Catfish Sampling Techniques: Where We Are Now and Where We Should Go

Kristopher A. Bodine

Texas Parks and Wildlife Department, Heart of the Hill Fisheries Science Center, 5103 Junction Hwy, Mountain Home, TX 78058. E-mail: kris.bodine@tpwd.texas.gov

Daniel E. Shoup

Department of Natural Resource Ecology and Management, Oklahoma State University, Stillwater, OK

Jason Olive

Arkansas Game and Fish Commission, South Central Regional Office, Camden, AR

Zachary L. Ford

Missouri Department of Conservation, Clinton, MO

Rebecca Krogman

California Department of Fish and Wildlife, Fisheries Branch, Sacramento, CA

Tyler J. Stubbs

Mississippi Department of Wildlife, Fisheries, and Parks, Tupelo, MS

ABSTRACT: *We review the peer-reviewed literature regarding sampling of the three most commonly managed ictalurids: Channel Catfish, Blue Catfish, and Flathead Catfish. For each species, we summarize what is known about data quality (accuracy and precision) and sampling efficiency of the most commonly used gears for surveying these species. We identify research needs and provide information to guide gear selection based on different sampling objectives. To rank gear-specific sampling efficiency (catch/h and catch/person-h), we report median catch rates and the interpolated 25th and 75th percentiles of published means. We also describe the accuracy of relative abundance and size-related metrics for each gear. For Channel Catfish, tandem baited hoop nets provide the most efficient (11–24 fish/net/tandem set, 20–60 fish/person-h) and accurate samples. Low-frequency electrofishing provides the most efficient samples of Blue Catfish (23–373 fish/h, 2.1–11.3 fish/person-h) and Flathead Catfish (19–62 fish/h, 2.1–2.5 fish/person-h) and the most accurate samples of Blue Catfish. No accuracy studies exist for Flathead Catfish. Other gears examined for each species may also be useful for some sampling objectives; however, most are inefficient or lack accuracy.*

Técnicas de muestreo de bagres: dónde estamos y hacia dónde deberíamos dirigirnos

RESUMEN: *en este trabajo se hace una revisión de la literatura sobre el muestreo de los tres ictalúridos más comunmente explotados: el bagre de canal, el bagre azul y el bagre piltontle. Para cada especie, se resume lo que se sabe sobre la calidad de los datos (exactitud y precisión) y la eficiencia de muestreo de las artes (equipo) más frecuentemente utilizadas para muestrear estas especies. Se identifican necesidades de investigación y se brinda información que puede servir de guía para la selección de artes de pesca de acuerdo a los objetivos de muestreo. Con la finalidad de calificar la eficiencia específica del equipo de muestreo (captura-h y captura/persona-h) se reporta tanto la mediana de las tasas de captura como una extrapolación de los percentiles 25 y 75 de las medias reportadas en la literatura. También se describe la exactitud de las medidas de abundancia relativa y las relacionadas a la talla para cada arte. Para el bagre de canal, el tándem de redes de aros con carnada produjo las muestras más eficientes (11–24 peces/red/tándem, 20–60 peces/persona-h) y exactas. La electropesca de baja frecuencia fue el arte más eficiente para el bagre azul (23–373 peces-h, 2.1–11.3 peces/persona-h) y el bagre piltontle (19–62 peces-h, 2.1–2.5 peces/persona-h) y produjo las muestras más exactas en el caso del bagre azul. No existen estudios de exactitud para el bagre piltontle. Para cada especie se examinaron otras artes que pudieran ser útiles para ciertos objetivos de pesca; no obstante, la mayoría son ineficientes o carecen de exactitud.*

Growing interest in catfish angling has created a need to better understand ictalurid catfish populations. Unfortunately, inadequate sampling techniques (e.g., low catch or biased size and age distributions) have often precluded efforts to effectively describe catfish populations (Michaletz and Dillard 1999; Brown 2009). Limited knowledge of appropriate sampling gears and methods ranked as one of the more urgent constraints among catfish managers (Michaletz and Dillard 1999). Historically, few management agencies have devoted specific resources to catfish management (Arterburn et al. 2002). This likely contributed to the lack of sampling knowledge for these species. Developing new or improving existing techniques has since been a priority for catfish managers nationwide (Brown 2009).

In 1998, the First International Catfish Symposium provided the first organized platform for fisheries professionals to report research findings and identify future research needs specifically for catfish (Irwin et al. 1999). The symposium proceedings included six articles that examined catfish sampling techniques (i.e., gear comparisons), including one that summarized gear evaluations published prior to 1999 (Vokoun and Rabeni 1999). These six articles, coupled with other published studies, provided fisheries scientists with information necessary to begin designing and implementing effective (i.e., accurate and precise) and efficient catfish sampling procedures.

However, during this time, appropriate sampling procedures were still in the early stages of development (Flammang and Schultz 2007; Brown 2009). Most gear evaluation studies were based on methods needed to increase catch and gave little consideration to potential biases or precision. Although some resource agencies developed internal sampling standards, most were developed with little scientific guidance. Catfish managers still cite gear bias as one of the biggest constraints on ictalurid management (Brown 2009).

Since the first catfish symposium, evaluations of sampling techniques have proliferated (e.g., Michaletz and Sullivan 2002; Dumont and Schlechte 2004; Flammang and Shultz 2007; Buckmeier and Schlechte 2009; Bodine and Shoup 2010; Ford et al. 2011; Stewart and Long 2012). New techniques have been developed, and many existing techniques have been improved. A Second International Catfish Symposium, held in 2010, provided an opportunity for catfish scientists to present and discuss current research findings (Michaletz and Travnichek 2011). During this meeting, the Catfish Technical Committees from the American Fisheries Society's North Central and Southern divisions determined that there was a need to consolidate the most current information (i.e., including studies published after 1999, when the first catfish symposium proceedings were printed) about ictalurid catfish sampling. This article is the culmination of work from an ad hoc committee formed by these committees to address this need. Herein, we summarize the most current peer-reviewed literature (prior to 2013, with special emphasis on studies published after 1999) related to sampling the three ictalurids most commonly managed (as sportfish) or monitored (in regions where these species are exotic or invasive) in the United States: Channel Catfish (*Ictalurus punctatus*), Blue Catfish (*I. furcatus*), and Flathead Catfish (*Pylodictis olivaris*). For each species, we report what is known about gear performance characteristics (i.e., accuracy and precision [data quality] and sampling efficiency [number of fish collected per unit effort]) of the most commonly used gears. We summarize gear performance characteristics (1) within gear groups to identify gear-specific characteristics that improve performance and (2) among gear groups (e.g., tandem hoop nets/hoop nets/gill nets/etc.; group-specific studies pooled) to examine relative differences in performance among general groups. We identify future research needs and provide information to help managers and researchers select the best gear(s) for their sampling objective(s). This review may also help agencies develop standard sampling protocols for ictalurids and can provide information needed to establish accepted catfish sampling procedures for North America.

GEAR PERFORMANCE DEFINITIONS

The goal of sampling fishes is to collect a sample representative of the population being surveyed (i.e., accurate and precise) with the least effort (i.e., highest sampling efficiency). Unfortunately, there is no one-size-fits-all gear that will always meet this goal for sampling ictalurids. The target species and project objectives should be considered against trade-offs for each prospective gear. A particular sampling gear is rarely the most accurate, precise, and efficient simultaneously. Understanding performance characteristics of each gear allows the appropriate quality and quantity of data to be collected to accomplish project objectives. Gear performance can be broadly grouped into two main categories: data quality (accuracy and precision) and sampling efficiency. Definitions of these terms vary in the literature, so it is important to define them as used in this article.

We define *accuracy* as the closeness of a statistic obtained by sampling to the true value of the population parameter (Zale et al. 2012). Size-related metrics (e.g., length frequency) can be inaccurate if a gear is effective at capturing only a portion of the total size distribution (Reynolds 1996). Other metrics commonly used to measure changes in population abundance (e.g., catch per unit effort [CPUE]) can also be inaccurate if *catchability* (herein defined as the percentage of the true number of fish present in an area that are sampled by a given unit of effort; Bonar et al. 2009) changes between measurements (i.e., CPUE does not consistently correlate with population size). The accuracy of a metric can be affected by two independent factors: sampling gear and sampling design. A sampling gear can accurately estimate a desired metric at each independent sampling location (e.g., one 5-min electrofishing replicate) but still inaccurately estimate the entire statistical population. This occurs when appropriate spatial replication is lacking (e.g., sampling all habitat types), a condition that is more likely if minimum sample sizes are not met (Bodine et al. 2011). Therefore, accuracy of the sampling gear and the sample design must be quantified. To truly quantify accuracy, a gear must be used to sample a population with known characteristics (e.g., population size/density, size structure, etc.). Without known population characteristics, studies with controlled gear comparisons can only assess whether gear types differ. When they differ, it is not clear which is more accurate. Unfortunately, most accuracy studies are limited in this regard.

We define *precision* as the degree of reproducibility of the measurement (Zale et al. 2012). Precision is inversely related to dispersion (e.g., variance, standard deviation, etc.) and is a function of both inconsistent measurement error (i.e., variation in accuracy) and the distribution of values in the statistical population (e.g., the range of possible lengths of the individuals in the population). Precision directly affects the power needed to detect statistical differences (G. P. Quinn and Keough 2002). When comparing precision of multiple gear types, it is tempting to select the gear with lower variability. However, a gear can be highly precise but lack accuracy (e.g., lower variation in mean length sampled may be achieved by excluding smaller or larger fish that actually existed in the population). In these situations, higher precision may not be beneficial.

We define *sampling efficiency* as the number of fish collected per unit of effort from an area (i.e., catch rate). Effort can be expressed in several ways (e.g., catch/h, catch/person-h, catch/net night, etc.), depending on study objectives, and is not always consistently defined in peer-reviewed literature. This is problematic when comparing sampling efficiency across gear types or gear-specific variables. Sampling efficiency is important because time, cost, and manpower often limit utility of a gear type. Gears that produce higher catch rates are often preferred because the cost of generating data is typically reduced. When comparing efficiency between gears or samples, the same units (e.g., number/person-h or number/h) and study design (e.g., travel time included/excluded) must be used. Some gears produce high catch/hour, but result in low catch/person-hour if excessive manpower is required to conduct the sample. Gears that are efficient often have higher precision because, at a given level of effort, they tend to produce larger data sets (and variance is inversely proportional to the number of data points; Zar 1998). However, highly efficient gears are not necessarily accurate.

In the following sections, we summarize sampling efficiency and sample accuracy within and among gear groups of the most commonly used sampling gears for each catfish species. To describe group-specific sampling efficiency, we report median catch rates and the interquartile range (interpolated 25th and 75th percentiles) of published means (pooled across studies). These values reflect the most common values that biologists could expect to observe, and pooled studies reflect overall gear-specific performance (i.e., across a variety of systems). Gear accuracy is described as defined above. Accuracy was only described from studies that sampled known populations or directly compared gear types in a systematic or controlled study design that allowed for direct gear comparison.

Photo 1. Setting and pulling hoop nets. Photo credit: Jason Olive.

Photo 2. Tandem hoop nets catching Channel Catfish. Photo credit: Craig Gemming.

CHANNEL CATFISH

Hoop Nets and Tandem Hoop Nets

Hoop nets are commonly used to survey Channel Catfish in river systems and small impoundments but also have some application in large standing waters (Brown 2009; Photo 1, Photo 2). Hoop nets can be constructed with various designs (e.g., different mesh and hoop sizes) and can be used with or without bait.

Traditionally, hoop nets produce low catch rates (median = 1.8 fish/net-set, range = 0.8 to 4.1; Table 1) and are insufficient for estimating Channel Catfish population metrics (Hanson 1986; Michaletz 2001). To improve catch rates, researchers developed a modified design, termed *tandem hoop net* (Sullivan and Gale 1999; Photo 3). Tandem hoop nets consist of two to three single hoop nets tied together in a series with a rope bridle (1–6 m between nets). Each tandem series is typically fished overnight for 1–3 days, which composes one replicate sample (CPUE typically expressed fish/tandem-series set). Tandem hoop nets have much larger catch rates than traditional hoop nets (median = 20.7 fish/net/set or 62.1 fish/tandem set; Table 1). Variations in net design and sampling procedures have been examined to identify methods that increase sampling efficiency and accuracy, each with varying degrees of success.

Sampling Efficiency

Tandem hoop nets are more efficient than any other gear used to sample Channel Catfish (Table 1). Catchability is higher than other gears, ranging from 0.2% to 1.2% in Texas and up to 8% in Missouri (Michaletz 2001; Buckmeier and Schlechte 2009). Catch rates in Missouri have exceeded 350 fish/tandem series (Michaletz and Sullivan 2002) and commonly range from 33 to 74 fish/tandem series (median range) for 3-day sets (Sullivan and Gale 1999; Michaletz and Sullivan 2002; Flammang and Schultz 2007; Flammang et al. 2011; Richters and Pope 2011). More important, tandem hoop nets require less total effort (20–60 fish/person-h) for the same sample quality compared to all other gear types (Sullivan and Gale 1999; Michaletz 2001; Table 1).

Variables such as soak duration, season, and net design can affect sampling efficiency. Nets fished for 2–3 days produce higher catch/hour and lower sampling variability than one-day sets (Michaletz and Sullivan 2002; Neely and Dumont 2011).

Table 1. Relative ranking of Channel Catfish sampling gears based on sampling efficiency (catch/gear-effort and catch/person-h) and accuracy of abundance and size-related metrics. Sampling efficiency is ranked by the median value observed in the literature. Percentile values are the interpolated 25th and 75th percentiles of published means.

Rank	Gear	Median	Percentiles (25th–75th)	Comments	Literature
Efficiency—catch/gear effort					
1	Tandem hoop nets	20.7	11.0–24.0	Gear effort = fish/net/tandem set (48–72 h)	Michaeltz (2001); Sullivan and Gale (1999); Richeters and Pope (2011); McCain et al. (2011); Flammang and Schultz (2007); Flammang et al. (2011); Michaeltz (2009); Michaeltz and Sullivan (2002); Neely and Dumont (2011); Stewart and Long (2012); Wallace et al. (2012); Schultz and Dodd (2008)
2	High-frequency electrofishing	7.0	2.8–9.2	Gear effort = fish/h	Vokoun and Rabeni (2001); Columbo et al. (2008); Michaels and Williamson (1982); Barada and Pegg (2011); Pegg et al. (2006); Santucci et al. (1999); McCain et al. (2011)
2	Low-frequency electrofishing	4.9	2.0–12.8	Gear effort = fish/h	Nelson and Little (1986); Barada and Pegg (2011); Arterburn (2001); Cailteux and Strickland (2009); Jolley and Irwin (2011)
3	Gill nets	4.3	1.0–5.7	Gear effort = fish/net-night	Gale et al. (1999); Nelson and Little (1986); Michaels and Williamson (1982); Yeh (1977); M. S. Robinson (1999); Michaletz (2001); Sullivan and Gale (1999); Richters and Pope (2011); Crandall et al. (1976); Argent and Kimmel (2005); Odenkirk (2002); Mitzner (1999); Jackson (1995); Elrod (1974); Homer and Jennings (2011); Pegg et al. (2006); Santucci et al. (1999)
3	Slat traps	2.1	0.4–3.8	Gear effort = fish/trap-night	M. S. Robinson (1999); Santucci et al. (1999); Perry and Williams (1987)
3	Single baited hoop nets	1.8	0.8–4.1	Gear effort = fish/net-night	Gale et al. (1999); Nelson and Little (1986); Kirby (2001); Vokoun and Rabeni (2001); Columbo et al. (2008); Michaels and Williamson (1982); Barada and Pegg (2011); Arterburn (2001); Pierce et al. (1981); J. W. Robinson (1994); Mayhew (1973); Tillman et al. (1997); Gerhardt and Hubert (1989); Jackson and Jackson (1997); Quist and Guy (1998); Holland and Peters (1992); Kubney (1992); Keller (2011); Cunningham and Cofer (2000); Jordan et al. (2004); Yeh (1977); M. S. Robinson (1999); Michaletz (2001)
3	Angler creel	1.5	0.3–3.0	Gear effort = fish/h	Santucci et al. (1999); Schultz and Dodd (2008); Parrett et al. (1999)
4	Single unbaited hoop nets	0.5	0.3–1.0	Gear effort = fish/net-night	Arterburn (2001); Pierce et al. (1981); J. W. Robinson (1994); Mayhew (1973); Tillman et al. (1997); Gerhardt and Hubert (1989); Jackson and Jackson (1997); Fratto et al. (2008); Funk (1958); Hesse (1980); Hesse et al. (1982); Hubert and Patton (1994); Parrett et al. (1999)
5	Hook and line	0.3	0.02–0.20	Gear effort = fish/hook-set	Gale et al. (1999); Nelson and Little (1986); Kirby (2001); Vokoun and Rabeni (2001); Arterburn (2001); Santucci et al. (1999); Arterburn and Berry (2002); Barabe and Jackson (2011); Jackson and Jackson (1999); Miranda and Killgore (2011)
Efficiency—catch/person-h					
1	Tandem hoop nets	40.0	20.0–60.0		Michaletz (2001); Sullivan and Gale (1999)
2	Slat traps	6.1	2.9–9.3		M. S. Robinson (1999); Santucci et al. (1999)
2	Single baited hoop net	5.6	1.6–11.6		Vokoun and Rabeni (2001); M. s. Robinson (1999); Michaletz (2001); Pugh and Schramm (1998)
2	Gill nets	3.7	1.6–5.5		M. S. Robinson (1999); Michaletz (2001); Sullivan and Gale (1999); Santucci et al. (1999)
3	Low-frequency electrofishing	1.2	1.2		Pugh and Schramm (1998)
3	High-frequency electrofishing	0.9	0.3–1.1		Vokoun and Rabeni (2001); Santucci et al. (1999); Pugh and Schramm (1998)
3	Hook and line	0.8	0.4–1.1		Vokoun and Rabeni (2001); Santucci et al. (1999)
3	Angler creel	0.5	0.5		Santucci et al. (1999)
Accuracy for abundance					
1	Tandem hoop nets			Consistent catchability	Flammang et al. (2011); Michaletz and Sullivan (2002)
1	Angler creel			Consistent catchability	Santucci et al. (1999)
1	Gill nets			Consistent catchability	Santucci et al. (1999)

Table 1. (continued).

Rank	Gear	Median	Percentiles (25th–75th)	Comments	Literature
2	Slat traps			Inconsistent catchabilty; may not accurately measure abundance	Vokoun and Rabeni (2001); Santucci et al. (1999)
2	High-frequency electrofishing			Inconsistent catchability; may not accurately measure abundance	Vokoun and Rabeni (2001); Santucci et al. (1999)
2	Hook and line			Inconsistent catchability; may not accurately measure abundance	Vokoun and Rabeni (2001); Santucci et al. (1999)
Accuracy for size-related metrics					
1	Tandem hoop nets			No bias for fish > 250 mm	Michaletz and Sullivan (2002); Buckmeier and Schlechte (2009)
2	Angler creel			Occasionally overrepresents fish < 300 mm	Santucci et al. (1999)
3	High-frequency electrofishing			Overrepresents fish < 300 mm	Vokoun and Rabeni (2001); Santucci et al. (1999)
3	Gill nets			Overrepresents fish > 460 mm; underrepresents fish < 250 mm	Michaletz (2001); Santucci et al. (1999); Buckmeier and Schlechte (2009)
4	Slat traps			Can overrepresent small or large fish	M. S. Robinson (1999); Santucci et al. (1999); Perry and Williams (1987)
4	Hook and line			Overrepresents large fish	Gale et al. (1999); Nelson and Little (1986); Vokoun and Rabeni (2001); Arterburn (2001); Kubney (1992); Santucci et al. (1999); Arterburn and berry (2002)

Photo 3. Tandem hoop net configuration. Photo credit: Jason Olive.

Neely and Dumont (2011) found that total effort needed to achieve acceptable sampling precision (i.e., relative standard error = 0.25, RSE_{25}) was 8–10 net nights with 2- to 3-day sample durations compared to 42 net nights with 1-day sample durations. Baits such as waste cheese and soybean cake significantly increase catch compared to nonbaited nets, although researchers disagree on which bait is more effective (Mayhew 1973; Yeh 1977; Stevenson and Day 1986; Gale et al. 1999; Flammang and Schultz 2007; Wallace et al. 2011). Restricted hoop-net throats (i.e., rear throat tied or clamped about 15 cm from the cod end to restrict the size of the opening; see Porath et al. [2011] for pictures and description) coupled with 25-mm mesh nets maximize catch rates, presumably by minimizing escapement (Hesse et al. 1982; Gale et al. 1999; Michaletz and Sullivan 2002; Flammang and Schultz 2007; Porath et al. 2011). Other mesh sizes, including variable-mesh nets, result in lower catch rates (Hesse et al. 1982; Holland and Peters 1992; Gale et al. 1999; Sullivan and Gale 1999; Colombo et al. 2008). Typically, lower variability and higher catch rates occur in summer (Flammang and Schultz 2007); lower catch rates occur in spring (Hesse et al. 1982; Cunningham and Cofer 2000; Wallace et al. 2011). However, mixed results relative to season have been observed in other studies (Michaletz 2001; Michaletz and Sullivan 2002). Other gear specifications such as hoop and net size, net length, and bridle length have minimal effect on catch efficiency or produce inconsistent results (Hubert and Patton 1994; Tillman et al. 1997; Cunningham and Cofer 2000; Michaletz and Sullivan 2002; Flammang et al. 2011).

Sample Accuracy

Tandem hoop nets are also one of the more accurate gears used to survey Channel Catfish (Table 1). Catch rates typically correlate with population density (Michaletz and Sullivan 2002; Flammang et al. 2011), which allows managers to use CPUE to accurately measure changes in population size. Size structure is also accurately represented for fish greater than 250 mm (Michaletz and Sullivan 2002; Buckmeier and Schlechte 2009). In some systems, fish as small as 150 mm are accurately represented (Michaletz 2001). Mesh size can affect estimates of size structure (Holland and Peters 1992; Gale et al. 1999; Colombo et al. 2008), and 25-mm mesh nets yield the most accurate size distribution (Michaletz and Sullivan 2002; Buckmeier and Schlechte 2009).

What We Don't Know

Although hoop nets have been well studied, future evaluations may still improve the accuracy and sampling efficiency of this gear. Most evaluations have focused on sampling in rivers and small impoundments (<200 ha); however, sampling requirements in large reservoirs (>200 ha) are not well studied (but see

Richters and Pope [2011] and Stewart and Long [2012]) and warrant further research before establishing formal sampling protocols. Sample accuracy should also be evaluated seasonally (e.g., the effects of day length, temperature, flow regime, etc.) to determine whether catchability remains constant and to identify when accuracy is greatest (accuracy has not been examined seasonally). Despite high catch rates and low variability, summer samples may or may not provide the most accuracy. Seasonal effects should also be compared among habitats (e.g., rivers versus reservoirs) to see whether interactions exist. Additional evaluations of net specifications (e.g., hoop size, throat size, and net length) should also be conducted to identify net designs that improve accuracy and sampling efficiency.

Gill Nets

Gill nets are most commonly used to survey Channel Catfish in reservoirs (Michaletz and Dillard 1999; Brown 2009; Photo 4). They are easy to use (Miranda and Boxrucker 2009) and can provide biological data at relatively low cost. Because gill nets are typically used for routine monitoring of pelagic species (e.g., temperate basses), data collection on additional species such as Channel Catfish adds little additional cost.

Experimental gill nets used to sample Channel Catfish range from 24 to 30 m long by 2 to 3 m deep and consist of five to eight panels, each with a different mesh size. Mesh sizes range from 10- to 102-mm bar mesh and can increase by increments of 6 or 13 mm between panels (Miranda and Boxrucker 2009). Any combination of these sizes can be used depending on the study objectives; however, a standardized net design has been proposed for use when sampling warmwater fish in standing waters (Miranda and Boxrucker 2009; Pope et al. 2009). Nets are typically deployed perpendicular to shore in 3- to 8-m-deep water (Miranda and Boxrucker 2009). Each net is fished overnight, encompassing two crepuscular periods, and catch is reported as catch per net night.

Sampling Efficiency

Gill nets are about five times less efficient than tandem hoop nets (Sullivan and Gale 1999; Table 1). Catch rates are often lower for gill nets (e.g., often <3 fish/net night and rarely more than 10 or 15 fish/net night; Yeh 1977; Gale et al. 1999; M. S. Robinson 1999; Santucci et al. 1999; Sullivan and Gale 1999; Michaletz 2001; Argent and Kimmel 2005; Homer and Jennings 2011; Richters and Pope 2011) than for tandem hoop nets (Richters and Pope 2011; Table 1). Even when they provide similar catch rates, more overall effort is needed to process data from gill nets because effort is required to untangle fish and process bycatch. Gill nets consistently produce a lower catch/person-hour (1.6–5.5; Table 1) compared to tandem hoop nets (20–60; Table 1).

Photo 4. Experimental gill nets. Photo credit: Ryan Ryswyk.

Catchability for gill nets is low (0.004% per net night; Buckmeier and Schlechte 2009) and sampling variability is often high. Wilde (1993) and Dumont and Schlechte (2004) found that 10–32 replicate samples were needed to achieve RSE_{25} in Texas reservoirs. About 300–400 Channel Catfish are needed to estimate length frequencies (Vokoun et al. 2001). To meet this recommendation, Dumont and Schlechte (2004) found that an average of 201 net nights (67 nights to capture 100 fish × 3) were needed to collect 300 fish; however, fewer fish can be used if biologists are willing to accept lower precision. The number of net nights required may also fluctuate depending on population density and net design (e.g., net length). In contrast to gill-net effort required, median effort needed for tandem hoop nets to collect 300 fish is 15 tandem sets (13–28 tandem sets based on interquartile range; Table 1).

Sample Accuracy

Experimental gill nets provide an accurate representation of Channel Catfish population density but may misrepresent size structure (Table 1). Santucci et al. (1999) found that catch rates were positively correlated with absolute density in a small impoundment. Stang and Hubert (1984) found that gill net CPUE was higher in July than August (June was intermediate but not significantly different from other months). This suggests that the accuracy of population density estimated by gillnets varies seasonally. However, other studies have found no seasonal differences in CPUE (Gale et al. 1999; Michaletz 2001). For size structure, gill nets accurately represent fish from 250 to 460 mm in large and small impoundments (Santucci et al. 1999; Buckmeier and Schlechte 2009). Fish less than 250 mm are underrepresented, whereas larger fish may be overrepresented (Michaletz 2001; Buckmeier and Schlechte 2009). However, few studies have effectively estimated size selectivity of gill nets for larger fish and only two have evaluated selectivity of smaller fish. Although some size bias exists, gill nets may still be beneficial because they provide a larger range of fish sizes than most other gears (Powell et al. 1971; Yeh 1977; Michaletz 2001; Richters and Pope 2011).

What We Don't Know

Many gill net designs have been used to sample Channel Catfish; however, little is known about the effects of net design (e.g., mesh size and net length) on accuracy, precision, and sampling efficiency. Mesh size often leads to size biases of gill nets (Miranda and Boxrucker 2009). Each mesh size rarely catches fish beyond 20% of the optimum fish size selected for each mesh (Hamley 1975). Even with variable-mesh nets, some fish sizes may not be accurately represented if incremental increases in mesh size are too large. Thus, selectivity curves (Hamley 1975) should be developed to allow for correction of length-frequency data from commonly used gill net mesh sizes. Other specifications such as net length and hanging ratio (i.e., how stretched the mesh is; Hayes et al. 1996) also have yet to be evaluated.

Additional catchability and size selectivity studies are also needed. Only two studies (Santucci et al. 1999; Buckmeier and Schlechte 2009) have used known populations to evaluate these metrics; thus, additional studies should be conducted in other lentic and lotic systems to examine reliability of these estimates. Studies should focus on identifying variables that affect sampling efficiency and size bias, as well as consistency between sampling events (e.g., between days, seasons, or years). Specifically, there is a need to evaluate the potential catch bias of gill nets for Channel Catfish greater than 460 mm total length (TL).

Other Gears

High-frequency electrofishing (HEF; 60 to 120 pulses per second [pps] DC or 60-Hz AC) is the third most commonly used gear to sample Channel Catfish (Brown 2009). Samples are typically conducted by boat near the shoreline and produce higher catch rates (typically 2–10 fish/h; Michaels and Williamson 1982; Santucci et al. 1999; Vokoun and Rabeni 2001) than other gears, except for baited tandem hoop nets. These moderately high catch rates make HEF attractive, especially in cases when HEF is already being used to sample other species, allowing Channel Catfish to be collected with little additional effort. However, biologists should be cautious about using this gear because high-frequency electrofishing typically selects smaller Channel Catfish, yielding inaccurate estimates of population size structure and abundance (Santucci et al. 1999; Vokoun and Rabeni 2001). Additionally, catch per person-hour from HEF (0.3–1.1 fish/ person-h; Pugh and Schramm 1998; Santucci et al. 1999; Vokoun and Rabeni 2001) is well below the sampling efficiency of tandem hoop nets, making it inefficient unless HEF is already being used to sample other species. Santucci et al. (1999) reported that HEF catch/person-hour values are similar to those reported for gill nets, slat traps, or angling methods.

Angler creels are also used to survey Channel Catfish (Photo 5). Santucci et al. (1999) found that creels were fairly efficient and accurate; angler catch rates were slightly lower (1.5 fish/h) than HEF catch rates (3.4 fish/h), but catch/person-hour was similar to other gears (Santucci et al. 1999). However, these catch rates are still lower than those reported for tandem hoop nets (Table 1), which were not evaluated in this study (Santucci et al 1999). In addition, Santucci et al. (1999) found that angler creel data correlated with population density and accurately represented size structure of channel catfish.

Trap nets, slat traps, and hook-and-line methods are also used to survey Channel Catfish (Houser 1960; Jacobs and Swink 1982; Stevenson and Day 1986; Topp et al. 1994; Santucci et al. 1999). Unfortunately, utility of these gears is limited because they are not well studied, biased, or less effective than other gears; therefore, these gears are not often used. However, each can be useful if biologists account for known biases and limitations. Some biologists have used these gears to supplement other sampling methods (Coon and Dames 1991; Vokoun and Rabeni 1999); however, biologists must use caution when combining data from multiple gears.

BLUE CATFISH

Low-Frequency Electrofishing

Low-frequency, pulsed-DC electrofishing (LFE) is one of the more common gears used to survey Blue Catfish (Photo 6). In a 2006 survey of catfish managers and researchers, Brown (2009) reported that LFE was used in 67% of Blue Catfish studies. Recently, LFE has been incorporated into standard sampling protocols in states such as Kansas, Oklahoma, and Texas. However, official standardized LFE sampling techniques have yet to be recognized in North America (Bonar et al. 2009).

Many variations of LFE techniques have been employed among researchers (see Corcoran 1979; Justus 1996; Buckmeier and Schlechte 2009; Cailteux and Strickland 2009; Bodine and Shoup 2010; Greenlee and Lim 2011; Schloesser et al. 2011). Samples are typically conducted during daytime by a boat equipped with a 5,000- to 9,000-W, generator-powered pulsator or variable-voltage pulsator electrofisher with output settings ranging from 7.5 to 30 pps, 340 to 1,000 V, and 1 to 5 A (based on electrofisher metering). Sampling usually occurs in pelagic

Photo 5. Creel surveys conducted on catfish anglers. Photo credit: Dane Balsman.

Photo 6. Low-frequency, pulsed-DC electrofishing for Blue Catfish, with a chase boat. Photo credit: Kris Bodine.

(open water) habitats where Blue Catfish are mostly abundant (Graham 1999; Bodine and Shoup 2010). Often, additional chase boats and personnel are used to collect fish that surface away from the electrofishing boat (Photo 6).

Ictalurids respond to LFE quite differently than they do to HEF techniques. For example, it takes about 30–90 s before fish begin surfacing (Bodine and Shoup 2010). Fish rarely surface near the electrodes and commonly surface up to 100 m from the electrofishing boat. Electrotaxis and narcosis are rarely observed. Typical surfacing behaviors include swimming in circles or along an erratic path, swimming directionally (but not necessarily toward the anode), or tetany (immobilization) and are not always consistent between systems or sampling events. It is unclear whether the fish response is involuntary (e.g., directional taxis and tetany) or voluntary (e.g., the absence of directional taxis and tetany but still physiologically affected by the electric field).

Sampling Efficiency

Compared to other studied gear types, LFE is the most efficient gear for surveying Blue Catfish (Table 2). Catch rates commonly range from 23 to 373 fish/h in freshwater systems (Jons 1997; Boxrucker and Kuklinski 2006; Cailteux and Strickland 2009; Bodine and Shoup 2010; Evans et al. 2011) and have exceeded 6,000 fish/h in tidal rivers (Greenlee and Lim 2011). Variability of abundance data is typically low (reported range coefficient of variation [CV] = 0.09–0.31) and minimal effort is needed to achieve high precision. Bodine and Shoup (2010) and Evans et al. (2011) found that 2–16 samples would produce RSE_{25} in 12 Oklahoma reservoirs; however, variability increased when only larger length groups were considered.

Several studies identified methods that increase sampling efficiency of LFE. Cailteux and Strickland (2009) reported that 15 pps produced higher catch rates than 7.5 or 30 pps. Water temperatures ranging from 18°C to 28°C produced higher catch rates and optimal precision (i.e., RSE $\leq$ 0.25) compared to other temperatures (i.e., 8–17.9°C and 28.1–32°C; Justus 1996; Grussing et al. 2001; Bodine and Shoup 2010). Many researchers used one or two additional boats to collect fish that surfaced away from the electrofishing boat (Boxrucker and Kuklinski 2006; Buckmeier and Schlechte 2009; Bodine and Shoup 2010). This presumably increases catch rates (i.e., catch/h); however, use of additional boats and personnel could potentially decrease overall sampling efficiency (i.e., catch/person-h).

Sample Accuracy

Although LFE produces higher catch rates than other gear types, it is not clear whether this gear accurately estimates relative abundance (Table 2). Two studies quantified catchability (Buckmeier and Schlechte 2009; Bodine and Shoup 2010) from populations with a known density and reported values ranging from 0.2% to 10%. Buckmeier and Schlechte (2009) found that catchability varied seasonally, and Bodine and Shoup (2010) found that catchability varied among intra-month samples. This variation in catchability is potentially problematic; if catchability changes between samples (weekly or annually), relative abundance data will not always accurately reflect changes in absolute density. However, in a separate evaluation, Bodine and Shoup (2010) also found no seasonal or yearly differences in CPUE in three Oklahoma reservoirs during optimal LFE sampling periods (>18°C water temperature). Although speculative, these findings suggest that catchability remained constant during their study period. Additional research is needed to further describe catchability and to determine whether LFE CPUE is linearly correlated with population density. If it is not, alternative methods such as mark–recapture may be required to estimate Blue Catfish abundances.

Despite potential inaccuracies in estimating relative abundance, LFE does produce accurate estimates of size structure of fish from 200 to 1,000 mm TL (Buckmeier and Schlechte 2009; Bodine and Shoup 2010). However, schools of Blue Catfish typically contain similar size fish, so a minimum of 10–20 replicate samples (each producing at least one fish) coupled with 200–800 total fish sampled are needed to accurately represent most populations (Bodine et al 2011). Unfortunately, LFE is not effective at sampling fish less than 200 mm (Buckmeier and Schlechte 2009).

What We Don't Know

Although we determined that LFE is currently the most efficient and accurate Blue Catfish sampling gear, limited scope in recent evaluations warrants further study. Catchability and size selectivity studies should be replicated in a variety of water bodies throughout the country. Environmental (e.g., conductivity and temperature) and biological (fish morphology, physiology, and behavior) factors can affect electrofishing catch (Reynolds 1996) and have not been fully examined for LFE. Researchers should identify these variables and develop catchability models that incorporate one or more variables.

When developing catchability models for Blue Catfish, future evaluations should focus on understanding the mechanisms causing the unique response of this species to LFE. It is unclear what power threshold is necessary to consistently immobilize Blue Catfish (at varying water conductivities, temperatures, etc.), or whether power-based goals are even the appropriate standardizing metrics given the atypical response exhibited by this species (i.e., being affected so far away from the boat). Alternative electrofishing control units (with fully adjustable output waveform settings) may need to be explored, especially when there is a need to standardize electric output (Neebling and Quist 2011).

Researchers should also identify additional methods to increase sampling efficiency. Future evaluations should quantify benefits of using a chase boat (or multiple chase boats). Sampling efficiency should be evaluated by calculating catch/person-hour. In addition, researchers should identify appropriate sampling durations because this can sometimes affect accuracy and precision of population metrics.

Gill Nets

Experimental gill nets are the second most commonly used gear to survey Blue Catfish (Brown 2009; Photo 4). Similar to sampling Channel Catfish, gill nets can provide a low-cost sample if gill nets are already being used to sample other species. Unfortunately, accuracy and precision of gill nets is lower than LFE (Buckmeier and Schlechte 2009; Evans et al. 2011; Table 2).

Sampling Efficiency

Experimental gill nets are up to 1,000 times less efficient than LFE when estimating relative abundance (Evans et al. 2011; Table 2). Evans et al. (2011) reported that in 13 Oklahoma reservoirs, catch rates ranged from 0.70 to 0.88 fish/net-night for gill nets, whereas LFE ranged from 61 to 848 fish/h. Other researchers found that catch rates typically range from 1 to 5.1 fish/net-night with a median of 4 fish/net-night (Crandall et al. 1976; Gale et al. 1999; Goeckler et al. 2003; Bartram et al. 2011; Homer and Jennings 2011). The number of overnight gill nets needed to achieve RSE_{25} ranged from 5 to 47 (Dumont and Schlechte 2004; Evans et al. 2011). Wilde (1993) found that 25 sites were needed to achieve RSE_{30}. Unfortunately, median catch rates suggest that 75 replicate samples are needed to collect at least 300 fish (Table 2). Catchability is also low; Buckmeier and Schlechte (2009) reported that mean gill net catchability was 0.005%/net night ($N = 46$ net nights, net length was 38.1 m long × 2.4 m high) in Lake Livingston, Texas.

Sample Accuracy

Although no studies have directly evaluated the accuracy of abundance estimates, gill nets may still provide reliable estimates of Blue Catfish abundance. We found only one study that examined catchability (see Buckmeier and Schlechte 2009), and they did not report changes in catchability between sampling events. Consistent catchability suggests that this gear may accurately reflect abundance. Additionally, Evans et al. (2011) found that gill net CPUE correlated with LFE CPUE, suggesting

Table 2. Relative ranking of Blue Catfish sampling gears based on sampling efficiency (catch/gear effort and catch/person-h) and accuracy of abundance and size-related metrics. Sampling efficiency is ranked by the median value observed in the literature. Percentile values are the interpolated 25th and 75th percentiles of published means.

Rank	Gear	Median	Percentiles (25th–75th)	Comments	Literature
Efficiency—catch/gear effort					
1	Low-frequency electrofishing	252.0	23.0–373.0	Gear effort = fish/h	Nelson and Little (1986); Cailteux and Strickland (2009); Jolley and Irwin (2011); Bartram et al. (2011); Evans et al. (2011); Greenlee and Lim (2011); Bodine and Shoup (2010); Boxrucker and Kuklinski (2006); Schloesser et al. (2011); Kuklinski and Patterson (2011); Mauck and Boxrucker (2004); Jons (1997)
2	Gill nets	4.0	1.0–5.1	Gear effort = fish/net-night	Gale et al. (1999); Crandall et al. (1976); Jackson (1995); Homer and Jennings (2011); Goeckler et al. (2003); Bartram et al. (2011); Evans et al. (2011)
3	High-frequency electrofishing	0.9	0.9	Gear effort = fish/h	McCain et al. (2011)
3	Hoop/trap/fyke nets	0.4	0.1–1.3	Gear effort = fish/net-night	Gale et al. (1999); Nelson and Little (1986); McCain et al. (2011); Jons (1997)
4	Hook and line	0.1	0.01–0.15	Gear effort = fish/hook-night	Gale et al. (1999); Barabe and Jackson (2011); Miranda and Killgore (2011)
Efficiency—catch/person-h					
1	Low-frequency electrofishing	6.7	2.1–11.3		Pugh and Schramm (1998); Jons (1997)
2	High-frequency electrofishing	0.5	0.5		Pugh and Schramm (1998)
3	Hoop nets	0.2	0.08–0.39		Pugh and Schramm (1998); Jons (1997)
Accuracy for abundance					
1	Low-frequency electrofishing			No systematic bias, but catchability varies seasonally	Buckmeier and Schlecte (2009); Bodine and Shoup (2010)
2	Gill nets			Correlates with low-frequency electrofishing but is more variable	Evans et al. (2011)
Accuracy for size-related metrics					
1	Low-frequency electrofishing			No bias for 250- to 1,000-mm fish	Buckmeier and Schlechte (2001); Bodine and Shoup (2010)
2	Gill nets			Overrepresents fish > 305 mm and underrepresents fish < 250 mm	Buckmeier and Schlechte (2009); Evans et al. (2011)
3	Hook and line			Overrepresents fish > 635 mm	Gale et al. (1999)

that it is at least similarly accurate to LFE. Further evaluation is necessary to determine whether catchability remains constant between annual samples and in different systems.

Only one study has evaluated the accuracy of experimental gill nets for estimating size-related metrics of Blue Catfish and found fish less than 250 mm were underrepresented, whereas fish greater than 350 mm were overrepresented (Buckmeier and Schlechte 2009). Although no studies have examined the number of replicate sites needed to accurately estimate size-related metrics, biologists can develop minimum sample sizes based on existing knowledge of Blue Catfish behavior. For example, Bodine et al. (2011) reported that Blue Catfish congregate with fish of similar size and, therefore, about 10–20 sites and 200–800 fish are needed to accurately estimate size-related metrics with LFE. This logic could also apply to other sampling gears; however, these sample sizes should be considered the minimum until a full evaluation is conducted with gill nets. Unfortunately, an unreasonably large number of gill net replicates may be necessary to collect the minimum of 200 fish that are needed to precisely describe size structure (Dumont and Schlechte 2004), given that average catch rates are typically less than 5 fish/net night.

What We Don't Know

Net specifications (e.g., mesh size, mesh type, net length, and hanging ratio) needed to accurately and efficiently measure Blue Catfish population metrics should be identified. Gill nets are routinely constructed with generalized specifications (Hubert 1996; Miranda and Boxrucker 2009) and are intended to collect a variety of fish species in a single sample. These nets may or may not contain mesh sizes suitable for collecting all sizes of Blue Catfish, which grow larger than many other species. Alternative mesh sizes (larger, smaller, or both) may be necessary to accurately measure Blue Catfish abundance and size structure. Identifying these specifications would improve gill net collection methods for Blue Catfish.

Sampling should be evaluated seasonally to identify when accuracy and efficiency are highest or to identify biases that occur during periods of preferred sampling. Gill nets are a passive sampling gear that requires high fish activity for optimal effectiveness (Hubert 1996). Blue Catfish movement varies according to environmental conditions (e.g., water temperature and spawning period; Lagler 1961; Pflieger 1997; Fischer et al. 1999; Graham 1999), and movement patterns may not be uniform across all fish sizes. To maximize efficiency, samples should be conducted during periods of peak movement when all size groups are active. Future studies should also examine sampling efficiency in terms of catch/person-hour, which is needed to effectively compare efficiency among gear types and determine overall effort needed to collect data.

Other Gears

Hook-and-line gears such as trotlines and jug lines have been used to sample Blue Catfish, but evaluations of accuracy and sampling efficiency are rare. Gale et al. (1999) recommended trotlines baited with cut Gizzard Shad (*Dorosoma cepedianum*) on 7/0 hooks along with 76-mm mesh gill nets be used to capture larger (≥381 mm) Blue Catfish in the Harry S. Truman Dam tailwater in Missouri. They observed that catch/hour of larger fish ranged from 0.19 to 0.33 fish/h for trotlines and 4.37 to 11.96 fish/h for 76-mm mesh gill nets. Although more labor intensive, trotlines collected the largest Blue Catfish. However, trotlines were ineffective at collecting fish less than 381 mm. Miranda and Killgore (2011) also used trotlines baited with worms on size 2/0 hooks to efficiently capture Blue Catfish 75–1,122 mm TL (median = 371) in the Mississippi River. However, these authors did not compare sampling efficiency or accuracy to other gear types. Jug lines (anchored or free floating) have also been used to target larger Blue Catfish (Missouri Department of Conservation and Texas Parks and Wildlife Department, unpublished data). Although jug lines might prove useful to meet specific study objectives or supplement primary sampling gears, scientific evaluations are lacking; therefore, biologists should use caution when using this gear for routine sampling.

Other gears such as HEF (60–120 pps) and hoop nets have also been used to collect Blue Catfish (Brown 2009). However, because of low catch rates (0.9 fish/h for HEF and 0.1–1.3 fish/net-night for hoop nets), high sampling variability (CV > 0.40), and unknown size selectivity, these gears are primarily used to supplement other, more effective (or at least better studied) gears (Nelson and Little 1986; Jons 1997; Pugh and Schramm 1998; Greenlee and Lim 2011; McCain et al. 2011). In some situations, these gears may be more desirable because they tend to capture more species compared to alternative gears (Jons 1997).

FLATHEAD CATFISH

Low-Frequency Electrofishing

Like Blue Catfish, the most common gear used to sample Flathead Catfish is LFE (49% of researchers use LFE; Brown 2009; Photo 7). Electrofisher output settings are similar

Photo 7. Low-frequency, pulsed-DC electrofishing for Flathead Catfish. Photo credit: Craig Gemming.

to those used for Blue Catfish (i.e., similar pulse frequency, duty cycle, current, and voltage). Studies using LFE have been conducted in lotic (e.g., Cailteux and Strickland 2009; Ford et al. 2011; Kaeser et al. 2011; Travnichek 2011) and lentic systems (Gilliland 1988; Cunningham 1995, 2000, 2004). Lotic sampling is usually conducted in a downstream direction during base flow conditions, and a chase boat is almost always used. Lentic sampling is also usually conducted with a chase boat (Gilliland 1988; Cunningham 1995, 2000), but chase boats may not necessarily increase sampling efficiency (Cunningham 2004).

Sampling Efficiency

Most studies addressing LFE for sampling Flathead Catfish have focused on factors related to gear efficiency (Table 3). Low-frequency electrofishing is the most efficient gear type in terms of overall catch rate and catch/person-hour. Reported catch rates typically range from 38.5 to 58.0 fish/h (median = 47.8) in lentic systems (Gilliland 1988; Cunningham 2000, 2004) and from 19.0 to 44.2 fish/h (median = 41.6) in lotic systems (S. P. Quinn 1986; Stauffer and Koenen 1999; Vrtiska et al. 2003; Bonvechio et al. 2011; Ford et al. 2011; Kaeser et al. 2011; Travnichek 2011). Reported catch/person-hour rates range from 2.1 to 3.99 (Pugh and Schramm 1998; Stauffer and Koenen 1999). However, Stauffer and Koenen (1999) included travel time in their catch rate calculations; thus, caution must be taken when comparing catch rates between these studies.

Several studies identified factors that affect Flathead Catfish gear efficiency. Maximum catch rates are achieved during summer months, when water temperatures exceed 20°C, and for river habitats, when water levels are low (S. P. Quinn 1986; Justus 1996; Travnichek 2011). Travnichek (2011) found that a wider size distribution was encountered in late summer (September) compared to early summer (June–August). Precision of LFE samples is typically low (CV > 0.50) but is highest in summer (CV = 0.34–0.36 in July and August; Travnichek 2011). Cunningham (1995) reported CVs ranging from 0.23 to 0.46 in 10–22 replicate samples. As with Blue Catfish, many researchers use additional boats to collect fish that surface away from the electrofishing boat (J. W. Robinson 1994; Bonvechio et al. 2011; Ford et al. 2011; Travnichek 2011). However, the efficiency of using a chase boat is higher in lotic systems (Daugherty and Sutton 2005) and may not provide meaningfully higher catch rates in lentic systems (Cunningham 2004). Though the

Table 3. Relative ranking of Flathead Catfish sampling gears based on sampling efficiency (catch/gear effort and catch/person-h) and accuracy of abundance and size-related metrics. Sampling efficiency is ranked by the median value observed in the literature. Percentile values are the interpolated 25th and 75th percentiles of published means.

Rank	Gear	Median	Percentiles (25th–75th)	Comments	Literature
Efficiency—catch/gear effort					
1	Low-frequency electrofishing	45	19.0–62.0	Gear effort = fish/h	J. W. Robinson (1994); Stauffer and Koenen (1999); Cailteux and Strickland (2009); Jolley and Irwin (2011); Porter et al. (2011); S. P. Quinn (1986); Travnichek (2011); Vrtiska et al. (2003); Bonvechio et al. (2011); Cunningham (2000, 2004); Gilliland (1998); Kaeser et al. (2011); Ford et al. (2011)
2	Gill nets	1.1	0.2–2.1	Gear effort = fish/net-night	Yeh (1977); Argent and Kimmel (2005)
3	High-frequency electrofishing	0.9	0.1–3.0	Gear effort = fish/h	Michaels and Williamson (1982); J. W. Robinson (1994); Stauffer and Koenen (1999); Pegg et al. (2006); McCain et al. (2011)
4	Hoop/trap/ fyke nets	0.1	0.03–0.33	Gear effort = fish/net-night	Michaels and Williamson (1982); Pierce et al. (1981); J. W. Robinson (1994); Yeh (1997); McCain et al. (2011); McCain et al. (2011); Fratto et al. (2008); Funk (1958); Ford et al. (2011)
5	Hook and line	0.08	0.002–0.15	Gear effort = fish/hook-night	**Stauffer and Koenen (1999); Miranda and Killgore (2011)**
Efficiency—catch/person-h					
1	Low-frequency electrofishing	2.3	2.1–2.5		Stauffer and Koenen (1999); Pugh and Schramm (1998)
2	Angler creel	0.8	0.8		Stauffer and Koenen (1999)
3	Hoop nets	0.6	0.6		Pugh and Schramm (1998)
4	Hook and line	0.4	0.4		Stauffer and Koenen (1999)
5	High-frequency electrofishing	0.16	0.1–0.23		Stauffer and Koenen (1999); Pugh and Schramm (1998)
Accuracy for abundance					
No data	No data	No data	No data	No data	No data
Accuracy for size-related metrics					
No data	No data	No data	No data	No data	No data

effect of sample design on sampling efficiency has not been studied, most authors used fixed sites or a modified predator approach (*sensu* Vokoun and Rabeni 1999) as opposed to random site selection.

Sample Accuracy

We are unaware of any published studies specifically addressing accuracy of LFE for sampling Flathead Catfish. However, anecdotal evidence suggests that LFE may be selective for fish less than 600 mm (Pugibet and Jackson 1989; Pugh and Schramm 1998; Brown 2009; Ford et al. 2011; McCain et al. 2011).

What We Don't Know

Appropriate methods to obtain an accurate sample of Flathead Catfish in lotic or lentic habitats are essentially unknown. Potential factors affecting LFE catch of Blue Catfish may also be applicable to Flathead Catfish, but none have been specifically addressed in published literature. Future studies should focus on specific variables (e.g., habitat, season, depth, conductivity, etc.) that affect estimation of abundance and size-related metrics and develop catchability models to account for potential biases.

More studies are also needed to examine sampling efficiency of LFE for Flathead Catfish. Most LFE studies have been conducted in lotic systems; gear specifications and optimal sampling conditions relative to sampling efficiency (i.e., season, water temperature, and boat movement) have not been evaluated for lentic habitats. Finally, appropriate sampling designs and sample durations need to be addressed.

Hoop Nets

Hoop nets are the second most commonly used gear to survey Flathead Catfish; 23% of respondents used hoop nets as their primary sampling gear for this species (Brown 2009). Single hoop nets are more commonly used than tandem hoop nets and are typically used in lotic habitats (Photo 8). We found only one study that used tandem hoop nets to collect Flathead Catfish (McCain et al. 2011). When deployed in flowing water, the cod end was usually tied to a natural snag or anchor and the mouth faced downstream (Pierce et al. 1981; Ford et al. 2011). The most common mesh sizes were between 25 and 38 mm; however, mesh as small as 19 mm has been used. Hoop nets were commonly baited with soybean cake, waste cheese, or live fish but were sometimes left unbaited. Nets were typically set for 24 or 48 h.

Photo 8. Single hoop nets catching Flathead Catfish. Photo credit: Craig Gemming.

Sampling Efficiency

Hoop nets are less efficient than other gears for sampling Flathead Catfish in rivers (Pugibet and Jackson 1989; Pugh and Schramm 1998; Stauffer and Koenen 1999; Ford et al. 2011; McCain et al. 2011). Catch rates typically range from 0.03 to 0.33 fish/net-set (Stauffer and Koenen 1999; Ford et al. 2011; McCain et al. 2011; Table 3). Pugh and Schramm (1998) reported a catch rate of 1.51 fish/person-h for hoop nets compared to 2.1–3.99 fish/person-h for LFE (Pugh and Schramm 1998; Stauffer and Koenen 1999). Unbaited hoop nets catch considerably more Flathead Catfish than baited hoop nets (Pierce et al. 1981). Little is known about the effect of season on the catch rates of Flathead Catfish, but Ford et al. (2011) found no differences for fish greater than stock size sampled from May to July. Most hoop net sampling has been conducted from May through October (Pierce et al. 1981; Stauffer and Koenen 1999; Fratto et al. 2008; Ford et al. 2011), which includes the prespawn and spawning season for this species (i.e., water temps of 26°C–28°C; Turner and Summerfelt 1971; Travnichek 2011). Therefore, it is possible that reproductive behavior influences catch rates of this gear.

Sample Accuracy

We are unaware of any published studies that address accuracy of hoop nets for sampling Flathead Catfish. Each study referenced in the previous section concluded that sampling with hoop nets yields a larger mean length and will catch more large fish (e.g., greater than preferred size) than LFE. However, these studies did not have populations with a known size distribution, so it is speculation as to which gear provides more accurate size -structure data.

What We Don't Know

Optimal net specifications, bait types, depth of set, season, water temperature, and river stage need evaluated to identify methods for improving hoop-net sampling efficiency for Flathead Catfish. Additionally, abundance and size-selectivity studies should be conducted to determine the accuracy of sampling with hoop nets. Catch rates should be reported as fish/person-hour so that sampling efficiency can be compared among gears.

Other Gears

Passive set-line gears such as trotlines and limb lines have been recommended for supplementing samples from other gears because of their tendency to capture larger Flathead Catfish.

Stauffer and Koenen (1999) reported that trotlines were the second most efficient gear for sampling Flathead Catfish in the Minnesota River. They reported catch rates of 0.16–0.85 fish/person-h compared to 2.1–3.99 fish/person-h for LFE (Stauffer and Koenen 1999; Pugh and Schramm 1998) and 0.02–0.69 fish/person-h for hoop nets (Pugh and Schramm 1998). However, others found that trotlines and bank poles required excessive person-hours and had very low catch rates (Ford et al. 2011). Using set-lines as a primary sampling gear is not recommended because of their low sampling efficiency and unknown biases; however, they may be useful for supplementing data collected by other gears in specific situations where large fish are needed and accurate size structure data are not required.

Flathead Catfish are occasionally collected by HEF (Brown 2009). However, compared to other sampling gears, HEF is quite labor intensive (0.1–3.0 fish/h and 0.1–0.23 catch/person-h; Michaels and Williamson 1982; Pugh and Schramm 1999; Stauffer and Koenen 1999; Pegg et al. 2006; McCain et al. 2011). HEF may collect a wider size distribution than other sampling gears (120–1,020 mm TL; Stauffer and Koenen 1999); however, accuracy of HEF has not been sufficiently examined.

DISCUSSION

Managing or monitoring catfish has become a priority to resource agencies across the United States. To effectively manage catfish, biologists must be able to accurately and efficiently measure population characteristics. Unfortunately, the lack of appropriate sampling techniques has inhibited the ability to measure these characteristics (Michaletz and Dillard 1999) and thus has hampered development of effective management strategies. Fortunately, recent evaluations of sampling gears have improved the ability to survey catfish populations.

Here we provided a comprehensive summary of ictalurid sampling information published prior to 2013. Most notably, we characterized gear performance attributes associated with the most commonly used gears for surveying ictalurids. Based on information from more than 80 scientific studies, we ranked each sampling gear by sampling efficiency (median catch rate) and accuracy for sampling each species and provided recommendations for preferred sampling gears for each data type.

Channel Catfish are the most studied of these species, and researchers have substantially refined the various techniques for sampling them. Although many gears are available for sampling Channel Catfish, we recommend using tandem baited hoop nets (Table 4), especially in small impoundments (≤200 ha). By far, this gear is the most efficient and produces the most accurate and precise estimates of all population characteristics. Catch rates are usually higher than other gears and less overall effort (i.e., person-h) is required. We also recommend that biologists incorporate these components into their methodology: (1) nets should be deployed for three continuous nights during summer, (2) cheese or soybean bait should be used, (3) the size of the mesh netting should be 25 mm, and (4) restricted throats should be used. These variables have been systematically tested and significantly improve sample accuracy and efficiency. In situations where samples are lacking some fish sizes (e.g., samples for age and growth), tandem hoop nets can be supplemented with other methods such as HEF or hook and line. Although other variables may also affect tandem hoop net performance, reported results varied among studies and, thus, these variables need further investigation before incorporating them into a sampling protocol. To further improve tandem hoop net design, future studies should use a systematic and controlled study design to evaluate variables. Future evaluations of tandem hoop nets should also focus on identifying efficient and accurate sampling methodologies for large reservoirs because these studies are rare.

Table 4. Recommended sampling gears for collecting various data types for each catfish species (THN = tandem baited hoop nets, LFE = low-frequency electrofishing).

Data type	Channel Catfish	Blue Catfish	Flathead Catfish
Abundance	THN	LFE	LFE
	Gill nets	Gill nets	Single hoop nets
Size structure	THN	LFE	LFE
	Gill nets		Single hoop nets
Age and growth	THN	LFE	LFE
	Gill nets	Gill nets	Single hoop nets
	Hook and line	Hook and line	Hook and line
Mortality	THN	LFE	LFE
	Gill nets		
Recruitment	THN	LFE	LFE
	Gill nets		

For Blue Catfish, we recommend sampling with LFE (Table 4). This gear provides an efficient means to monitor Blue Catfish populations because it produces extremely high catch rates that accurately represent population size and age structure, so long as minimum sample sizes are met. We recommend sampling (1) with 15 pps, (2) when water temperatures are 18°C–28°C, and (3) in a minimum of 10–20 replicate sites (with 200–800 total fish collected). These variables have been systematically tested and significantly improve sampling efficiency and accuracy. Use of a chase boat will undoubtedly increase catch rates; however, further studies (measuring catch/person-h) are needed to determine whether the additional manpower required will reduce the overall sampling efficiency. We do advise caution when using LFE to examine relative abundance until further research can determine whether catchability is constant or variable. Further research is needed to identify the power threshold needed to immobilize Blue Catfish so that power-based standardization can be achieved and consistent catchability ensured (Reynolds and Kolz 2012).

Flathead Catfish are the least studied of these catfish species. Based on current knowledge, we also recommend the use of LFE when sampling Flathead Catfish (Table 4). This gear provides the most efficient and precise samples. Highest sampling efficiency will be achieved (1) with 15 pps and (2) during late summer at water temperatures higher than 20°C. However, no studies have evaluated LFE with known Flathead Catfish populations, so accuracy of abundance and size-structure metrics are unknown. Quantifying LFE accuracy should be a top priority because LFE may select against larger fish (>600 mm; Ford et al. 2011), which could introduce bias when estimating some population demographics. Until this information is known, it may be advantageous to supplement LFE samples with other gears (e.g., hoop nets) to fully examine Flathead Catfish populations. Additional research is also needed to determine the appropriate way to standardize power output.

Our sampling recommendations are based on methods needed to maximize gear performance (accuracy, precision, and sampling efficiency); however, biologists should strongly consider trade-offs of each gear and its associated performance characteristics, as well as project objectives, management needs, data needs (e.g., acceptable accuracy or confidence levels), and cost before selecting a sampling gear. Depending on study objectives, some sampling gears may become more or less desirable. For example, we recommend tandem hoop nets for sampling Channel Catfish because gear performance is highest. However, if project objectives require a multispecies or community structure evaluation, other gears such as gill nets or HEF may be more appealing because they collect a wider variety of species. Project cost may also factor into gear selection. Although tandem hoop nets are most efficient at sampling Channel Catfish, gill nets may be more attractive to biologists who already use gill nets to survey other species. Adding tandem hoop nets to a sampling schedule may be costly or time prohibitive. In this case, biologists may consider choosing a gear with a slightly lower gear performance to reduce sampling cost, as long as they understand the trade-offs.

Summaries provided in this article are based on the best available knowledge of gear performance for each gear and species combination. This summary includes 64 Channel Catfish, 28 Blue Catfish, and 35 Flathead Catfish gear evaluations encompassing 167 small impoundments, 923 reservoirs (>200 ha), and 100 rivers from 27 states. However, some performance characteristics (e.g., most accuracy studies) lack appropriate spatial replication among geographic regions or habitat types (i.e., rivers, reservoirs, and small impoundments); thus, summaries presented here should be interpreted accordingly. To effectively characterize and compare sampling efficiency among gear groups, we pooled all similar gears within a particular gear group (e.g., all tandem hoop net studies were pooled), despite somewhat differing gear specification (e.g., 48- and 72-h soak duration). The purpose of these data is to provide an overall picture of group-specific sampling efficiencies. We also advise readers to interpret these data accordingly and refer to the Sample Accuracy and Sampling Efficiency sections for each gear-specific combination to understand how group-specific characteristics can affect gear performance.

We also recommend considering a few additional aspects before developing a sampling protocol. First, all sampling gears discussed in this manuscript are ineffective at surveying young-of-the-year catfishes, a problem shared by most gears used to sample sportfish. Brewer and Rabeni (2008) found that prepositioned electrofishing grids were effective for sampling juvenile Channel Catfish (9–245 mm) and juvenile Flathead Catfish (16–277 mm) in a river; however, they did not evaluate gear performance. Future studies should determine whether this gear provides accurate and efficient samples of young of the year catfishes. Second, gear performance attributes may differ between river and reservoir habitats as well as system-specific variables (e.g., habitat and fish population density). Few studies have addressed these aspects and we suggest that future research should focus on these issues to modify or improve sampling procedures.

Regardless of species or gear type, future studies should focus on quantifying sampling accuracy, especially for sampling Channel Catfish in reservoirs and Blue Catfish and Flathead Catfish in all habitat types. Although these studies are logistically and economically challenging, these data are lacking yet are essential to both describing population demographics and effectively managing ictalurid populations.

This article is intended to provide a review of gear performance of the most commonly used catfish sampling gears. Although other sampling gears (e.g., wire baskets, seines, and trawls) have been previously documented, these gears are seldom used. Thus, we felt that it was not necessary to include them in this article. However, it is possible that alternative gears not discussed in this article could provide adequate or improved samples of ictalurids. We encourage further research to either improve existing gears or develop new ones.

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