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Abstract.—Twenty-six Nebraska water bodies representing two ecosystem types (small standing waters and large standing waters) were surveyed during 2008 and 2009 with tandem-set hoop nets and experimental gill nets to determine if similar trends existed in catch rates and size structures of channel catfish Ictalurus punctatus captured with these gears. Gear efficiency was assessed as the number of sets (nets) that would be required to capture 100 channel catfish given observed catch per unit effort (CPUE). Efficiency of gill nets was not correlated with efficiency of hoop nets for capturing channel catfish. Small sample sizes prohibited estimation of proportional size distributions in most surveys; in the four surveys for which sample size was sufficient to quantify length-frequency distributions of captured channel catfish, distributions differed between gears. The CPUE of channel catfish did not differ between small and large water bodies for either gear. While catch rates of hoop nets were lower than rates recorded in previous studies, this gear was more efficient than gill nets at capturing channel catfish. However, comparisons of size structure between gears may be problematic.

Introduction

Channel catfish *Ictalurus punctatus* are notoriously difficult to sample in lentic systems. Gill nets are the primary sampling method used by state agencies to sample channel catfish in small impoundments and reservoirs, despite their known size selectivity and low, variable catch rates (Hubert 1983; Michaletz and Dillard 1999). Managers often express a need for more effective sampling methods that will provide adequate data to estimate abundance, size and age structure, and growth rates (Vanderford 1984; Michaletz and Dillard 1999; Brown 2007).

Recently, several Midwest agencies recommended the use of baited, tandem-set hoop nets to assess channel catfish populations in small impoundments (Sullivan and Gale 1999; Michaletz and Sullivan 2002; Flammang and Schultz 2007). Sullivan and Gale (1999) reported tandem-set hoop nets fished for 48 h yielded catch rates that were 5.6 times greater than experimental gill nets when catch rates were compared based on personnel-hours invested. Michaletz and Sullivan (2002) reported in a 2001 survey of 66 small impoundments in Missouri that a tandem-set hoop-net series consisting of three nets, baited with waste cheese and fished for 72 h, captured on average of about 90 channel catfish. Similarly, Flammang and Schultz (2007) report that tandem-set hoop nets captured an average of about 100 channel catfish/series in summer surveys of 72 h duration using nets baited with soybean cake.

Though tandem-set hoop nets can be effective at capturing large quantities of channel catfish in small impoundments, there remains uncertainty as to their ability to capture fish in large standing waters. Our intent was to determine if similar trends existed for catch rates of channel catfish between tandem-set hoop nets and experimental gill nets fished in Nebraska's small and large standing waters. Additionally, we intended to determine whether size structure of captured fish differed between gears.

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Methods

Channel catfish were collected during 2008 and 2009 from 26 water bodies using tandem-set hoop nets and experimental gill nets. Water bodies were classified as small (≤200 ha) or large (>200 ha) standing waters (Bonar et al. 2009). A single survey was conducted with each gear at 14 small standing waters and 12 large standing waters (Table 1). Small standing waters included flood-control reservoirs and excavated pits. Small flood-control impoundments are characterized by relatively shallow depths and restricted limnetic zones, whereas excavated pits are characterized by narrow littoral zones and steep sloping banks (Pope et al. 2009). Large standing waters included irrigation reservoirs and

TABLE 1. Size structure of stock-length channel catfish from tandem-set hoop-net and gill-net surveys (2008–2009) of 26 Nebraska water bodies representing two ecosystem types, small standing waters (SSW), and large standing waters (LSW). *N* is the total number of fish captured. Range is the minimum and maximum 10-mm length-groups in which fish were sampled. Minimum lengths of channel catfish for stock (*S*), quality (*Q*), preferred (*P*), and memorable (*M*) lengths are 280, 410, 610 mm, and 710 mm, respectively. Proportional size distribution (PSD), PSD-*P*, and PSD-*M* were calculated for surveys where *N* > 25.

	Hoop nets					Gill nets				
Water body	*N*	Range	PSD	PSD-*P*	PSD-*M*	*N*	Range	PSD	PSD-*P*	PSD-*M*
SSW										
Wagon Train	90	280–720	59	8	2	55	300–780	91	51	20
Zorinsky	422	280–900	5	0	0	22	280–790	[a]	[a]	[a]
Conestoga	35	280–610	54	3	0	7	280–590	[a]	[a]	[a]
East Twin	167	310–680	54	1	0	11	340–510	[a]	[a]	[a]
Stagecoach	214	280–690	2	1	0	26	300–700	8	4	0
Summit	9	280–730	[a]	[a]	[a]	6	290–550	[a]	[a]	[a]
Standing Bear	6	390–670	[a]	[a]	[a]	3	430–660	[a]	[a]	[a]
Walnut Creek Lake	151	280–920	61	28	16	14	340–530	[a]	[a]	[a]
North Platte I-80	249	280–700	13	3	0	0				
Willow Island	3	700–770	[a]	[a]	[a]	0				
Blue Hole	35	310–630	37	3	0	8	300–700	[a]	[a]	[a]
Cheyenne	11	370–420	[a]	[a]	[a]	3	290–530	[a]	[a]	[a]
Bassway Strip West	3	320–730	[a]	[a]	[a]	1	330	[a]	[a]	[a]
Two Rivers	162	280–750	35	12	4	24	280–720	[a]	[a]	[a]
LSW										
Harlan	56	280–670	23	5	0	38	280–720	71	29	5
Swanson	33	410–590	100	0	0	0				
Merritt	38	340–700	37	5	0	0				
Sherman	26	310–820	85	12	8	55	290–750	31	2	2
Minatare	37	310–570	41	0	0	17	280–640	[a]	[a]	[a]
Branched Oak	19	280–670	[a]	[a]	[a]	29	310–710	45	7	3
Red Willow	74	280–820	61	16	5	13	340–730	[a]	[a]	[a]
Box Butte	33	280–640	58	6	0	0				
Elwood	17	320–640	[a]	[a]	[a]	5	300–730	[a]	[a]	[a]
Whitney	53	280–440	6	0	0	14	380–360	[a]	[a]	[a]
Pawnee	81	280–680	46	9	0	13	290–660	[a]	[a]	[a]
Willow Creek Lake	393	280–720	49	2	1	0				

[a] Insufficient data to calculate PSD values.

flood-control reservoirs and are characterized by having two distinct environments, the littoral and limnetic zones (Miranda and Boxrucker 2009), and by relatively cooler summer temperatures than small standing waters (Pope et al. 2009). Irrigation reservoirs experience seasonal fluctuations in water levels, whereas flood control reservoirs maintain relatively stable water levels.

Tandem-Set Hoop Nets

Tandem-set hoop-net surveys were conducted during June–August in accordance with methodology established for small impoundments in Missouri and Iowa (Michaletz and Sullivan 2002; Flammang and Schultz 2007). Tandem-set hoop nets consisted of three nets, attached bridle to cod end, an anchor, and two weights. A 6.8-kg winged anchor was attached to the rear net, and a 4.5-kg concrete weight was attached between the front and middle nets to reduce buoyancy. An additional 4.5-kg weight was attached to the bridle of the front net to prevent the series from collapsing. Nets were baited with soybean cake pellets as a fish attractant (Flammang and Schultz 2007). Hoop nets measured approximately 3.4 m in length and were constructed of #15 twine with 25.4-mm bar mesh and seven fiberglass hoops, the largest of which was 0.8 m in diameter and equipped with a bridle of 1-m rope. Two-fingered crow foot throats were attached to the second and fourth hoops. To reduce escapement from the cod end, the rear throat was constricted with plastic zip ties (Porath et al., in press). Nets were set parallel to the shoreline along a constant depth profile, above the thermocline and at a depth of 1–6 m. Orientation of net mouths was randomly determined (uplake or downlake) for each set. Using existing bathymetric maps or aerial photographs, sampling sites were randomly selected from points marked at 200-ft intervals along the perimeter of the water body. Randomly selected sites that proved to have steep slopes, heavy vegetation, or significant development (i.e., boat docks or swimming beaches) were substituted with more appropriate, randomly selected sites. The number of tandem sets employed on a water body was determined by size of water body: four for water bodies ≤20 ha, six for water bodies greater than 20 and ≤60 ha, and eight or nine for water bodies greater than 60 ha. Tandem-set hoop nets (hereafter referred to as hoop nets) were fished undisturbed for three consecutive nights (approximately 72 h).

Experimental Gill Nets

Experimental gill-net surveys were completed during September–October, in accordance with Nebraska's standardized sampling protocol. Where available, sample sites were selected from Nebraska Game and Parks Commission (NGPC) standard survey locations (Zuerlein and Taylor 1985). Site selection by NGPC was intended to maximize catch of target species, often walleye *Sander vitreus*. For water bodies that lacked standardized sampling sites for gill nets, sites were selected in open water areas with depths and benthic topography suitable for gill-net deployment (Hubert 1983). Experimental gill nets were fished on the bottom, set perpendicular to shore, and oriented with the smallest mesh nearshore. Gill-net surveys were conducted after waters destratified; therefore, thermocline was not a consideration in gill-net placement. Nets were constructed from monofilament webbing; dimensions were 45 × 1.8 m with 9-m panels of 13-mm, 19-mm, 25-mm, 32-mm, and 38-mm bar measure mesh sizes. Gill-net surveys consisted of four nets per water body, in accordance with Nebraska standards. Experimental gill nets (hereafter referred to as gill nets) were fished undisturbed overnight (approximately 24 h).

Analysis

For hoop-net and gill-net surveys, total length (nearest millimeter) was measured for all fish captured. Studies indicate that tandem-set hoop nets do not capture fish less than 250 mm in proportion to their abundance (Michaletz and Sullivan 2002; Buckmeier and Schlechte 2009). Accordingly, we chose to consider only stock-length fish for gear comparison. Minimum total lengths of channel catfish for stock (*S*), quality (*Q*), preferred (*P*), and memorable (*M*) lengths are 280, 410, 610, and 710 mm, respectively (Gabelhouse 1984).

Catch per unit effort (CPUE; number per net-night) was calculated as the number of channel catfish caught per 72-h tandem series for hoop nets and per 24-h net set for gill nets. Pearson's correlation was used to determine whether there was a relationship in catch rates of channel catfish sampled in hoop nets and gill nets for each ecosystem type. We used analysis of variance (ANOVA) to compare catch rates between ecosystem types for both gears. For this analysis, CPUE was log-transformed to better meet the assumptions of normality and homogeneity of variances. Statistical significance was assumed at $\alpha = 0.05$ for all assessments.

To quantify gear efficiency, we used CPUE from each survey to determine the effort required to capture 100 channel catfish (E_{100}). In order to calculate an E_{100} value in instances where CPUE was zero, we added 1 to the total catch at each water body. We then recalculated CPUE and divided that estimate into 100 to calculate E_{100} for each water body. We chose an effort threshold of 100 fish based on Anderson and Neumann's (1996) recommendation that a sample of ≥100 fish is optimal for estimating proportional size distribution (PSD). Pearson's correlation was used to determine whether there was a relationship in the number of net-nights required to capture ≥100 channel catfish in hoop nets and gill nets.

Size structure was quantified using PSD, PSD of *P* length fish (PSD-*P*), and PSD of *M* length fish (PSD-*M*) (Guy et al. 2006). Channel catfish catch in gill nets was insufficient for PSD estimation (<100) in all 26 surveys, and channel catfish catch in hoop nets was insufficient in 21 of 26 surveys. Therefore, PSD, PSD-*P*, and PSD-*M* were calculated for water bodies where total catch exceeded 25 channel catfish (Table 1). A Kolmogorov-Smirnov test was used to compare length-frequency distribution between gears in four water bodies (Harlan County, Sherman, Stagecoach, and Wagon Train) where total catch exceeded 25 channel catfish in both hoop-net and gill-net surveys.

Results

Catch Rates

Catch per unit effort of channel catfish was greater in hoop nets than gill nets for 21 of 26 water bodies (Figure 1). Among ecosystem types, channel catfish CPUE in hoop nets did not differ significantly between small and large standing waters (ANOVA, F = 0.23; df = 1,24; P = 0.63). Mean ± SE CPUE in hoop nets was 13.9 ± 3.5. Similarly, channel catfish CPUE in gill nets did not differ significantly between small and large standing waters (F = 0.27; df = 1,24; P = 0.61). Mean ± SE CPUE in gill nets was 3.8 ± 0.8. The CPUE of channel catfish in hoop nets was not correlated with CPUE in gill nets in small (r = 0.17; N = 14; P = 0.57) or large (r = –0.28; N = 12; P = 0.39) standing waters.

Gear Efficiency

In small standing waters, median E_{100} values were 9 for channel catfish in hoop nets (25% quartile = 4 and 75% quartile = 81) and 32 in gill nets (25% quartile = 19 and 75% quartile = 100). In large standing waters, median E_{100} values were 21 for channel catfish in hoop nets (25% quartile = 13 and 75% quartile = 25) and 28 in gill nets (25% quartile = 14 and 75% quartile = 250). The E_{100} value ranged from 2 to 100 for channel catfish in hoop nets and from 7 to 400

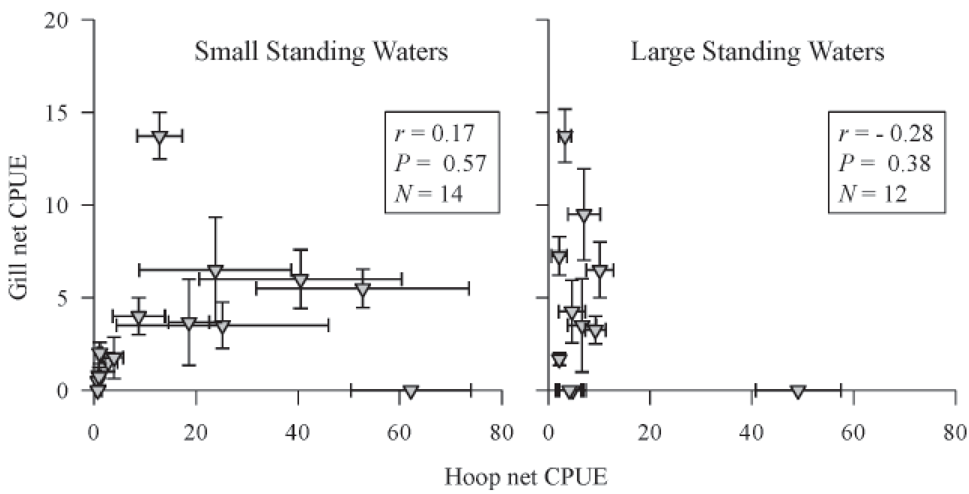

FIGURE 1. Mean ± SE catch per unit effort (CPUE; number per net-night) for stock-length channel catfish captured with tandem-set hoop nets and gill nets during 2008 and 2009 from 26 Nebraska water bodies representative of two ecosystem types: small standing waters (N = 14) and large standing waters (N = 12). Pearson's correlation statistics comparing channel catfish CPUE in hoop nets and gill nets are indicated for each ecosystem type.

in gill nets (Table 2). The E_{100} values of channel catfish in hoop nets and in gill nets were not correlated in small (r = 0.51; N = 14; P = 0.06) or large (r = –0.23; N = 12; P = 0.47) standing waters. Hoop nets were more efficient (i.e., the E_{100} value was less) in 20 of 26 water bodies, and gill nets were more efficient in 5 of 26 water bodies. In most instances, efficiency values did not differ greatly between gears; however, in 5 of 26 water bodies, hoop nets greatly outperformed gill nets (i.e., E_{100} of channel catfish in gill nets was 10–200 times greater than in hoop nets) (Table 2; Figure 2).

Size Structure

Length-frequency distributions were estimated for channel catfish from Harlan County, Sherman, Stagecoach, and Wagon Train reservoirs and were significantly different between gears (P < 0.03) at each water body (Figure 3). In small standing waters, PSD was greater for channel catfish in gill nets than hoop nets at both Wagon Train and Stagecoach reservoirs (PSD_{gill} = 91; PSD_{hoop} = 59 and PSD_{gill} = 8; PSD_{hoop} = 2, respectively). In large standing waters, PSD for channel catfish was greater in gill nets than

TABLE 2. Summary of stock-length channel catfish catches (2008–2009) using two gears in 26 Nebraska water bodies representing two ecosystem types, small standing waters (SSW), and large standing waters (LSW). Catch per unit effort (CPUE) is the mean catch per 72-h tandem-set series (hoop) or per net night (gill). Range is the minimum and maximum catch per survey. E_{100} is the effort required to capture 100 channel catfish.

		Hoop				Gill			
Water body	Area (ha)	Effort	CPUE	Range	E_{100}	Effort	CPUE	Range	E_{100}
SSW									
Wagon Train	127	7	12.9	1–35	8	4	13.8	11–17	7
Zorinsky	103	8	52.8	4–187	2	4	5.5	3–8	17
Conestoga	93	9	3.9	0–17	25	3	2.3	1–5	38
East Twin	85	9	18.6	2–43	5	3	3.7	0–8	25
Stagecoach	79	9	23.8	0–139	4	4	6.5	3–15	15
Summit	77	8	1.1	0–3	80	3	2.0	1–3	43
Standing Bear	55	6	1.0	0–2	86	4	0.8	0–2	100
Walnut Creek	28	6	25.2	0–129	4	4	3.5	1–7	27
North Platte I-80	11	4	62.3	30–84	2	2	0		200
Willow Island	10	4	0.8	0–3	100	2	0		200
Blue Hole	10	4	8.8	0–20	11	2	4.0	3–5	22
Cheyenne	7	4	2.8	0–8	33	2	1.5	1–2	50
Bassway Strip West	4	4	0.8	0–1	100	2	0.5	0–1	100
Two Rivers	3	4	40.5	2–96	2	4	6.0	2–9	16
LSW									
Harlan	5463	8	7.0	0–28	14	4	9.5	4–16	10
Swanson	2013	8	4.1	0–22	24	4	0		400
Merritt	1176	8	4.8	0–22	21	2	0		200
Sherman	1151	8	3.3	0–10	30	4	13.8	10–17	7
Minatare	873	8	4.6	0–17	21	4	4.3	1–9	22
Branched Oak	728	9	2.1	0–14	45	4	7.3	5–9	13
Red Willow	659	8	9.3	0–19	11	4	3.3	2–5	29
Box Butte	647	8	4.1	0–20	24	4	0		400
Elwood	538	8	2.1	0–5	44	3	1.7	1–2	50
Whitney	364	8	6.6	0–19	15	4	3.5	0–11	27
Pawnee	299	8	10.1	2–21	10	2	6.5	5–8	14
Willow Creek Lake	283	8	49.1	17–92	2	4	0		400

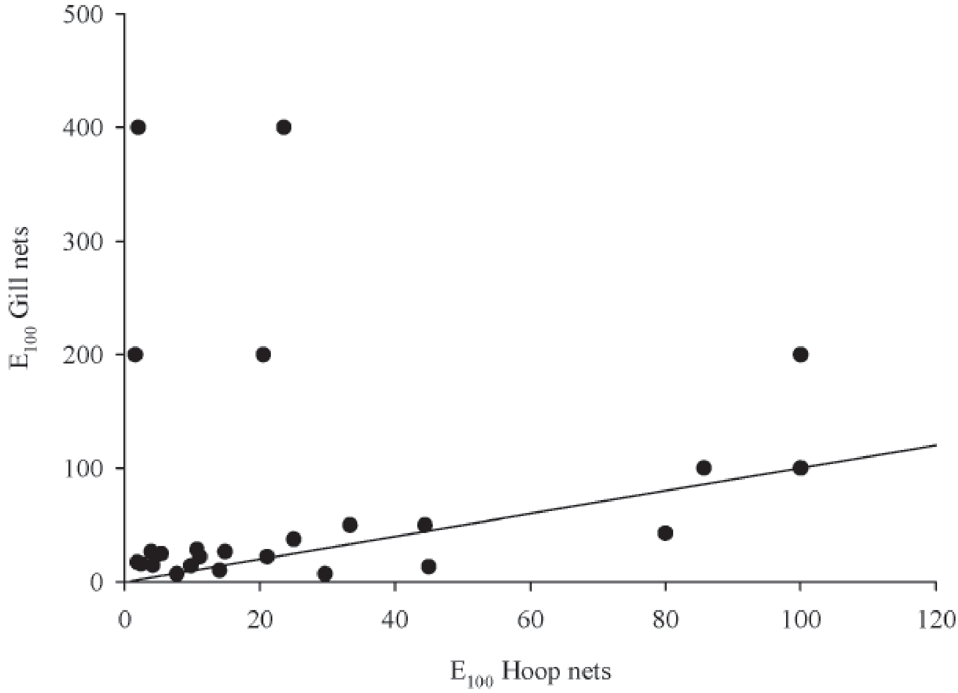

FIGURE 2. Efficiency (E_{100}; number of net-nights required to capture ≥100 fish) of tandem-set hoop nets and gill nets for capturing channel catfish during 2008 and 2009 in 26 Nebraska water bodies. Reference line (1:1) indicates equal E_{100} between these two gears.

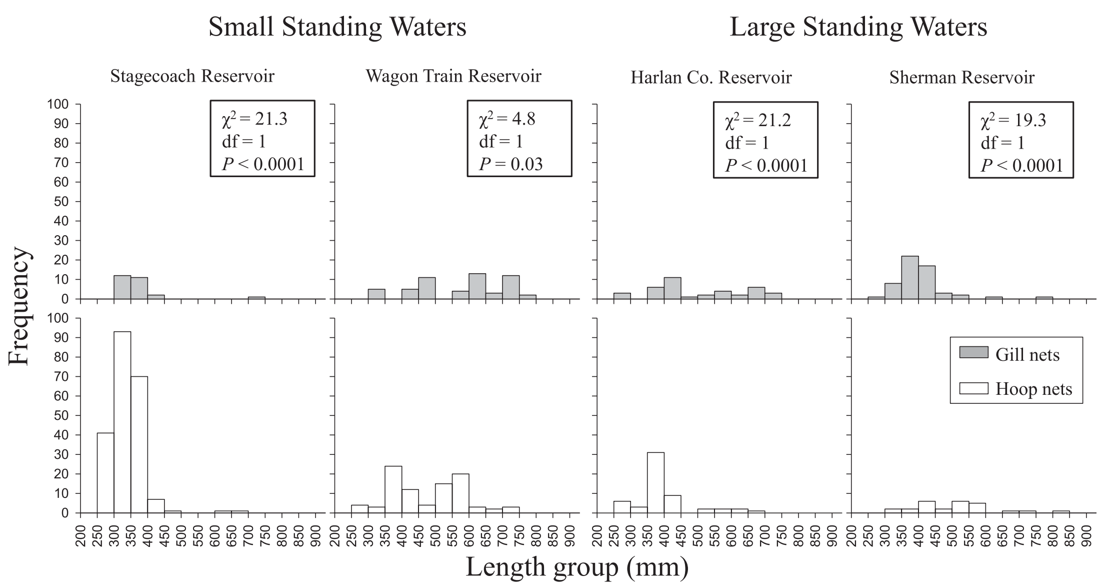

FIGURE 3. Length-frequency distributions of stock-length channel catfish captured with tandem-set hoop nets and gill nets during 2008 and 2009 from four Nebraska water bodies representing two ecosystem types: small standing waters and large standing waters. Kolmogorov-Smirnov test statistics comparing hoop-net and gill-net catches are indicated for each water body.

hoop nets at Harlan County Reservoir (PSD_{gill} = 71; PSD_{hoop} = 23) and was greater in hoop nets than gill nets at Sherman Reservoir (PSD_{gill} = 31; PSD_{hoop} = 85) (Table 1).

Discussion

In 20 of 26 surveys, hoop nets were more efficient than gill nets (i.e., 100 fish could be captured with fewer hoop-net sets than gill-net sets). Perhaps this is a function of the longer soak time (72 h to 24 h). We did not consider personnel hours invested for this study, though Sullivan and Gale (1999) found that hoop nets catch more fish than gill nets with similar personnel effort, due to the large amount of bycatch associated with gill nets and the time invested in untangling and removing fish (bycatch and target species). For hoop-net surveys, longer soak time and an increased number of nets, as compared to gill-net surveys, are not associated with an increase in personnel effort. Additionally, mortality is greatly reduced in hoop nets. For example, Sullivan and Gale (1999) reported no channel catfish mortality and 8% bycatch mortality in hoop nets; in gill nets, they reported 8% channel catfish mortality and 82% bycatch mortality. Similarly, Michaletz and Sullivan (2002) reported only 0.3% channel catfish mortality in hoop nets. Therefore, while greater catch in hoop nets may be a function of longer soak time, this information is of value to management because increased catch without an associated increase in effort, as well as the low mortality associated with hoop nets, are desirable.

Though we found that hoop nets captured more fish than gill nets (total catch was greater in hoop nets for 23 of 26 water bodies), we did not observe catch rates that approached those of previous studies, where channel catfish CPUE in hoop nets averaged 90–100 fish per series (Michaletz and Sullivan 2002; Flammang and Schultz 2007). Even with the inclusion of substock-length (<280 mm) channel catfish, average CPUE did not approach 100 fish per series. The mechanism causing comparatively lower catch rates in this study is unknown. While it is possible that lower catch rates of channel catfish with hoop nets reflect regional variability in populations, our catch rates of channel catfish with gill nets were similar to other recorded catches. For example, Sullivan and Gale (1999) reported a median catch rate of 14.1 channel catfish per gill net-night at Longview Lake, Missouri, and in this study, median catch rate (inclusive of substock-length channel catfish) was 12.5 channel catfish per gill net-night.

Our study did not address whether hoop nets capture channel catfish in proportion to their true abundance, but Buckmeier and Schlechte (2009) found that channel catfish samples collected with hoop nets provide accurate estimates of size structure and relative abundance.

Additionally, they reported that length distribution of captured fish was similar between hoop nets and gill nets. In contrast, among the four water bodies that we assessed in this study, length-frequency distributions of channel catfish were dissimilar between gears. It is difficult to state the nature of these differences due to the small sample sizes of channel catfish collected during our surveys; however, these findings suggest that comparisons of channel catfish size structure between hoop nets and gill nets should be made with caution.

In general, hoop nets are effective for capturing channel catfish in small impoundments (Michaletz and Sullivan 2002; Flammang and Schultz 2007). In this study, hoop nets captured enough fish for PSD estimates in 6 of 14 surveys of small standing waters and 1 of 12 surveys of large standing waters. Additionally, hoop nets were more efficient in small standing waters (median E_{100} = 9) than in large standing waters (median E_{100} = 21). However, CPUE of channel catfish in hoop net surveys did not differ between small and large standing waters, suggesting that while hoop nets may be less efficient at capturing fish in large water bodies, with increased effort they can be an effective sampling method in both small and large standing waters.

We found that catch rates of channel catfish with hoop nets in a single survey of 4–8 tandem sets are often not sufficient to estimate standard population indices. For example, Vokoun et al. (2001) recommend a minimum 300 fish for an accurate description of population size structure. Michaletz and Sullivan (2002) agreed that 300 channel catfish can provide sufficient information for size structure of the population vulnerable to the sampling method (i.e., fish $\geq$ 250 mm). In this study, hoop nets captured a minimum of 300 stock-length channel catfish in only 2 of 26 water bodies. Nonetheless, hoop nets capture more channel catfish than gill nets and can be a useful tool for managers wishing to gather data to inform a management decision. In Nebraska, if hoop nets are to be used for standard surveys, it may be necessary to increase effort to capture enough fish to make useful temporal comparisons of population indices, particularly in large water bodies. Hoop nets have previously been proven effective for capturing channel catfish in small standing waters, and they have potential utility for sampling channel catfish in large standing waters as well.

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