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Abstract.—In recent years, several state agencies have adopted the use of baited, tandem-set hoop nets to assess lentic channel catfish *Ictalurus punctatus* populations. Some level of escapement from the net is expected because an opening exists in each throat of the net, although factors influencing rates of escapement from hoop nets have not been quantified. We conducted experiments to quantify rates of escapement and to determine the influence of throat configuration and fish density within the net on escapement rates. An initial experiment to determine the rate of escapement from each net compartment utilized individually tagged channel catfish placed within the entrance (between the two throats) and cod (within the second throat) compartments of a single hoop net for overnight sets. From this experiment, the mean rate (±SE) of channel catfish escaping was 4.2% (±1.5) from the cod (cod throat was additionally restricted from the traditionally manufactured product), and 74% (±4.2) from the entrance compartments. In a subsequent experiment, channel catfish were placed only in the cod compartment with different throat configurations (restricted or unrestricted) and at two densities (low [6 fish per net] and high [60 fish per net]) for overnight sets to determine the influence of fish density and throat configuration on escapement rates. Escapement rates between throat configurations were doubled at low fish density (13.3 ± 5.4% restricted versus 26.7 ± 5.6% unrestricted) and tripled at high fish density (14.3 ± 4.9% restricted versus 51.9 ± 5.0% unrestricted). These results suggest that retention efficiency is high from cod compartments with restricted throat entrances. However, managers and researchers need to be aware that modification to the cod throats (restrictions) is needed for hoop nets ordered from manufacturers. Managers need to be consistent in their use and reporting of cod end throat configurations when using this gear.

Introduction

Hoop nets are used to sample channel catfish *Ictalurus punctatus* by trapping individuals within a framework of fabric mesh stretched over circular hoops with funnel or v-shaped entrances. Vokoun and Rabeni (2001) stated that the use of hoop nets to sample riverine catfishes is widespread, although it has not been extensively evaluated for precision and efficiency. Hesse et al. (1982), Holland and Peters (1992) and Shoup et al. (2003) reported that hoop net mesh size influences catch and size structure data for channel catfish. Retention by total length was found to be biased for channel catfish less than 250 mm (Michaletz and Sullivan 2002) while hoop nets accurately portrayed larger channel catfish size distributions (between 250 and 556 mm) in both river (Barada 2009) and reservoir habitats (Buckmeier and Schlechte 2009). Traditionally applied in lotic

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systems to assess catfish populations (Michaletz and Dillard 1999), it has recently been adapted for use in impounded waters. This gear has shown promise as an effective method for sampling channel catfish populations when set as a series of three individual hoop nets placed in tandem, usually baited with scrap cheese or soybean products and fished for several days (Walker et al. 1996; Sullivan and Gale 1999; Michaletz and Sullivan 2002; Flammang and Schultz 2007).

Efficacy of passive netting gear is apportioned to its ability to encounter, entangle or entrap, and retain targeted aquatic organisms (Hubert 1996). For a fish to be successfully captured, it must be susceptible to and retained by the gear until it is retrieved. Channel catfish were routinely observed escaping hoop nets being used as overnight holding pens (T. Barada, University of Nebraska-Lincoln, personal communication), suggesting that complete retention within this gear may not be a valid assumption. Studies assessing net escapement rates in freshwater lentic systems is limited (Hansen 1944; Patriarche 1968; Breen and Ruetz 2006) and typically focuses on permeability of individuals through the mesh panels of netting gear (Meyer and Merriner 1976; Craig 1980; Hesse et al. 1982; Fujimon et al. 1996; Schlacher and Wooldridge 1996). Limited work suggests that certain sensitive species (Stone 2005; Fratto et al. 2008) and the presence of conspecifics or predators (Zhou and Shirley 1997; Breen and Ruetz 2006) may affect the retention of fish through hoop net entrance throats. Additionally, mesh size (Holland and Peters 1992; Shoup et al. 2003), fish length (Michaletz and Sullivan 2002; Buckmeier and Schlechte 2009), multiple day sets (Hamley and Howley 1985; Zhou and Shirley 1997), different baits (Walker et al. 1996; Sullivan and Gale 1999; Stone 2005), and presence of other conspecifics (Young et al. 2003) or predators (Breen and Ruetz 2006) may all influence catch, yet no investigation has been conducted to estimate the basal (standard level) escapement rates of channel catfish from hoop nets.

The purpose of this project was to estimate basal escapement rates from hoop nets under controlled conditions and identify how two frequently encountered conditions can influence the rate of escapement by channel catfish. Initial trials were used to quantify escape probabilities through each throat of a hoop net, and an additional experiment was conducted to determine if escapement rates from the cod end compartment were influenced by fish density or by altering the throat configuration from a commercially produced hoop-net design.

Methods

Individual hoop nets measured 3.4 m in length and were constructed of #15 twine with 25.4 mm mesh (bar measure) covering seven fiberglass hoops, each decreasing slightly in diameter from the mouth to the cod end, from 0.8 m in diameter (largest) to 0.54 m diameter (smallest). Two fingered crow-foot throats were attached to the second and fourth hoops, creating entrance (hereafter mid) and cod compartments. The cords for the crow-foot throat attached to the second hoop were tied on opposite sides of the fourth hoop, creating a larger entrance than the cod crow-foot throat cords, which were joined with nylon zip ties and exited the end of the net as described in Sullivan and Gale (1999).

We employed the use of raceways at the Calamus State Fish Hatchery (CSFH) in Burwell, Nebraska to minimize the variability associated with differing abiotic and biotic factors in lentic systems. These raceways feature individual water controls to regulate flow rates and depth typically used for fish production. Water quality was easily maintained as our experimental densities were substantially less than traditional production efforts. Portable mesh aluminum screens divided raceways into individual pens (2.4 × 4.6 m) where a hoop net was placed with the cod end at the head of the raceway with incoming reservoir water flows set at two volume exchanges per hour, a rate that did not produce an observable current within the raceway.

Trials for Basal Escapement from Net Compartments

Channel catfish were pond-raised at CSFH and the timing of our experimental trials coincided with the fall harvest and stocking of these fish across the state. Channel catfish from drained ponds were manually graded by size with screening baskets prior to loading into transport vehicles. Screens designed to retain fish greater than 228 mm were used to collect channel catfish for the experimental trials. Eighteen individual pens (six replicates of three pens per block) were used for our experimental trials in 2008. Each pen consisted of 12 individually marked (six colors of nylon zip ties placed on left or right pectoral spines) channel catfish between 230 and 300 mm (mean length = 250.4 SE = ±1.77 mm total length). Each pen within a block was randomly assigned one of three treatments (treatment A = 6 channel catfish placed in the cod end, 0 in the mid compartment, and 6 placed outside of the net in the raceway; treatment B = 0 cod, 6 mid, 6 outside of net; treatment C = 6 cod, 6 mid, 0 outside of net). Each pen within a block experienced all treatments once during the 3-d study period (3 × 3 Latin square design) of September 15–18, 2008. Twelve individually marked channel catfish were randomly assigned to a starting position corresponding to the assigned treatment for each pen. After 24 h, the ending position (cod, mid, outside of net) within the hoop net for each fish was recorded. Fish were then placed into their randomly assigned position within the same net and pen for the next treatment and the process repeated. If an individual channel catfish lost its identifying mark (shed its nylon tie) during a trial, it was marked again before the next trial.

Trials for Basal Escapement as Function of Fish Density and Throat Configuration

In 2009, raceway experiments to evaluate escapement from the cod end compartments of hoop nets were again conducted using pond raised channel catfish from CSFH. A 2 × 2 factorial design was employed with two fish density treatments (6 or 60 channel catfish) placed into a cod end compartment with two gear configurations (crow-foot finger throat entrance restricted or unrestricted; Figure 1). Large

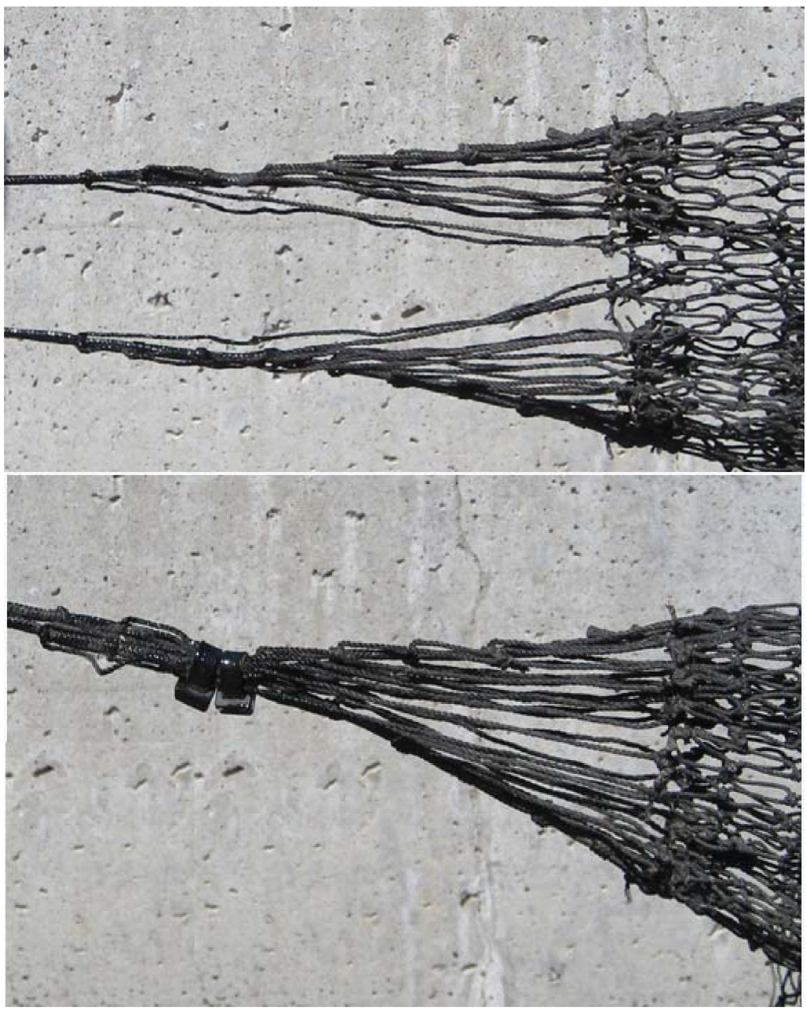

FIGURE 1. Exposed hoop-net cod-end throat configurations. The upper photo shows a typical fingered crow-foot cod throat as received from a manufacturer, with cords exiting the rear of the net. The lower photo shows the throat cords restricted by two nylon ties, a modification recommended and first described by Sullivan and Gale (1999).

raceways were used to create five blocks of four or 20 individual pens (i.e., four pens/block) for our experimental trials. Each pen contained either 6 or 60 channel catfish (242.0 ± 0.45 mm TL) placed into the cod end compartment, with both the treatments (density and cod throat configuration) and subjects randomly assigned. After 24 h, each net within a block was lifted and the number of fish in each ending position (cod, mid, outside) was recorded. Unlike 2008, channel catfish were not individually marked and those retrieved outside of the cod end compartment of the net (within the mid compartment or outside the net but in the raceway) were given a unique fin clip by day (left pelvic on day 1, right pelvic on day 2), placed in a common tank, and randomly mixed prior to assignment to the next day's treatment. Trials were conducted September 14–17, 2009 for 3 d with no pen experiencing a treatment more than once. At the conclusion of the trials, each channel catfish was measured to the nearest 10 mm length-group and inspected for fin clips to determine frequency of escapement for each subject.

Data Analysis

We determined that escapement had occurred when a subject was no longer in their starting position after 24 h. For the initial trials in 2008, escapement rates were calculated as the percentage of fish no longer in their starting position, and because subjects were individually marked, their ending position (cod, entrance, outside the net) was also recorded. As escapement rates were expressed as ratios, the square root of the escapement rates were arcsine transformed to approximate a normal distribution. A general linear model (PROC GLM; SAS Institute 2002) was constructed with starting position, day of trial and adjacency (i.e., were channel catfish more likely to enter the cod if other fish were already there), and their interactions as factors. Day and adjacency were included as factors to address whether escapement rates remained the same, increased, or decreased over the three trial days and to determine whether treatment adjacency influenced escapement. The probability level of significance for all statistical analyses was set at $\alpha = 0.05$. Pairwise comparisons of least-square means were conducted on significant model factors to determine differences in escapement rates to ending positions.

Escapement for 2009 experiments was determined in the same manner. A general linear model (PROC GLM; SAS Institute 2002) was constructed with day of trial, fish density, and cod throat configuration (restricted or unrestricted) and their interactions as factors followed by pairwise comparisons of least-square means for significant factors. A Kruskal–Wallis test was applied to the length-frequency distributions for each escapement frequency group using the methods described by Neumann and Allen (2007) to determine if escapement rates were related to channel catfish total length.

Results

Trials for Basal Escapement from Net Compartments

A total of 216 individually marked channel catfish was used for three consecutive days to conduct the escapement evaluation in 2008. A single mortality was recorded during the experiment. Tag loss was minimal with 48 fish shedding tags throughout the trials at a rate of less than 1/pen/d. All but four fish that shed their tags could be assigned the correct ending position. The information from those four individuals was not included in the analysis of escapement.

Of the 636 recorded observations, slightly less than half (48%, 304/636) did escape from their starting position. The general linear model was significant ($P < 0.0001$, df = 17, $F = 18.95$) with starting position ($P < 0.0001$, df = 2, $F = 108.1$), day of trial ($P = 0.0003$, df = 2, $F = 8.83$), and their interaction ($P = 0.0005$, df = 4, $F = 5.52$) as significant factors. The adjacency of other fish at the beginning of a trial and interactions with starting position and day were not significant and were therefore excluded from pairwise comparisons.

Of the 304 channel catfish that were no longer in their starting position after 24 h, 157 escaped the mid compartment, 138 entered the net (escaping the starting position of "outside"), and 9 escaped the cod end compartment (Table 1). No daily differences in escapement rates were detected for either the cod or mid starting positions, but fish placed outside the hoop nets in the raceway pens as a starting position escaped significantly less often on the third than the first or second days of the trial.

Escapement to other positions, as determined through paired comparisons (Figure 2), found no differences in the rate that channel catfish left the cod end (4.2%, 9/213) and ended the trial in the mid compartment (1.4%, 3/213) or outside (2.8% 6/213) of the hoop net. However, the rate at which they escaped the mid compartment and entered the cod end (56%, 118/212) versus exiting the hoop net to the

TABLE 1. Escapement rates of channel catfish from hoop nets in daily trials by starting position (Cod = cod end compartment, Mid = entrance compartment inside the mouth, Out = area outside the net but within the raceway pen) reported by ending position and day of trial, percent escapement, with number subjects escaping and total used in the trial.

Starting position	Ending position	Daily escapement rates: Day 1	Day 2	Day 3	Totals
Cod	Mid	4.2% (3/72)	0% (0/72)	0% (0/72)	1.4% (3/213)
	Out	1.4% (1/72)	4.2% (3/72)	2.9% (2/72)	2.8% (6/213)
	Combined	5.6% (4/72)	4.2% (3/72)	2.9% (2/69)	4.2% (9/213)
Mid	Cod	70.8% (51/72)	47.8% (33/69)	47.9% (34/71)	55.7% (118/212)
	Out	8.3% (6/72)	18.8% (13/69)	28.2% (20/71)	18.4% (39/212)
	Combined	79.2% (57/72)	66.7% (46/69)	76% (54/71)	74.1% (157/212)
Out	Cod	69.4% (50/72)	62.3% (43/69)	32.9% (23/70)	55% (116/211)
	Mid	18.1% (13/72)	13.0% (9/72)	0% (0/72)	10.4% (22/211)
	Combined	87.5% (63/72)	75.4% (52/69)	32.9% (23/70)	65.4% (138/211)

pen outside (18%, 39/212) was significantly different ($P < 0.0001$, df = 35, $t = 4.80$). Channel catfish placed in the raceway that entered the net during a trial were retained disproportionally ($P < 0.0001$, df = 35, $t = 6.52$) more often in the cod end (55%, 116/211) versus the mid compartment (10%, 22/211) across all trials. However, the rate of these fish entering the net declined substantially by day 3. On day 1, 88% (63/72) of the channel catfish placed in the raceway entered the net, 75% (52/69) on day 2, and 33% (23/70) on day 3.

Trials for Basal Escapement as Function of Fish Density and Throat Configuration

A total of 660 channel catfish was used for three consecutive days of trials being randomly assigned each

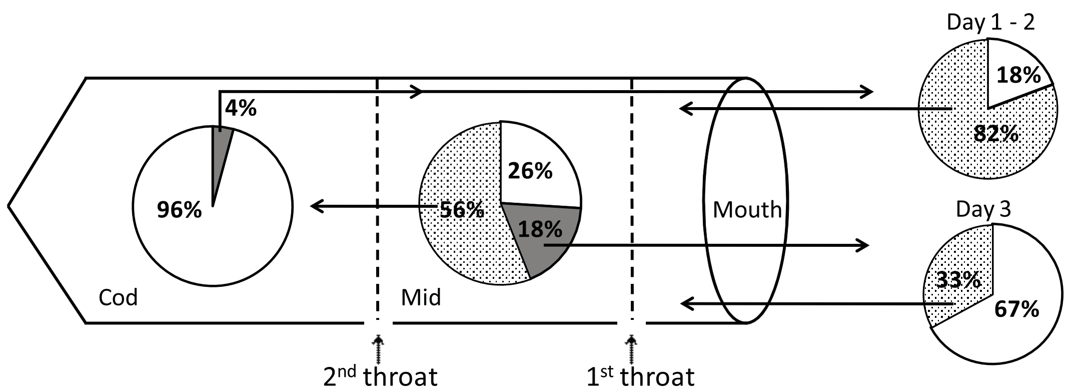

FIGURE 2. Experiment diagram and results of escapement analysis through interior fingered crow-foot throats of a standard hoop net. The first throat's cords are attached to hoop frames and the second throat's cords were fastened together (restricted) and exited the rear of the net. Pie charts illustrate rates of escapement (gray fill) and retention (no fill) from the cod end compartment (Cod) and the first entrance (Mid) compartment. Arrows indicate direction of escapement from their starting position; lines crossing multiple positions indicate no significant difference between ending positions. Pattern fill indicates rate of subjects entering the net from the exterior raceway or entering the Cod end from the Mid net compartment. Right-hand charts represent rates of entry by subjects placed outside the net in the raceway pen and their subsequent entry into the net (no significant difference in ending positions). Entry into the net was not significantly different between the first and second days of the trial but was significantly lower on day 3. See Table 1 for complete list of escapement rates.

day to one of four treatments. The number of channel catfish escaping each day of the trial from all treatments was nearly identical, ranging from 31% to 32% (205/660 on day 1, 214/660 on day 2, and 213/660 on day 3). We identified significant differences in escapement rates by starting fish density ($P < 0.0001$, df = 1, $F = 77.61$), cod throat configuration ($P < 0.0001$, df = 1, $F = 30.32$), and their interaction ($P < 0.0001$, df = 1, $F = 26.30$), but not by day of trial. Channel catfish escapement (Figure 3) was the lowest 13.3% (12/90) for low density and restricted throats and the highest for unrestricted throats and high density (51.9%, 467/900). The high density and restricted throat treatment yielded a 14.3% escapement rate (129/900), and the unrestricted throat low density escapement rate was 26.7% (24/90).

The proclivity of a few individual channel catfish to continuously escape and skew our results did not occur. In three days of trials, we found that only 2.2% (15/664 channel catfish used in 2009 experiments) escaped the cod end in every trial while 31% (208/664) never escaped the cod end, 44% (294/664) escaped once, and 22% (147/664) escaped twice, suggesting that a few individuals did not influence trial results. Examining differences between multiple length frequency distributions using a Kruskal–Wallis test indicated no significant differences (chi-square statistic = 8.15; 4 df; $P = 0.086$) in the lengths of fish that escaped once, twice, three times or fish that never escaped.

Discussion

We provided initial estimates of the probabilities associated with the movement of channel catfish between compartments within hoop nets in lentic systems. Conducting trials on individual hoop nets without the influence of bait confirms that a basal level of escapement occurs daily, and while escapement from hoop nets with restricted cod throats can be considered low, it is measurable. These data will assist managers and researchers when determining the level of precision needed for appropriate population assessments using hoop nets.

The escapement rates for channel catfish at low treatment densities through restricted cod throats was similar for 2008 (4.2%) and 2009 (13.3%), suggesting that retention efficiency should range from approximately 85% to 95% with this gear configuration. Increasing the fish density (a magnitude, 60

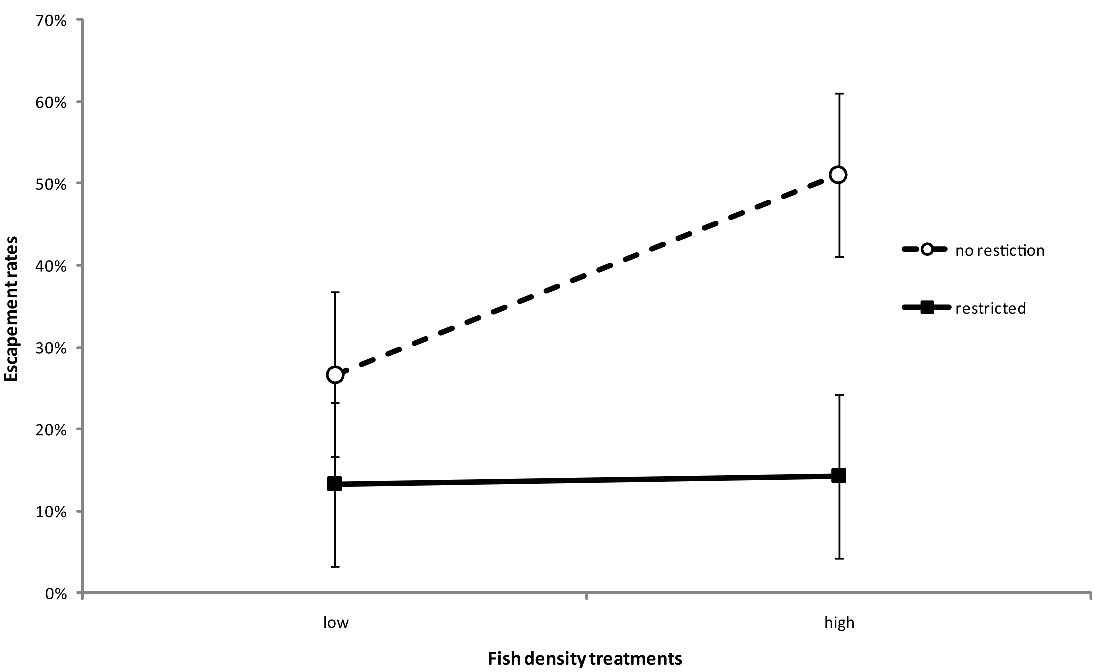

FIGURE 3. Escapement rates (±SE) of channel catfish from cod compartments of hoop nets undergoing treatments with two levels of starting fish density (low and high) and two levels of cod throat configuration (restricted or unrestricted).

versus 6 subjects) did result in slightly more escapement (14.3%) with this gear configuration, but dramatically more escapement (51%) occurred without the cod throat restriction. The interaction of cod throat configuration and fish density both contribute to the rate of escapement from hoop nets. While our study design included both cod throat design configurations, it only measured the escapement rates at two treatment density levels, which has previously been implied as a significant factor influencing escapement (Breen and Ruetz 2006). By using only two treatment level densities, we increased the rigor of our study design but limited our scope of inference. We choose to use two densities that were a magnitude apart in scale but still commonly seen by managers in the field when sampling lentic waters with hoop nets. At the low density treatments, escapement rates doubled between the restricted and unrestricted cod throats, but at the high density treatment, escapement rates more than tripled, suggesting that the relation between cod throat configuration and fish density may not be simply proportional. Further defining this relation at higher but less frequently encountered capture densities and for other lengths of channel catfish would be of value to both managers and researchers. Even if capture densities of more than 60 channel catfish per hoop net are less frequent, they may still constitute a large portion of the population sample, and if escapement rates change at higher densities or for different lengths of fish, the assumptions of homogeneous capture probabilities are no longer applicable, which has implications for both mark–recapture and basic population investigations.

Previous research has suggested that the configuration of net throats may influence the escapement and retention of fish species. Hansen (1944) described one limitation of unrestricted fingered throat designs when he indicated that only fish approaching the throat from the sides but not from above, below, or directly in front might have a reduced opportunity for escapement. Sullivan and Gale (1999) and Vokoun and Rabeni (1999) restricted the cod throats of their hoop nets, suggesting that it should improve retention of catfish. We provide additional support for restricting cod throats and quantified differences in escapement rates between hoop nets with and without cod throat restrictions. Unrestricted cod throats permitted 26.7% and 51.9% escapement at low and high densities, respectively, reducing retention efficiency to 48–73% compared to efficiencies of more than 85% on restricted throat nets. These results emphasize the importance of standardizing the restriction of the cod end throat configuration and the importance of reporting gear configurations when publishing study findings. Comparisons of catch per unit effort between or within populations sampled by hoop netting with and without restricted throats should not be made as escapement differences essentially classify these as separate gears, especially when densities vary significantly between sample sites.

The practice of baiting (waste cheese or soybean meal products placed inside nets as an attractant) to increase catch (Pierce et al. 1981) is commonly used in population surveys and differences in bait type can influence catch rates (Flammang and Schultz 2007), as long as the bait is present. Our study was not designed to explore the relation between encounter rates and capture efficiency of hoop nets, but rather what proportion of channel catfish entering a hoop net we can expect to be retained and the effect it may have on catch. For example, if bait is completely consumed within 24 h, the attractant ability is removed but the rate of escapement continues throughout the remaining 48 h of a typical 3-d gear deployment period, further underestimating catch.

Numerous factors influence catch rates with entrapment gears (Hubert 1996). Within a single gear type, there have been a number of documented effects by species behaviors (Shoup et al. 2003), seasonal variations (L. K. Richters, unpublished data), diel patterns (Shoup et al. 2004), presence of conspecifics during spawning seasons (Young et al. 2003; Johnson et al. 2005) or predators (Breen and Ruetz 2006), and duration of deployment (Hamley and Howley 1985; Zhou and Shirley 1997), but other species-specific influences may be occurring as well. The significant decrease in rates of entry into the gear on the third day of trials by channel catfish placed in the raceway outside the nets raises some interesting questions on potential influences of learned behavior and could be an especially important consideration for analyses, though the rates of escapement from compartments did not change throughout the trial period. Buckmeier and Schlechte (2009) suggested that trap avoidance may have been a factor in their evaluation of channel catfish hoop net capture efficiency and noted the potential for influencing mark–recapture studies. Our data suggests that these results have implications for other gears using fingered crow-foot throats, including fyke or trap style nets, typically used to assess littoral fish assemblages. Do escapement rates through unrestricted fingered crow-foot throats vary by species and are they also influenced by density? Will restricting these throats in a similar fashion reduce escapement and increase precision of these gears? These are some of the same questions originally asked by Hansen (1944) and Patriarche (1968) and are only partially answered today.

We recommend that managers and researchers studying channel catfish with hoop nets in lentic systems standardize the use of restricting the cod throat to enhance precision in population studies, especially when variable densities may be encountered. Furthermore, we encourage authors to accurately report within their methods section or gear descriptions whether cod throat restrictions were utilized or not to facilitate accurate interpretation and comparison with other study results. Standardized application of this gear will aid in management decisions by ensuring accurate communication and application of sampling results.

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