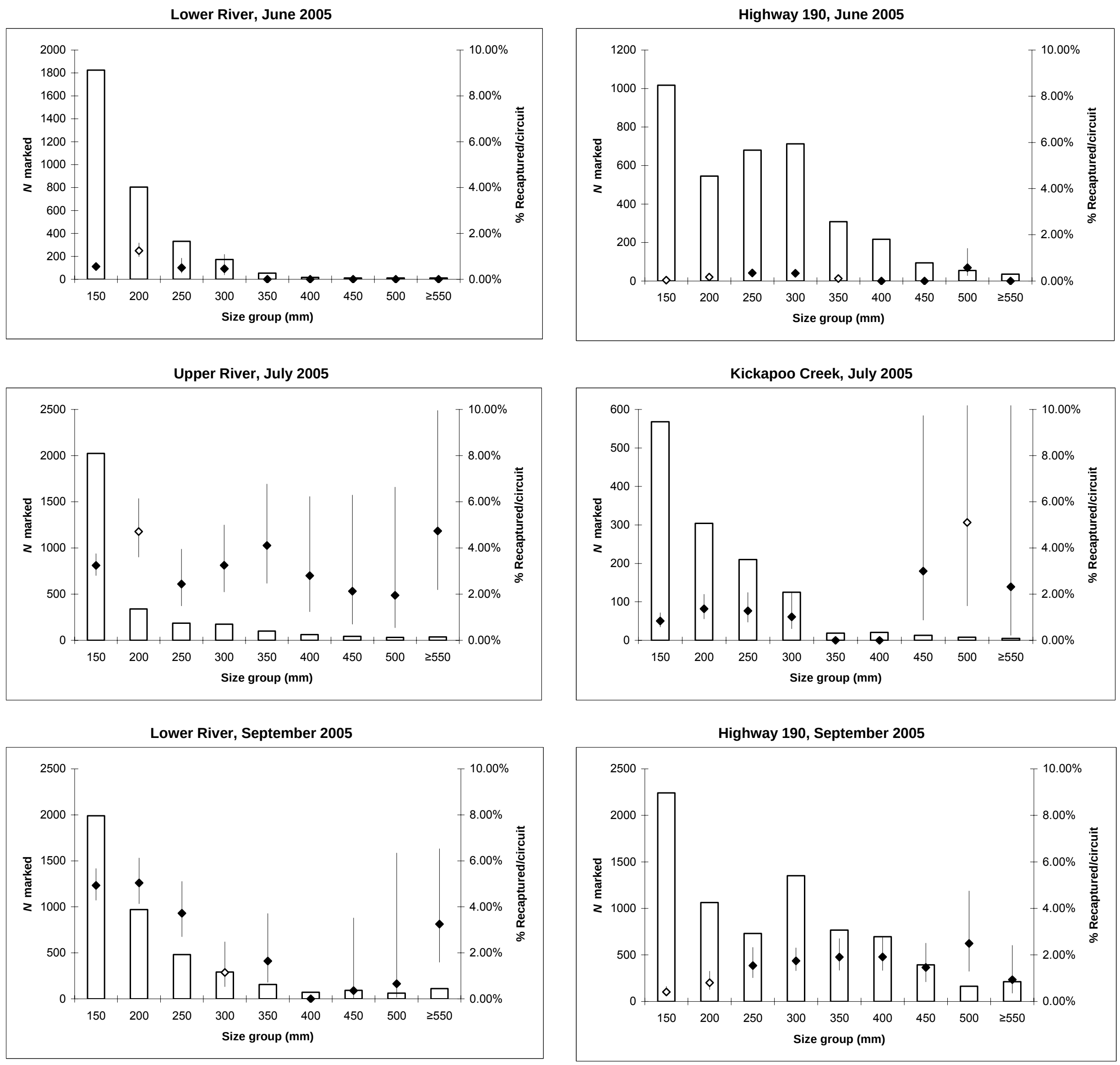
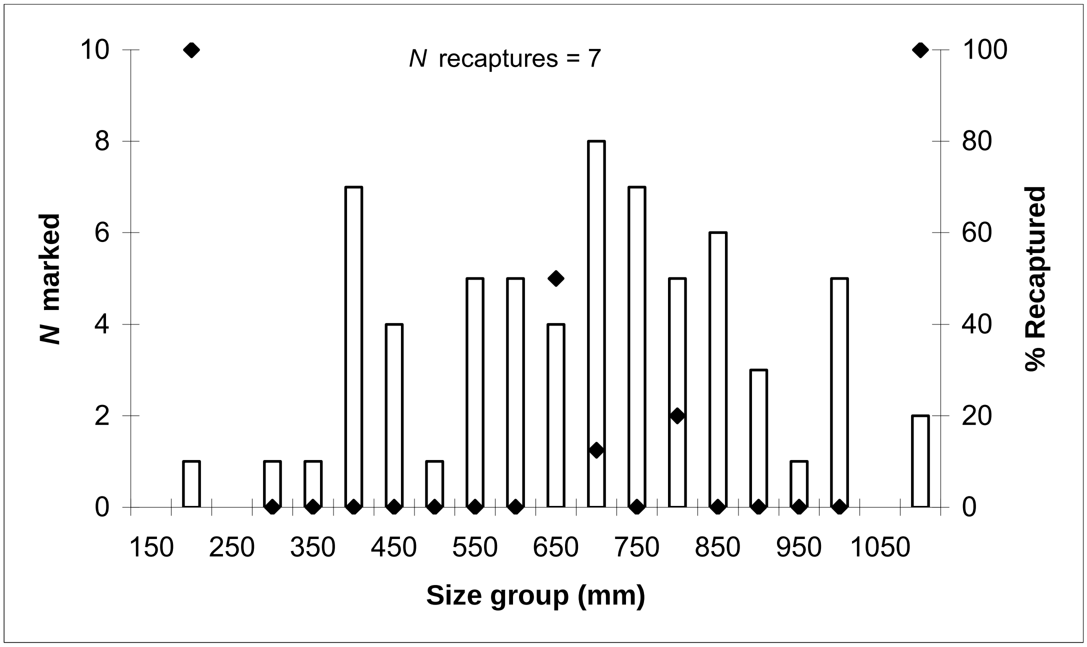


Figure 2. Length-frequency histograms of marked blue catfish and average recapture rates (across all circuits) with 95% confidence limits. Unfilled diamonds indicate that the recapture rate (standardized for effort) for that size group differed from the 250-mm size group (Wald chi-square statistic, $P \leq 0.05$). Upper confidence limits were 16% and 21% for 500- and ≥ 550-mm size groups at Kickapoo Creek.

Reservoir Sites



River Sites

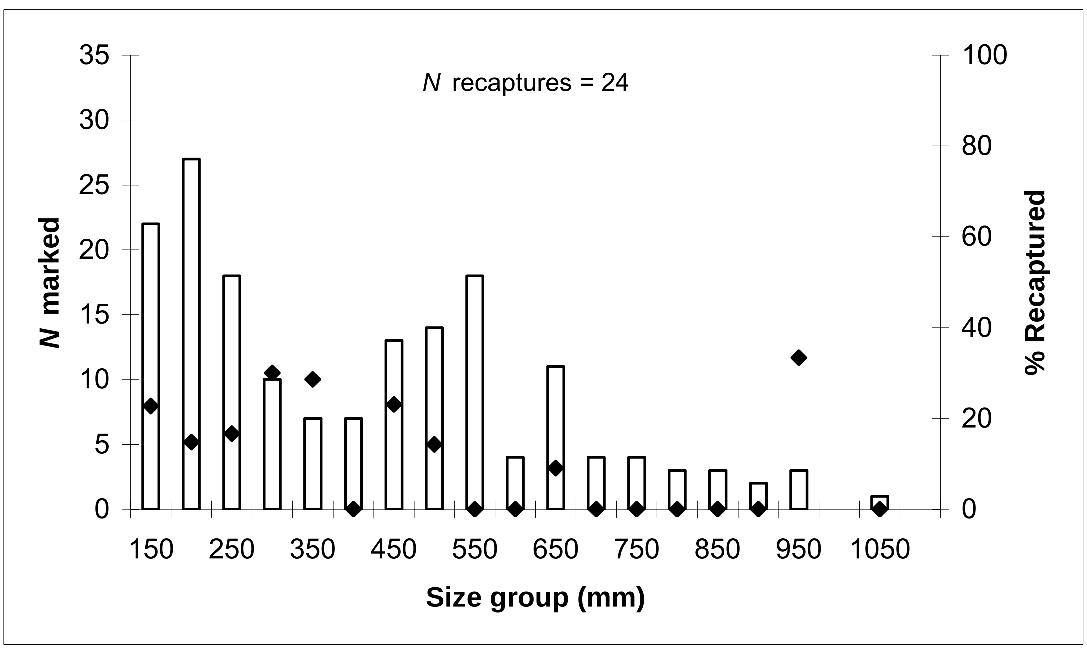
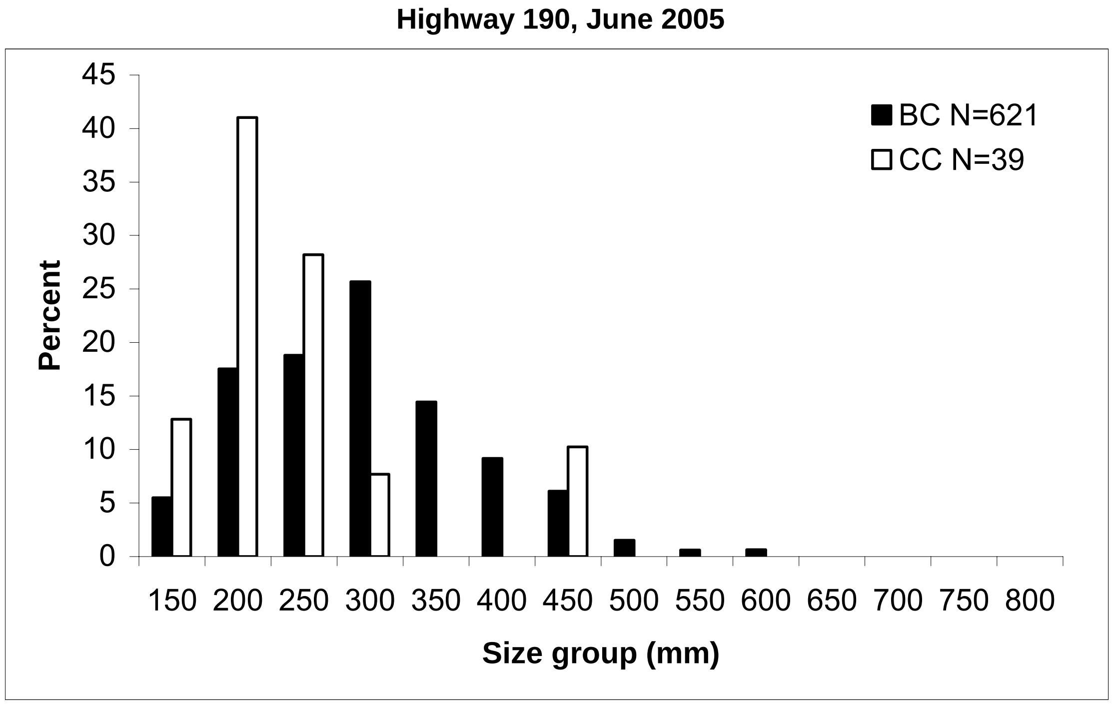


Figure 3. Length-frequency histograms of marked flathead catfish at river and reservoir sites in week 1 and percent of marked fish recaptured in week 2. Confidence limits were not derived because samples were pooled by habitat and circuit effects could not be examined.



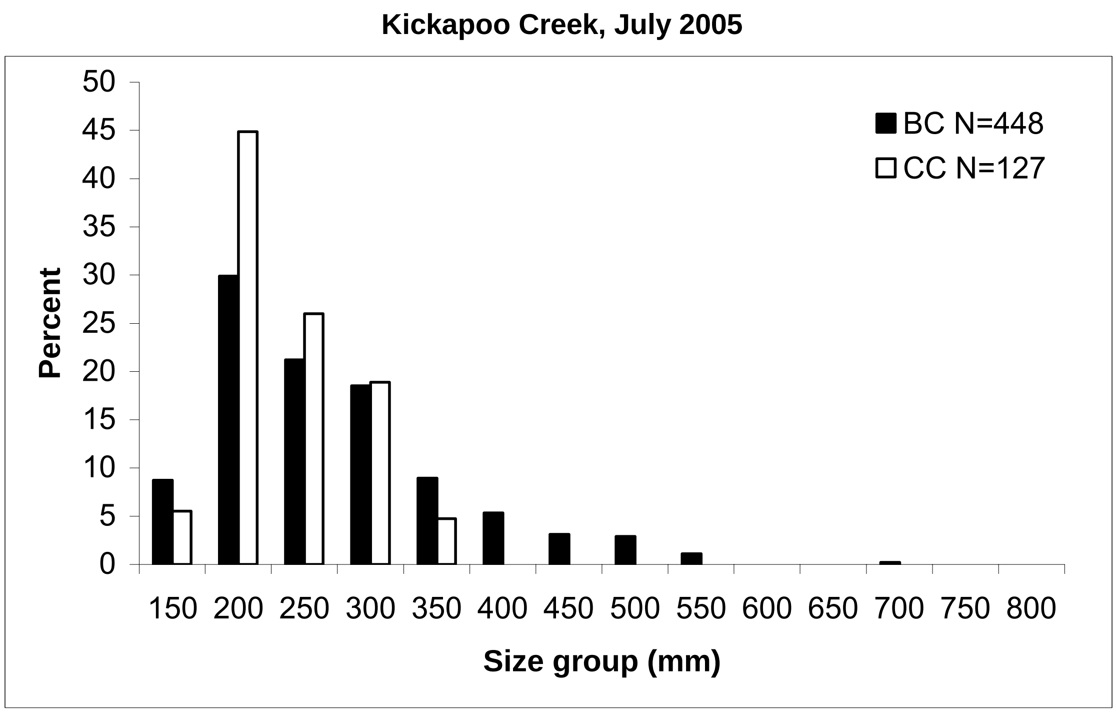
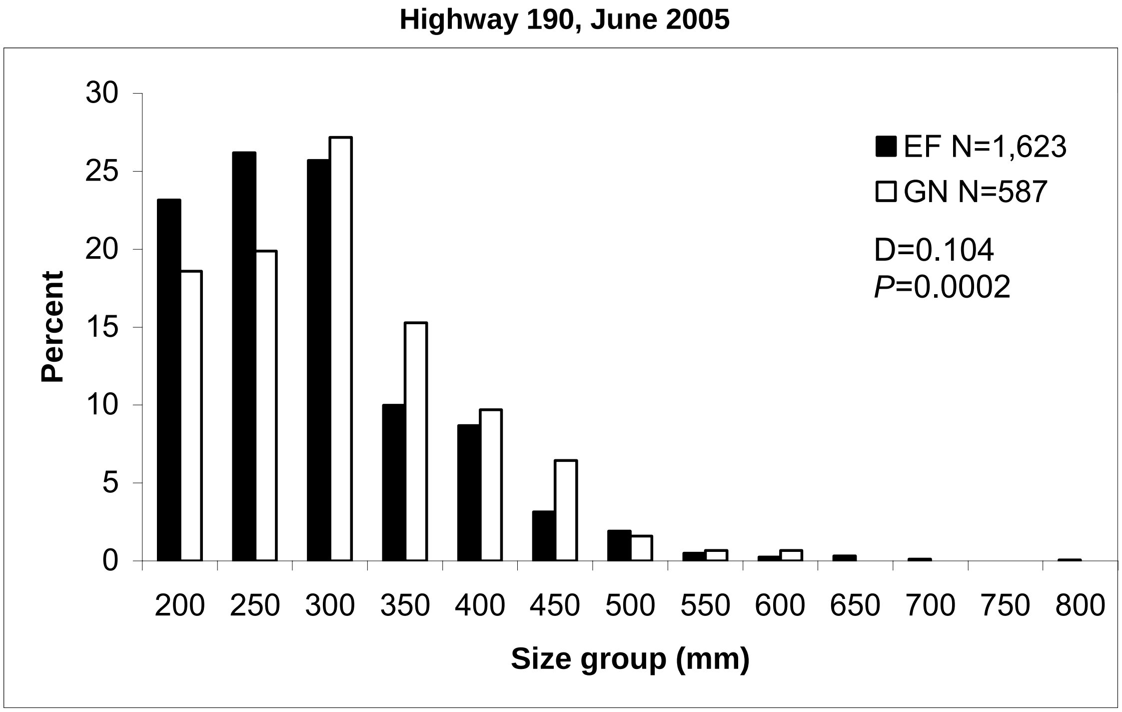


Figure 4. Length distributions of channel (CC) and blue (BC) catfish captured with standard TPWD experimental gill nets at Highway 190 and Kickapoo Creek.



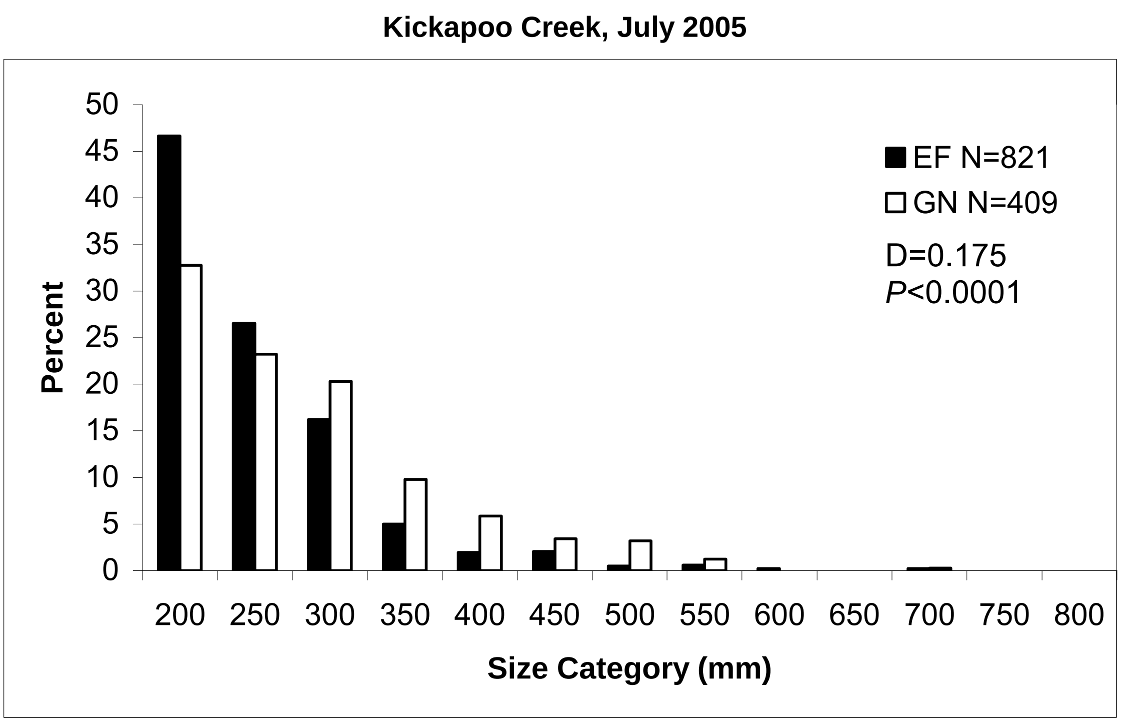
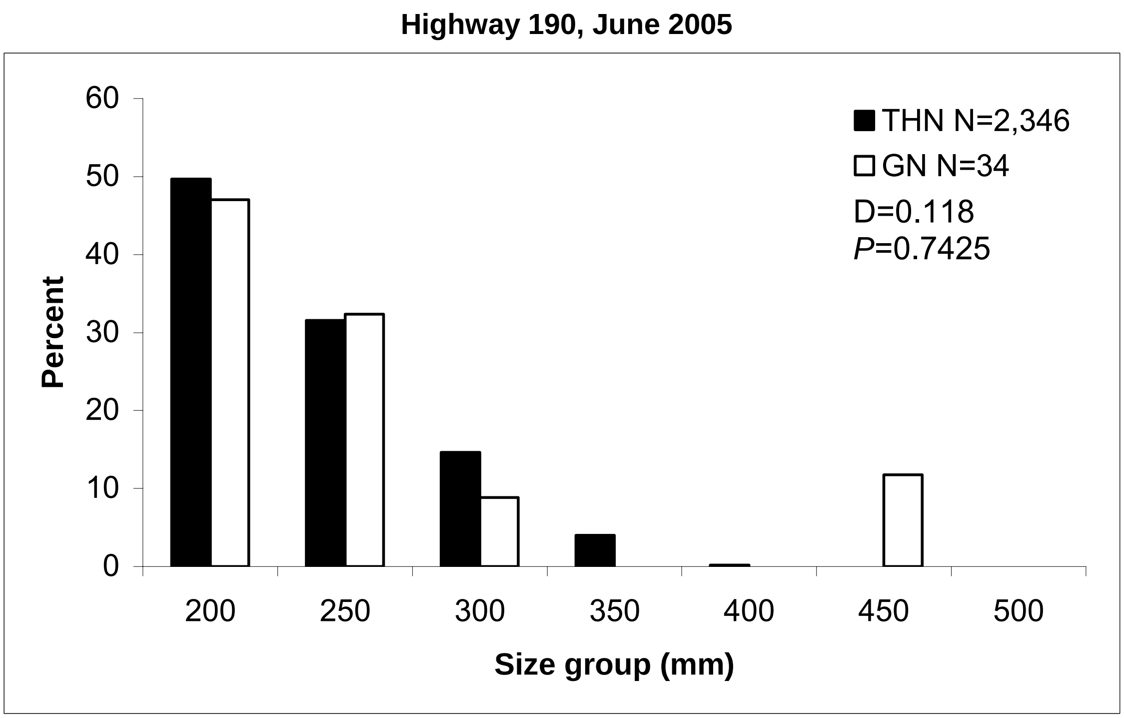


Figure 5. Length distributions (for fish ≥ 200 mm) of blue catfish captured with standard TPWD experimental gill nets (GN) and low-frequency DC electrofishing (EF) one week earlier at Highway 190 and Kickapoo Creek.



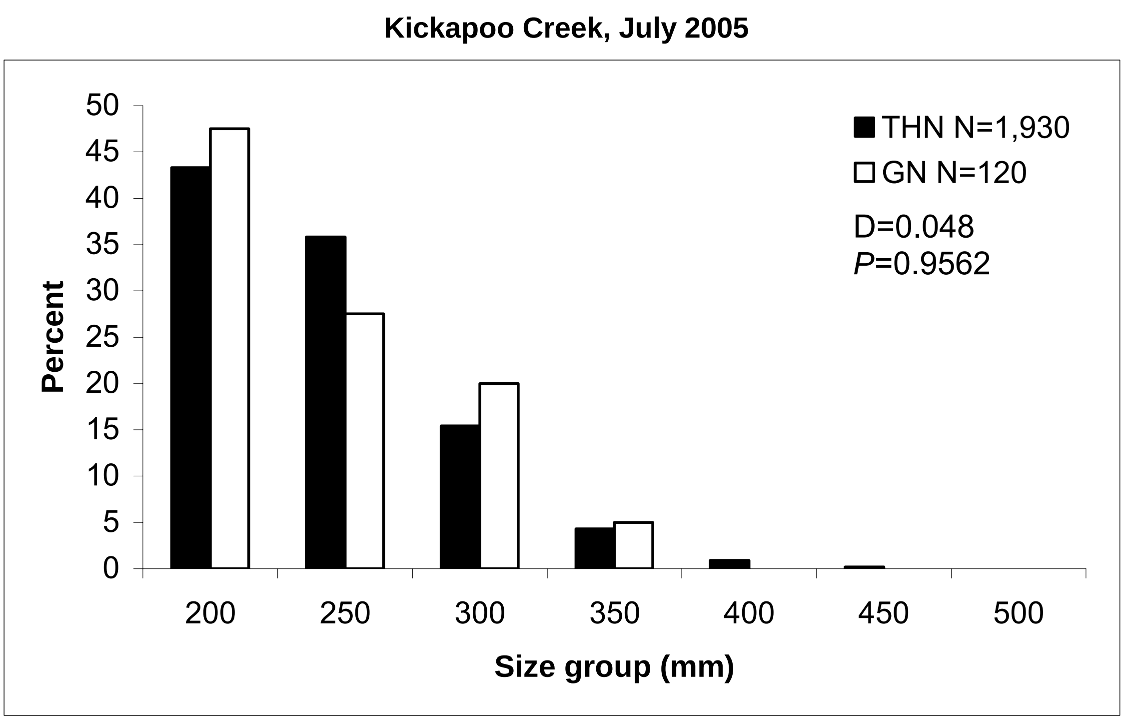


Figure 6. Length distributions (for fish ≥ 200 mm) of channel catfish captured with standard TPWD experimental gill nets (GN) and tandem hoop net series (THN) one week earlier at Highway 190 and Kickapoo Creek.

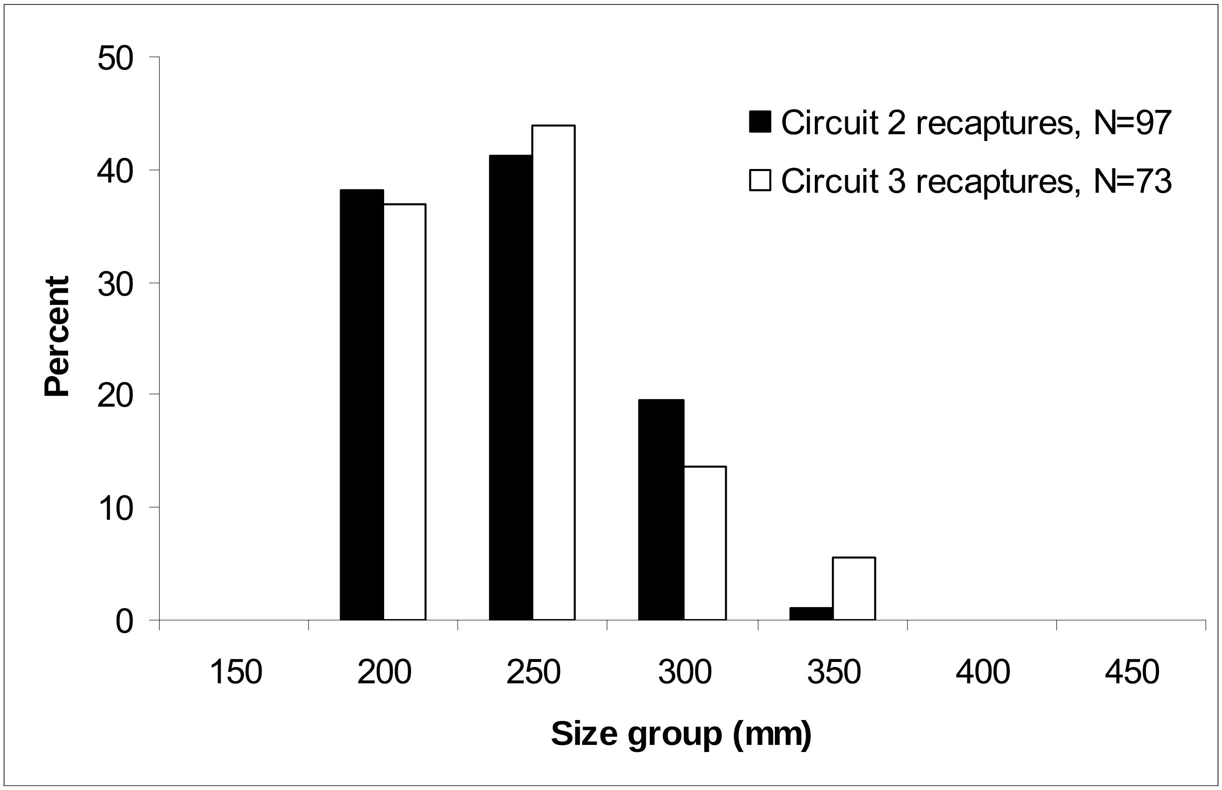


Figure 7. Length distributions of channel catfish recaptured in circuits 2 and 3 with tandem hoop-net series at Kickapoo Creek in July 2005.