Surveys

Gear and Seasonal Bias Associated with Abundance and Size Structure Estimates for Lentic Freshwater Fishes

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Abstract

All freshwater fish sampling methods are biased toward particular species, sizes, and sexes and are further influenced by season, habitat, and fish behavior changes over time. However, little is known about gear-specific biases for many common fish species because few multiple-gear comparison studies exist that have incorporated seasonal dynamics. We sampled six lakes and impoundments representing a diversity of trophic and physical conditions in Iowa, USA, using multiple gear types (i.e., standard modified fyke net, mini-modified fyke net, sinking experimental gill net, bag seine, benthic trawl, boat-mounted electrofisher used diurnally and nocturnally) to determine the influence of sampling methodology and season on fisheries assessments. Specifically, we describe the influence of season on catch per unit effort, proportional size distribution, and the number of samples required to obtain 125 stock-length individuals for 12 species of recreational and ecological importance. Mean catch per unit effort generally peaked in the spring and fall as a result of increased sampling effectiveness in shallow areas and seasonal changes in habitat use (e.g., movement offshore during summer). Mean proportional size distribution decreased from spring to fall for white bass *Morone chrysops*, largemouth bass *Micropterus salmoides*, bluegill *Lepomis macrochirus*, and black crappie *Pomoxis nigromaculatus*, suggesting selectivity for large and presumably sexually mature individuals in the spring and summer. Overall, the mean number of samples required to sample 125 stock-length individuals was minimized in the fall with sinking experimental gill nets, a boat-mounted electrofisher used at night, and standard modified nets for 11 of the 12 species evaluated. Our results provide fisheries scientists with relative comparisons between several recommended standard sampling methods and illustrate the effects of seasonal variation on estimates of population indices that will be critical to the future development of standardized sampling methods for freshwater fish in lentic ecosystems.

Keywords: gear comparison; lakes; reservoirs; freshwater fishes; size structure; relative abundance

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Introduction

Assessments of fish populations with standard sampling methodologies are crucial to the appropriate management of fisheries, accurate environmental monitoring, and comparison of data across spatial and temporal scales (Willis and Murphy 1996; Yoder and Smith 1998). However, the selection of freshwater fish sampling methods is not straightforward due to the numerous unknown biases (e.g., gear, season, location) inherent to any fish sampling design or technique (Ricker 1969; Hayes et al. 1996; Pope and Willis 1996). Nevertheless, standard sampling methods (i.e., gear type, sample timing) are necessary to maintain consistency and repeatability in assessments of freshwater fishes (Bonar et al. 2009). Research on the quantitative assessment of fish sampling methods and associated constraining factors (e.g., season, gear construction specifications and materials) has unfortunately been limited by the high cost and labor associated with sampling across large temporal and spatial scales with numerous methods. Sampling protocols therefore are often not based on previous research for all potentially encountered species but rely predominately on traditionally used sampling methods. Despite numerous methodological advancements in fisheries science as a whole, little is known about the most effective sampling technique(s) used for the majority of freshwater fish species throughout the world.

The number of sampling methods required to target commonly encountered freshwater fish species varies largely by the physical characteristics of the aquatic habitat, such as water temperature (i.e., coldwater, warmwater) and waterbody size (e.g., wadeable stream, nonwadeable river, small standing water; Bonar et al. 2009). Unlike rivers and streams where relatively few standard sampling methods (e.g., electrofisher, seine, trammel net) are commonly used to characterize fish populations and assemblages (Guy et al. 2009; Rabeni et al. 2009), numerous methods (e.g., electrofisher, seine, fyke net, gill net, trawl, hoop net) and modifications (e.g., sinking and floating gillnets, nocturnal and diurnal electrofishing) are regularly used to sample fish in lentic systems (Pope et al. 2009; Miranda and Boxrucker 2009). Although more sampling methods should theoretically produce more species of greater size ranges, fish sampling protocols often attempt to minimize the number of gear types used because of difficulties with standardizing multiple methods and cost associated with increased sampling equipment and labor (Fischer and Quist 2014). Multiple fish sampling methods are typically required if the objective is to target multiple species or accurately characterize the range of sizes or ages present in a population because lentic waterbodies have distinct zones (i.e., pelagic, littoral) that differ in physicochemical characteristics and fish use. Furthermore, differences in physical characteristics (e.g., water depth, water clarity, vegetation presence) can affect the efficiency of sampling methods in differing zones that often vary by individual size and species. For example, more than one sampling method is often necessary to sample both juvenile and adult fish of the same species due to differing habitat use and size biases associated with sampling methods (e.g., Boxrucker et al. 1995; Bonvechio et al. 2008). However, most of our knowledge of lentic fish sampling biases is based on relatively few studies focused on species of recreational importance (e.g., Boxrucker et al. 1995; Sammons et al. 2002), and much is unknown for the majority of species commonly found in lakes and reservoirs.

Studies evaluating the influence of multiple sampling methods or seasonal dynamics are necessary because they inform fisheries managers and researchers about the relative bias of different sampling techniques. However, the ultimate selection of sampling methods and sample timing are not always straightforward as project or agency goals and finances change over time or vary regionally with zoogeography and political boundaries. Therefore, it is important to provide fisheries scientists with multiple ways to compare fish sampling gear types so that the selection of standard sampling methods can be based on observed biases and seasonal dynamics. Previous studies that have evaluated multiple sampling methods in lentic ecosystems have generally focused on single species assessments at small spatial scales (e.g., Boxrucker et al. 1995; Cross et al. 1995; Guy et al. 1996; Allen et al. 1999) or on relatively few methods used in a single season (e.g., Fago 1998; Pierce et al. 2001; Sammons et al. 2002; Bonvechio et al. 2008). The lack of research on the influence of methods and timing to assess fish populations of species frequently targeted in lentic ecosystems necessitates additional research. Furthermore, the recent formation of standard sampling methods for sampling freshwater fishes in North America (see Bonar et al. 2009) emerged from a need to have comparable information among natural resource agencies. The widespread adoption of standard sampling methods, like all things new, will almost certainly meet some degree of resistance. As such, information on the effects of sampling methodology and timing will likely be needed for natural resource managers and agencies to fully adopt standard methods, particularly if large financial requirements are needed (e.g., purchasing new equipment for an entire state or province).

The goal of this study was to evaluate methods for sampling fish populations of 12 recreationally and ecologically important species (e.g., invasive) in Iowa lakes and impoundments. The specific objectives of this study were to evaluate seasonal patterns of catch per unit effort (CPUE) and size structure estimates (i.e., proportional size distribution [PSD]), and determine the number of samples (e.g., individual hauls, net deployments) required to obtain 125 stock-length individuals using a variety of sampling methods. The intention of the study was to characterize the effectiveness of standard methods used to sample fish in lentic systems across multiple seasons.

Study Area

Three natural lakes and three impoundments were selected to represent the range of physical and chemical conditions present throughout Iowa (Table 1). Waterbodies were selected to represent the most (i.e., high total phosphorus, low water clarity, low macrophyte abundance and diversity) and least eutrophic conditions present throughout Iowa. Impoundments included Pleasant Creek Lake (Linn County), Don Williams Lake (Boone County), and Prairie Rose Lake (Shelby County). Natural lakes included West Okoboji Lake, Lake Minne-

Table 1. Waterbody, type, county, surface area, mean depth (Z), fish sampling effort (number of net-nights for passive gear types, number of seine hauls, number of 3-min benthic trawls, and number of 5-min runs with boat-mounted electrofisher conducted within a season), mean Secchi depth, mean chlorophyll *a* (Chl-*a*) concentration, and mean total phosphorus (TP) concentration for six waterbodies located in Iowa. Waterbodies were sampled three times yearly between May and August (2000–2008) for measures of Secchi depth, Chl-*a*, and TP, and values represent the mean of annual means.

Water body	Type	County	Surface area (ha)	Z (m)	Sampling effort	Secchi depth (m)	Chl-*a* (μg/L)	TP (μg/L)
Prairie Rose	Impoundment	Shelby	70	2.7	10	0.7	48	91
Don Williams	Impoundment	Boone	60	5.5	10	1.7	24	84
Pleasant Creek	Impoundment	Linn	162	4.8	12	2.1	15	40
Silver	Natural lake	Dickenson	432	2.3	20	0.7	37	167
Minnewashta	Natural lake	Dickenson	48	3.1	10	1.7	22	116
West Okoboji	Natural lake	Dickenson	1,557	11.6	20	5.4	4	27

washta, and Silver Lake located in Dickinson County in northwestern Iowa.

Methods

Fish sampling

Fish sampling techniques included both active and passive methods. Several of the gear types were selected based on the recommended standard sampling methods for small and large standing waters (i.e., boat electrofisher, standard modified fyke net, sinking experimental gill net, bag seine) provided in Bonar et al. (2009). However, additional sampling methods (e.g., benthic trawl, mini-modified fyke net) were also used. Standard modified fyke nets (1 × 2 m frame, 12.7-mm bar-measure mesh, 15.2-m lead; Miranda and Boxrucker 2009) were used to sample structure-oriented species, such as centrarchids located in littoral habitats (Hubert 1996). In addition to using the standard modified fyke nets, a smaller version (hereafter mini-modified fyke net; 0.6 × 1.2-m frame, 6.4-mm ace mesh, 7.6-m lead) was used to sample small-bodied species and age-0 fish common in littoral habitats (Fago 1998; Barko et al. 2004). Both types of fyke net were set perpendicular to the shore at dusk and retrieved the following morning. A sinking experimental gill net was used to sample fishes not typically sampled with fyke nets (e.g., pelagic species). Gill nets were constructed of monofilament and were 30.5 m in length × 2 m in depth with ten 3.1-m long panels in a quasi-random order (127-, 38-, 57-, 25-, 44-, 19-, 64-, 32-, 51-, and 102-mm bar-measure mesh with a 0.5 hanging ratio; Miranda and Boxrucker 2009; Pope et al. 2009). Similar to fyke nets, gill nets were deployed overnight and retrieved the following morning. A bag seine (9.1 m in length × 2 m in depth, 2 × 2 × 2-m bag, 6.4-mm ace mesh) was used to sample littoral habitats without extensive woody debris or large boulders. Seining was conducted during the day using quarter-arc hauls. Littoral and benthic habitats were also sampled with a small benthic trawl. The benthic trawl was used to sample small-bodied species and juveniles of larger species and had a headrope length of 2.4 m, footrope length of 3.7 m, and upright length of 0.6 m. The trawl body consisted of a small (6.3-mm delta mesh) outer mesh and a large (34.9-mm bar mesh of 1.0-mm multifilament nylon) inner mesh. Trawl towlines were 38.1 m in length to allow for a maximum effective depth of 5.4 m with a 7:1 drop ratio. Additional information on the design, development, and specification of the Mini-Missouri trawl as used in lotic habitats was described by Herzog et al. (2005), Guy et al. (2009), and Neebling and Quist (2011). Trawls were towed perpendicular from the shore for 3 min at approximately 3.2 km/h during the day. Lastly, a boat-mounted, pulsed DC electrofisher (hereafter electrofishing) was used to sample fishes not collected with other sampling methods. Because electrofishing catch rates are influenced by diel period (Sanders 1992; Reynolds 1996; McInerny and Cross 2004), electrofishing equipment was used diurnally (30 min after sunrise to 30 min before sunset) and nocturnally (30 min after sunset to 30 min before sunrise). Boat-mounted electrofisher output was standardized at 2,750–3,250 W (Burkhardt and Gutreuter 1995; Miranda 2009; Miranda and Boxrucker 2009). Electrofishing runs were conducted for 5 min, parallel to the shoreline, and with two netters using 6.3-mm delta mesh dipnets. All sampled fish were identified to species and measured to the nearest millimeter of total length. Unidentified specimens were preserved in 10% formalin and identified and measured in the laboratory.

Fish were sampled seasonally to evaluate the optimal time of year to characterize fish populations for each sampling gear. Samples were collected in the spring (i.e., April 11–May 31), summer (i.e., late June 22–July 13), and fall (i.e., September 14–October 31). Experimental sinking gill nets were only used in the fall to minimize mortality associated with overnight sets. A systematic random sampling design was used to allocate samples for each waterbody (Figure 1). Specifically, the shoreline was divided into segments that included at least one sample from each gear. The number of shoreline segments, delineated for each lake or impoundment, was based on the effort required for all sampling methods (Table 1). For example, a 75-ha lake included 10 samples of each gear. Therefore, at least 10 shoreline segments were identified to ensure a sample from each sampling method. Shoreline segments were further divided into eight reaches. In total, eight reaches was selected to include an individual reach for each of the seven sampling methods (i.e., mini-modified fyke net, standard

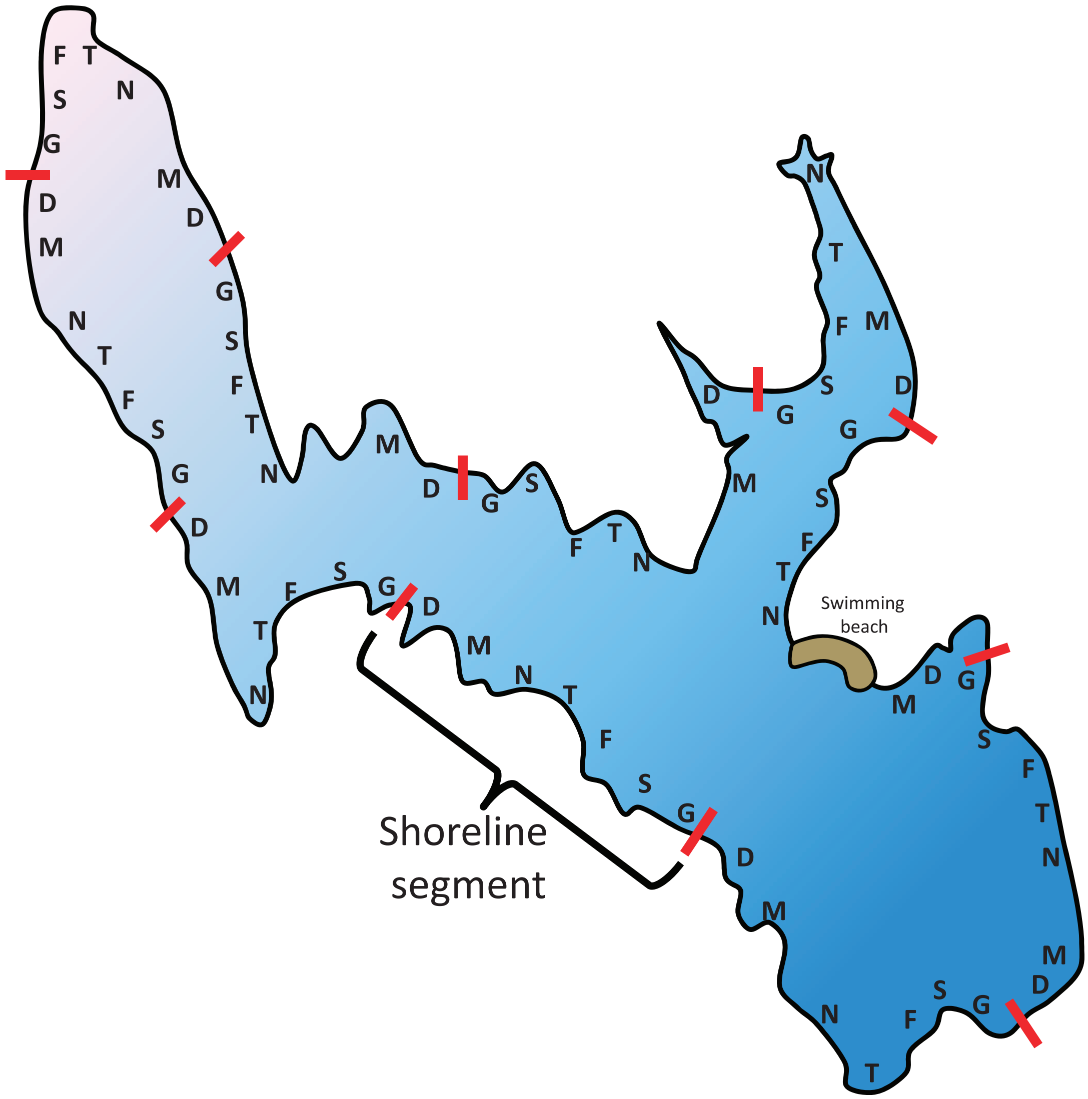

Figure 1. Systematic random sampling design used to allocate gear types for each waterbody sampled in 2008. Number of shoreline segments delineated and effort for each sampling gear type was adjusted for surface area (Table 1). Letters designate hypothetical locations of gear types used: bag seine (S), benthic trawl (T), diurnal electrofishing (D), nocturnal electrofishing (N), standard modified fyke net (F), mini-modified fyke net (M), and sinking experimental gill net (G).

modified fyke net, sinking experiment gill net, seine, benthic trawl, electrofishing during the day, electrofishing during the night) in addition to an alternate reach that was used to allocate gear types that were unable to be used in a preselected reach (e.g., enclosed swimming beach, spillway). Individual gear types were randomly assigned to reaches in each segment. Gear types assigned to a specific reach were used to sample fish in that reach throughout the study (i.e., spring, summer, fall).

Data analysis

Comparisons between sampling gear types and timing focused on 12 species that commonly occur in lentic ecosystems throughout North America (Lee et al. 1980). Species of interest included common carp *Cyprinus carpio*, black bullhead *Ameiurus melas*, yellow bullhead *Ameiurus natalis*, channel catfish *Ictalurus punctatus*, white bass *Morone chrysops*, bluegill *Lepomis macrochirus*, largemouth bass *Micropterus salmoides*, white crappie *Pomoxis annularis*, black crappie *Pomoxis nigromaculatus*, yellow perch *Perca flavescens*, walleye *Sander vitreus*, and freshwater drum *Aplodinotus grunniens*. Mean CPUE and associated standard errors were estimated for each species, gear, and season separately for each waterbody. Estimates of CPUE for the mini-modified fyke net, standard modified fyke net, and gill net were the number of fish per net night. Estimates of CPUE for the bag seine and benthic trawl were the number of fish per haul. Estimates of CPUE for diurnal and nocturnal electrofishing were calculated as the number of fish per hour. Additionally, mean CPUE was estimated separately for stock- and substock-length individuals of each species to evaluate the selectivity of each gear type.

Proportional size distribution is a common index used to numerically describe length–frequency distributions,

Table 2. Total number of individuals sampled in spring (Sp), summer (Su), and fall (Fa) for seven sampling methods from six lakes and impoundments in Iowa, 2008.

	Bag seine			Benthic trawl			Diurnal electrofishing		
Family and species	**Sp**	**Su**	**Fa**	**Sp**	**Su**	**Fa**	**Sp**	**Su**	**Fa**
Cyprinidae									
Common carp *Cyprinus carpio*	1		3	4	4	1	50	44	30
Ictaluridae									
Black bullhead *Ameiurus melas*	1	1	3	8	5	8	1	16	8
Yellow bullhead *Ameiurus natalis*			70		1	1	1	1	1
Channel catfish *Ictalurus punctatus*	1			2	13	1	9	12	9
Moronidae									
White bass *Morone chrysops*	2		7	2		7	47	17	68
Centrarchidae									
Bluegill *Lepomis macrochirus*	50	142	2,744	210	667	1,815	199	162	414
Smallmouth bass *Micropterus dolomieu*		2	1		20		17	12	22
Largemouth bass *Micropterus salmoides*	6	687	57	2	48	10	192	99	249
White crappie *Pomoxis annularis*			6	4		15	2		5
Black crappie *Pomoxis nigromaculatus*		256	36	139	2,991	616	36	16	49
Percidae									
Yellow perch *Perca flavescens*		196	5	19	159	18	11	49	73
Walleye *Sander vitreus*		4	4	4	39	8	3	12	27
Sciaenidae									
Freshwater drum *Aplodinotus grunniens*		1	58		228	22	25	25	35
Total	61	1,289	2,994	394	4,175	2,522	593	465	990

thereby providing useful information on recruitment, growth, and mortality of fishes (Willis et al. 1993; Anderson and Neumann 1996; Guy et al. 2007). Proportional size distributions can be influenced by biased sampling associated with selectivity for different sizes of fish throughout the year and should be considered when determining sampling methods (see Willis et al. 1993; Pope and Willis 1996). Size structure of populations was estimated using PSD using standard length categories (Gabelhouse 1984; Anderson and Neumann 1996; Bister et al. 2000; Guy et al. 2007). Mean PSD and associated standard errors were estimated separately for all gear types and seasons where at least 50 stock-length individuals were sampled from a waterbody.

Determining the number of individual fish required (i.e., sampled and measured) to accurately estimate characteristics (e.g., mean length, size structure, PSD) of a fish population is essential to choosing standard methods for fisheries assessments. Furthermore, the required number of individuals depends on characteristics of the species (e.g., body size) and the population (e.g., size and age structure; Vokoun et al. 2001; Miranda 2007). For example, Vokoun et al. (2001) recommended measuring 300–400 individuals to estimate length frequency using information on channel catfish and bluegill populations. Miranda (2007) recommended measuring 375–1,200 and 150–425 individuals to estimate 1-cm and 2.5-cm length–frequency histograms, respectively, using data from black crappie, bluegill, and largemouth bass populations. Additionally, the characteristic being estimated can have an influence on the required number of individuals. Miranda (2007) reported that 75–160 and 75–140 fish were required to accurately estimate mean length and PSD, respectively, for black crappie, bluegill, and largemouth bass. Following these guidelines, Quist et al. (2009) recommend a minimum sample size of 125 for calculating PSD. Therefore, the mean number of samples required to collect 125 stock-length individuals were calculated for each season, gear, and species. Estimates of the numbers of samples required to collect 125 stock-length individuals were based on mean CPUE data for each season, gear, and species. Additionally, the percentage of waterbodies where 50 and 125 stock-length individuals were sampled was calculated for each gear type and season.

Results

Across all waterbodies, seasons, and gear types, 61,293 fish were sampled. The most abundant species sampled was bluegill (27,940 individuals), followed by black crappie (9,309), freshwater drum (6,021), black bullhead (3,305), white bass (2,383), and largemouth bass (2,085). The 12 focal species accounted for 91% of all individuals sampled among all seasons and sampling methods (Table S1, *Supplemental Material*). Bluegill, black bullhead, and largemouth bass were sampled with every sampling method in every season, whereas several other species (i.e., common carp, black crappie, yellow perch, walleye) were sampled with all methods in nearly every season (Table 2).

Table 2. Extended.

Nocturnal electrofishing			Standard modified fyke net			Mini-modified fyke net			Sinking experimental gill net	
Sp	Su	Fa	Sp	Su	Fa	Sp	Su	Fa	Fa	Total
34	29	42	166	157	118	1	1	2	118	805
85	40	17	1,423	655	553	182	91	36	173	3,306
18	10	15	282	139	169	21	1	9	22	761
12	14	21	6	78	12		2	1	188	381
99	23	406	405	231	552	13	8	50	446	2,383
1,643	716	869	1,947	5,502	2,338	146	418	7,929	29	27,940
33	11	24		1			1		11	155
277	172	226	9	7	27	4	3	4	6	2,085
		3	21	9	18			5	9	97
172	21	49	769	1,799	1,873	15	34	201	236	9,308
163	63	134	100	176	165	1	10	46	225	1,613
119	54	132	65	112	145	3	11	12	152	906
37	65	154	10	84	3,868		6	1,134	269	6,021
2,692	1,218	2,092	5,203	8,950	9,838	386	586	9,429	1,884	55,761

Gear types that specifically targeted small-bodied and age-0 fish (i.e., seine, trawl, mini-fyke nets) were effective at sampling substock-length individuals for several of the focal species (Figure 2). Specifically, mean CPUE was highest for substock-length bluegill and yellow perch with mini-fyke nets. Substock-length individuals of some species were almost exclusively sampled with a single method in an individual season. For example, mean CPUE was highest for substock-length largemouth bass (seine) and black crappie (trawl) during the summer. In contrast, substock-length white bass were sampled with several gear types with higher mean CPUE in the fall. Seasonal patterns in mean CPUE of substock-length individuals were also observed for several of the gear types. Mean CPUE of substock-length walleye and yellow perch was lowest in the summer with peaks in spring and fall. Increases in mean CPUE throughout the year were observed for substock-length bluegill (benthic trawl) and yellow perch (electrofishing during the day), whereas decreases from spring to fall were observed for common carp (fyke nets). Similar patterns between mean CPUE of substock-length individuals and CPUE of stock-length individuals (Figure 2) were found for common carp (fyke nets) and walleye (nocturnal electrofishing). Gill nets were generally not effective at sampling substock-length individuals, but resulted in the highest mean CPUE for common carp and channel catfish.

Seasonal patterns in CPUE of stock-length individuals were observed for numerous species (Figure 3). For example, mean CPUE of stock-length individuals increased throughout the year (i.e., from spring to fall) for walleye (fyke nets), yellow perch (nocturnal electrofishing and fyke nets), and freshwater drum (electrofishing during the day). Similarly, mean CPUE of stock-length individuals decreased throughout the year for common carp with fyke nets. Catch-per-unit-effort of stock-length individuals was generally lower in the summer for several of the focal species. Specifically, mean CPUE of stock-length individuals was lowest in the summer for black crappie (standard fyke net), largemouth bass (diurnal and nocturnal electrofishing), walleye (nocturnal electrofishing), channel catfish (diurnal and nocturnal electrofishing), black bullhead (standard fyke net), yellow bullhead (nocturnal electrofishing and standard fyke net), and white bass (diurnal and nocturnal electrofishing, standard fyke nets). Although individuals were sampled with nearly every method in each season, some species were noticeably more susceptible to one or a small subset of sampling methods. For instance, stock-length largemouth bass were predominately sampled with electrofishing. Black bullhead (79.6% of total individuals sampled), freshwater drum (65.8%), common carp (54.8%), white bass (49.9%), white crappie (49.5%), black crappie (47.7%), and bluegill (35.0%) were primarily sampled with standard fyke nets regardless of season.

At least 50 stock-length bluegills were sampled in all lakes with standard fyke nets in summer (Table 3). However, the percentage of lakes where at least 125 stock-length bluegill were sampled was greatest with fyke nets in the fall (83.3%). The percentage of lakes where 50 stock-length black crappie were sampled was also greatest with fyke nets in the fall (66.7%); however,

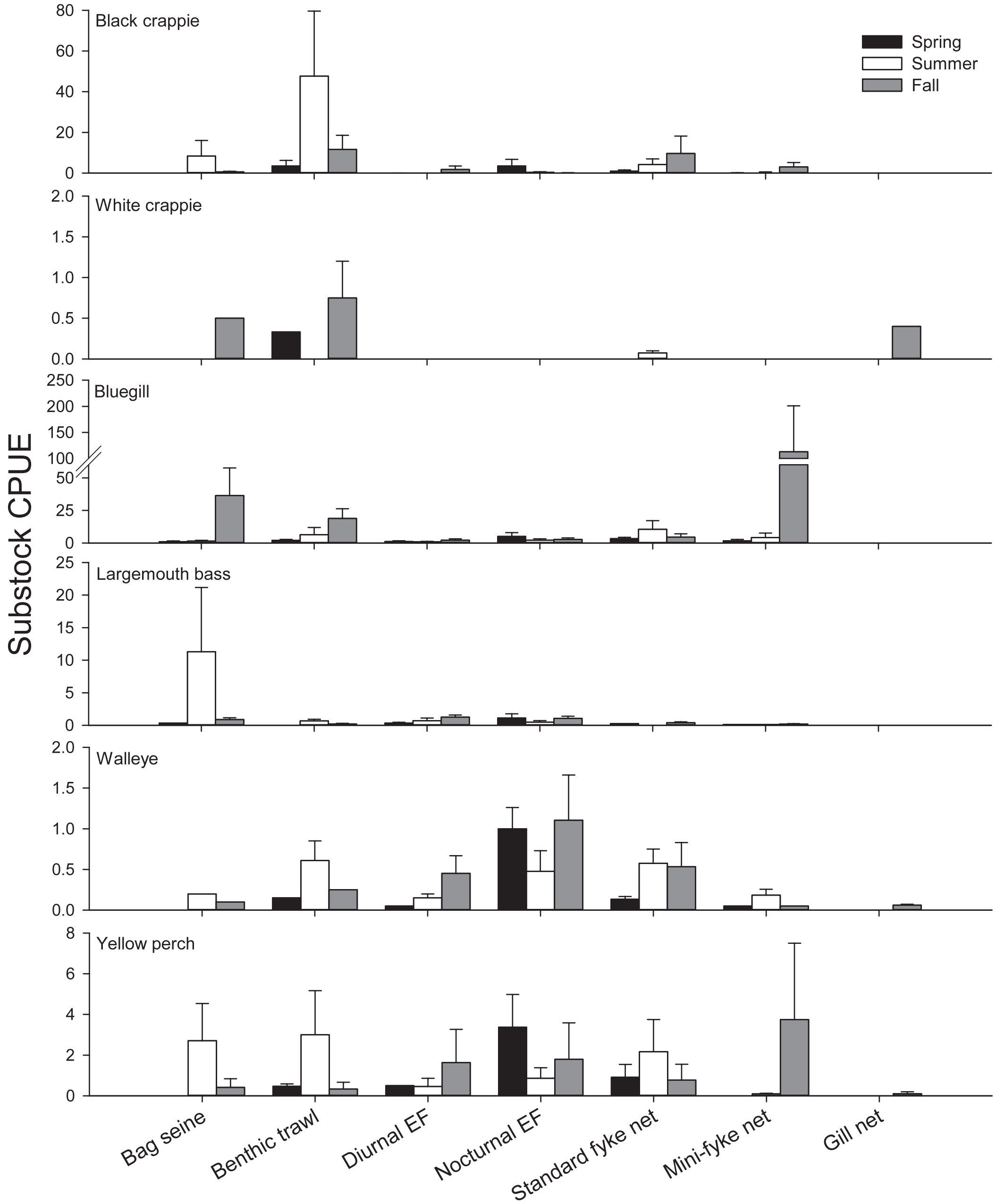

Figure 2. Mean catch per unit effort (CPUE) of substock-length common carp *Cyprinus carpio*, black bullhead *Ameiurus melas*, yellow bullhead *Ameiurus natalis*, channel catfish *Ictalurus punctatus*, white bass *Morone chrysops*, bluegill *Lepomis macrochirus*, largemouth bass *Micropterus salmoides*, white crappie *Pomoxis annularis*, black crappie *Pomoxis nigromaculatus*, yellow perch *Perca flavescens*, walleye *Sander vitreus*, and freshwater drum *Aplodinotus grunniens* from seasonal sampling with seven methods in six lakes and impoundments in Iowa, 2008. Values of CPUE for were calculated for independently for bag seine (number per haul); benthic trawl (number per 3-min trawl); diurnal and nocturnal electrofishing (EF; number per hour); and standard modified fyke net (Standard fyke net), mini-modified fyke net (Mini-fyke net), and sinking experimental gill net (Gill net; number per net night). Error bars represent 1 SE.

fyke nets used in the spring maximized the percentage of lakes where 125 stock-length black crappie were sampled (33.3%). Fifty stock-length individuals were not sampled in a single lake for any of the season and gear combinations for channel catfish and white crappie (Table 3). Mean bluegill PSD from fyke nets was lowest in fall (36 ± 11 [overall mean ± SE]), but similar for bluegills sampled in spring (56 ± 9) and summer (56 ± 13; Table 4). Mean PSD for bluegill sampled with electrofishing at night was also lowest in fall (39 ± 12). Black crappie mean PSD was highest in spring for standard fyke net samples (75 ± 21). Mean largemouth bass PSD decreased from spring through fall with night electrofishing. Black bullhead and yellow bullhead mean PSDs were consistent among seasons using standard fyke nets, whereas mean PSD of white bass was similar between spring and summer, but lower in the fall for standard fyke net samples. Mean PSD for yellow perch and walleye

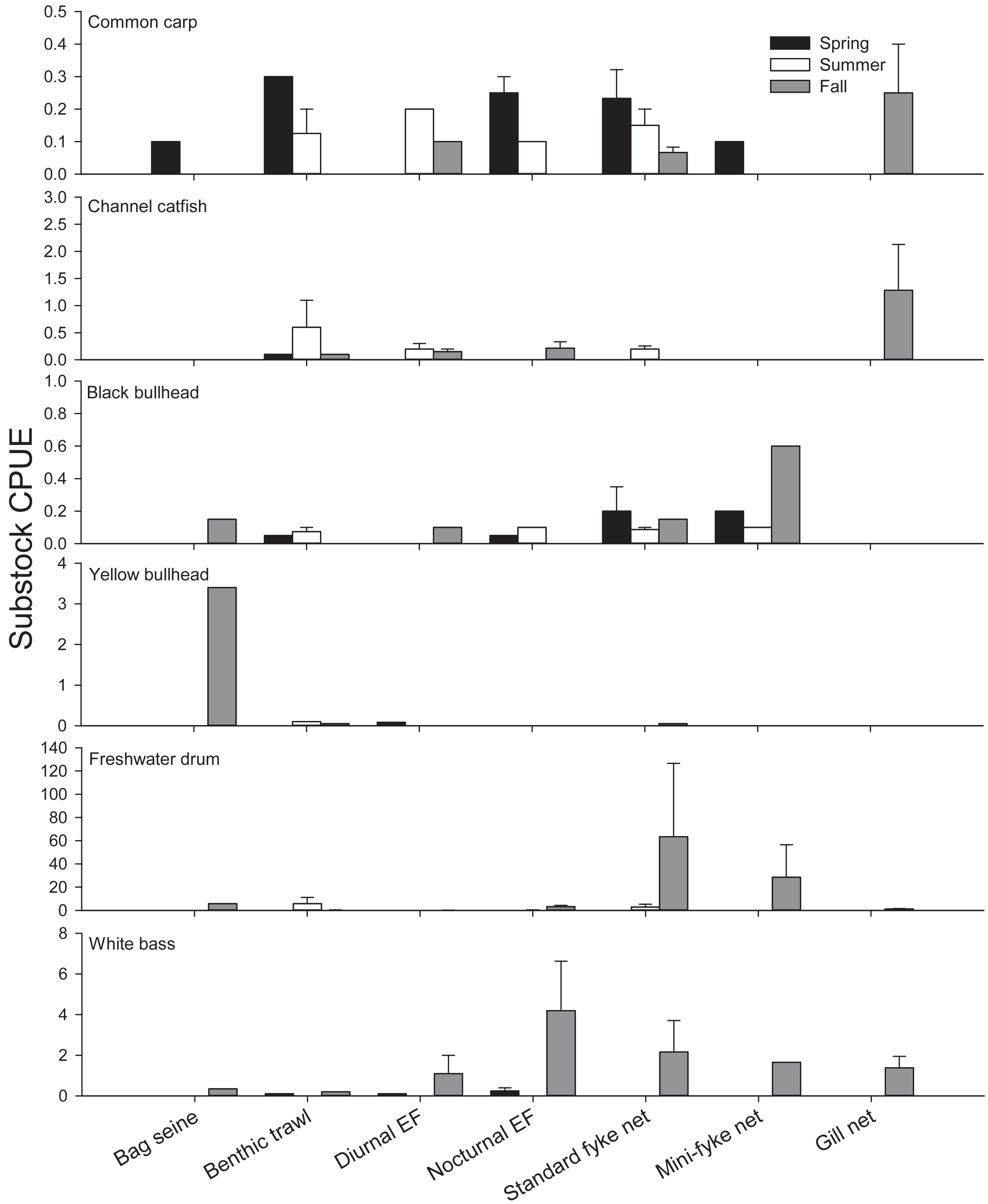

Figure 2. Continued.

sampled with fyke nets were lower in fall than summer. Mean PSD for both species in fall was greater for gill nets than standard fyke nets.

Gill nets minimized the mean number of samples needed to sample 125 stock-length individuals for walleye (147 ± 58 net nights), yellow perch (34 ± 3), channel catfish (150 ± 96), freshwater drum (87 ± 55), and white bass (29 ± 5; Figure 4). The mean number of samples required to sample 125 stock-length individuals was minimized with fyke nets in the spring for common carp (83 ± 37 net nights), in the summer for bluegill (10 ± 5) and black bullhead (14 ± 5), and in the fall for black crappie (45 ± 22). Nocturnal electrofishing in spring minimized the mean number of samples required to sample 125 stock-length largemouth bass (39 ± 5 5 min electrofishing runs) followed closely by spring electrofishing during the day (47 ± 9) and fall electrofishing during the night (54 ± 12).

Discussion

Several well-known patterns of sampling bias were observed in our study. For instance, species and size selectivities for an individual gear were detected for many of the species. Largemouth bass were almost exclusively sampled with electrofishing (i.e., stock-length) and seining (i.e., substock-length). Selectivity for adult

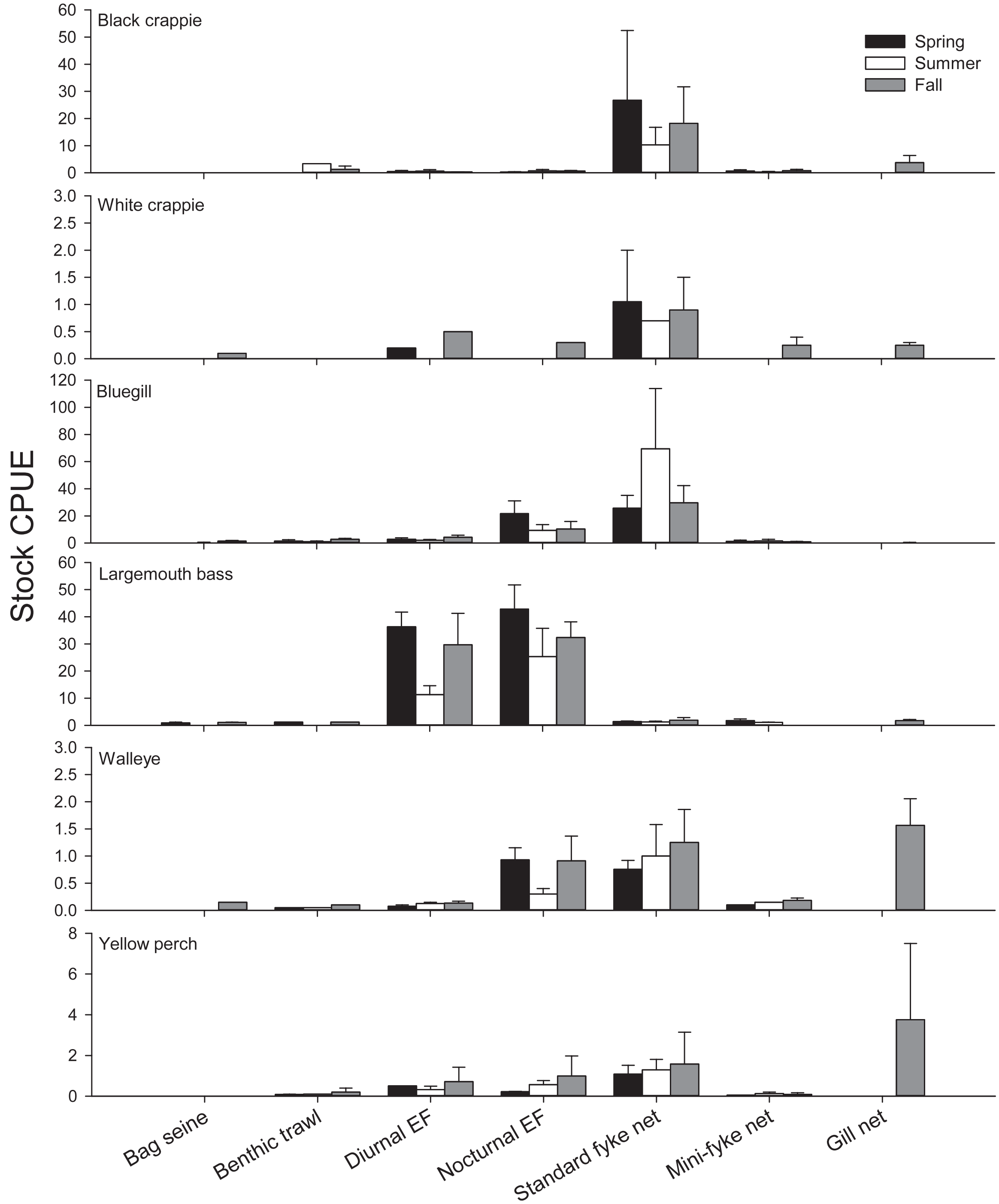

Figure 3. Mean catch per unit effort (CPUE) of stock-length common carp *Cyprinus carpio*, black bullhead *Ameiurus melas*, yellow bullhead *Ameiurus natalis*, channel catfish *Ictalurus punctatus*, white bass *Morone chrysops*, bluegill *Lepomis macrochirus*, largemouth bass *Micropterus salmoides*, white crappie *Pomoxis annularis*, black crappie *Pomoxis nigromaculatus*, yellow perch *Perca flavescens*, walleye *Sander vitreus*, and freshwater drum *Aplodinotus grunniens* from seasonal sampling with seven methods in six lakes and impoundments in Iowa, 2008. Values for CPUE were calculated for independently for bag seine (number per haul); benthic trawl (number per 3-min trawl); diurnal and nocturnal electrofishing (EF; number per hour); and standard modified fyke net (Standard fyke net), mini-modified fyke net (Mini-fyke net), and sinking experimental gill net (Gill net; number per net night). Error bars represent 1 SE.

and juvenile largemouth bass with electrofishing and seining, respectively, has long been known, and these two methods are regularly recommended (e.g., Swingle 1956; Jackson and Noble 1995). In contrast, the use of multiple gear types are commonly recommended for targeting bluegill (Bettross and Willis 1988), black crappie (Sammons et al. 2002), and yellow perch (Robillard et al. 1995). Our results showed that specific sampling

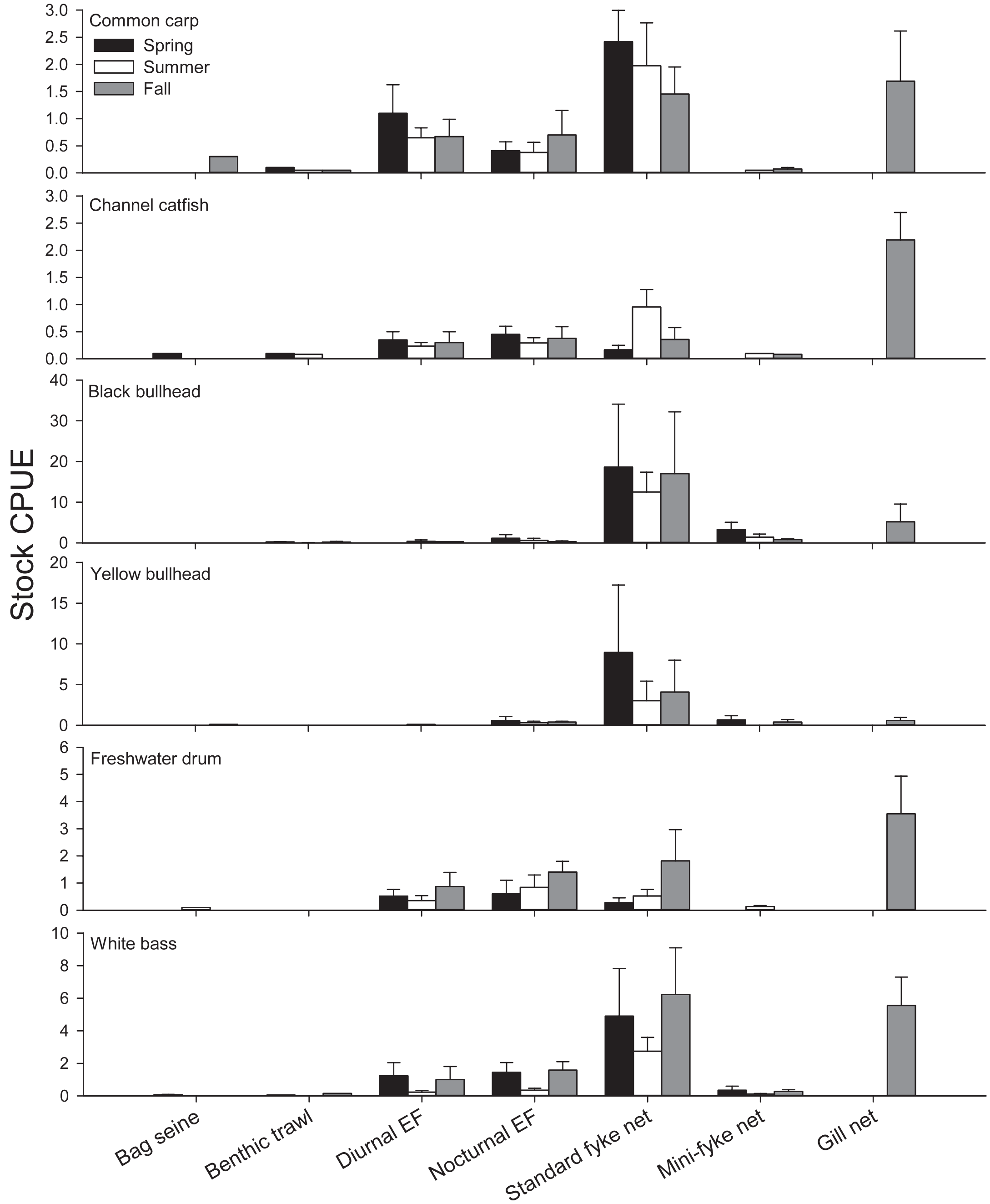

Figure 3. Continued.

methods and seasons consistently resulted in higher mean CPUE for stock- or substock-length individuals for the 12 focal species evaluated. Specifically, modified fyke nets are frequently used to target structure-oriented species and were particularly effective at sampling black crappie, white crappie, bluegill, walleye, common carp, black bullhead, yellow bullhead, and white bass. Gill nets are a commonly used passive sampling technique that target pelagic and highly mobile species (Hubert 1996). In our study, gill nets generally resulted in higher mean CPUE of stock-length walleye, yellow perch, common carp, channel catfish, freshwater drum, and white bass. Electrofishing is used to target a variety of freshwater fish species and was effective at sampling the majority of species evaluated in our study. Overall, our results provide fisheries scientists with relative comparisons of sampling data for several recreationally and ecologically important species that can be used to guide the selection of standardized sampling methods.

The use of multiple sampling methods to quantify abundance of adults and juveniles of the same species is common (e.g., Boxrucker et al. 1995; Bonvechio et al. 2008). Seining is generally considered an effective method for sampling littoral areas of lakes, as it can be conducted with minimal personnel and equipment needs, and it provides quantitative estimates of fish

Table 3. Number (N) of lakes and impoundments present and the percentage of waterbodies in Iowa where 50 and 125 (parentheses) stock-length individuals were sampled from six lakes and impoundments in Iowa with a bag seine (S), benthic trawl (T), diurnal electrofishing (D), nocturnal electrofishing (E), standard modified fyke net (F), mini-modified fyke net (M), and sinking experimental gill net (G) in spring, summer, and fall 2008.

	Spring							Summer	
Family and species	**N**	**S**	**T**	**D**	**E**	**F**	**M**	**S**	**T**
Cyprinidae									
Common carp *Cyprinus carpio*	6	x	x	X	x	16.7 (0)	x	x	x
Ictaluridae									
Black bullhead *Ameiurus melas*	4	x	x	X	25.0 (0)	50.0 (25.0)	25.0 (25.0)	x	x
Yellow bullhead *Ameiurus natalis*	5	x	x	x	x	20.0 (20.0)	x	x	x
Channel catfish *Ictalurus punctatus*	6	x	x	x	x	x	x	x	x
Moronidae									
White bass *Morone chrysops*	5	x	x	x	x	40.0 (20.0)	x	x	x
Centrarchidae									
Bluegill *Lepomis macrochirus*	6	x	x	33.0 (0)	83.3 (50.0)	83.3 (66.7)	x	x	x
Largemouth bass *Micropterus salmoides*	6	x	x	x	16.7 (0)	x	x	x	x
White crappie *Pomoxis annularis*	4	x	x	x	x	x	x	x	x
Black crappie *Pomoxis nigromaculatus*	6	x	x	x	x	50.0 (33.3)	x	x	x
Percidae									
Yellow perch *Perca flavescens*	4	x	x	x	x	x	x	x	x
Walleye *Sander vitreus*	6	x	x	x	x	x	x	x	x
Sciaenidae									
Freshwater drum *Aplodinotus grunniens*	4	x	x	x	x	x	x	x	x

Table 4. Mean proportional size distribution (PSD) and standard error (parentheses) of 12 fish species sampled from six lakes and impoundments in Iowa with a bag seine (S), benthic trawl (T), diurnal electrofishing (D), nocturnal electrofishing (E), standard modified fyke net (F), mini-modified fyke net (M), and sinking experimental gill net (G) in spring, summer, and fall 2008. Proportional size distributions were only estimated for gear types with greater than 50 stock-length individuals sampled within a season from an individual waterbody.

	Spring						Summer		
Family and species	**S**	**T**	**D**	**E**	**F**	**M**	**S**	**T**	**D**
Cyprinidae									
Common carp *Cyprinus carpio*	x	x	x	x	100 (0)	x	x	x	x
Ictaluridae									
Black bullhead *Ameiurus melas*	x	x	x	100 (0)	93.0 (6.9)	100 (0)	x	x	x
Yellow bullhead *Ameiurus natalis*	x	x	x	x	99.2 (0)	x	x	x	x
Channel catfish *Ictalurus punctatus*	x	x	x	x	x	x	x	x	x
Moronidae									
White bass *Morone chrysops*	x	x	x	x	99.4 (0.6)	x	x	x	x
Centrarchidae									
Bluegill *Lepomis macrochirus*	x	x	45.6 (28.9)	45.2 (12.4)	55.9 (9.4)	x	x	x	x
Largemouth bass *Micropterus salmoides*	x	x	x	84.6 (0)	x	x	x	x	x
White crappie *Pomoxis annularis*	x	x	x	x	x	x	x	x	x
Black crappie *Pomoxis nigromaculatus*	x	x	x	x	75.4 (21.3)	x	x	x	x
Percidae									
Yellow perch *Perca flavescens*	x	x	x	x	x	x	x	x	x
Walleye *Sander vitreus*	x	x	x	x	x	x	x	x	x
Sciaenidae									
Freshwater drum *Aplodinotus grunniens*	x	x	x	x	x	x	x	x	x

Table 3. Extended.

Summer				Fall						
D	E	F	M	S	T	D	E	F	M	G
x	x	16.7 (0)	x	x	x	x	x	x	x	16.7 (0)
x	x	75.0 (25.0)	25.0 (0)	x	x	x	x	50.0 (25.0)	x	25.0 (25.0)
x	x	20.0 (0)	x	x	x	x	x	20.0 (20.0)	x	x
x	x	x	x	x	x	x	x	x	x	x
x	x	40.0 (0)	x	x	x	x	20.0 (0)	40.0 (40.0)	x	60.0 (20.0)
x	83.3 (16.7)	100 (66.7)	16.7 (0)	x	16.7 (0)	33.3 (0)	66.7 (16.7)	83.3 (83.3)	x	x
x	16.7 (0)	x	x	x	x	33.3 (0)	16.7 (0)	x	x	x
x	x	x	x	x	x	x	x	x	x	x
x	x	16.7 (16.7)	x	x	x	x	x	66.7 (16.7)	x	16.7 (16.7)
x	x	20.0 (0)	x	x	x	x	20.0 (0)	20.0 (0)	x	20.0 (0)
x	x	16.7 (0)	x	x	x	x	x	16.7 (0)	x	16.7 (0)
x	x	x	x	x	x	x	x	x	x	25.0 (25.0)

Table 4. Extended.

Summer			Fall						
E	F	M	S	T	D	E	F	M	G
x	98.2 (0)	x	x	x	x	x	x	x	41.4 (0)
x	95.7 (2.6)	100 (0)	x	x	x	x	97.2 (2.6)	x	99.3 (0)
x	98.0 (0)	x	x	x	x	x	98.1 (0)	x	x
x	x	x	x	x	x	x	x	x	x
x	98.3 (0.8)	x	x	x	x	29.3 (0)	71.2 (28.8)	x	81.8 (18.2)
52.7 (13.2)	55.9 (12.5)	50.7 (0)	x	17.7 (0)	45.6 (23.2)	38.9 (12.0)	35.9 (11.4)	x	x
66.7 (0)	x	x	x	x	49.5 (10.2)	54.9 (0)	x	x	x
x	x	x	x	x	x	x	x	x	x
x	12.6 (0)	x	x	x	x	x	50.4 (13.4)	x	16.5 (0)
x	74.1 (0)	x	x	x	x	28.8 (0)	37.9 (0)	x	73.6 (26.4)
x	35.2 (0)	x	x	x	x	x	24.6 (0)	x	43.2 (0)
x	x	x	x	x	x	x	x	x	99.3 (25.0)

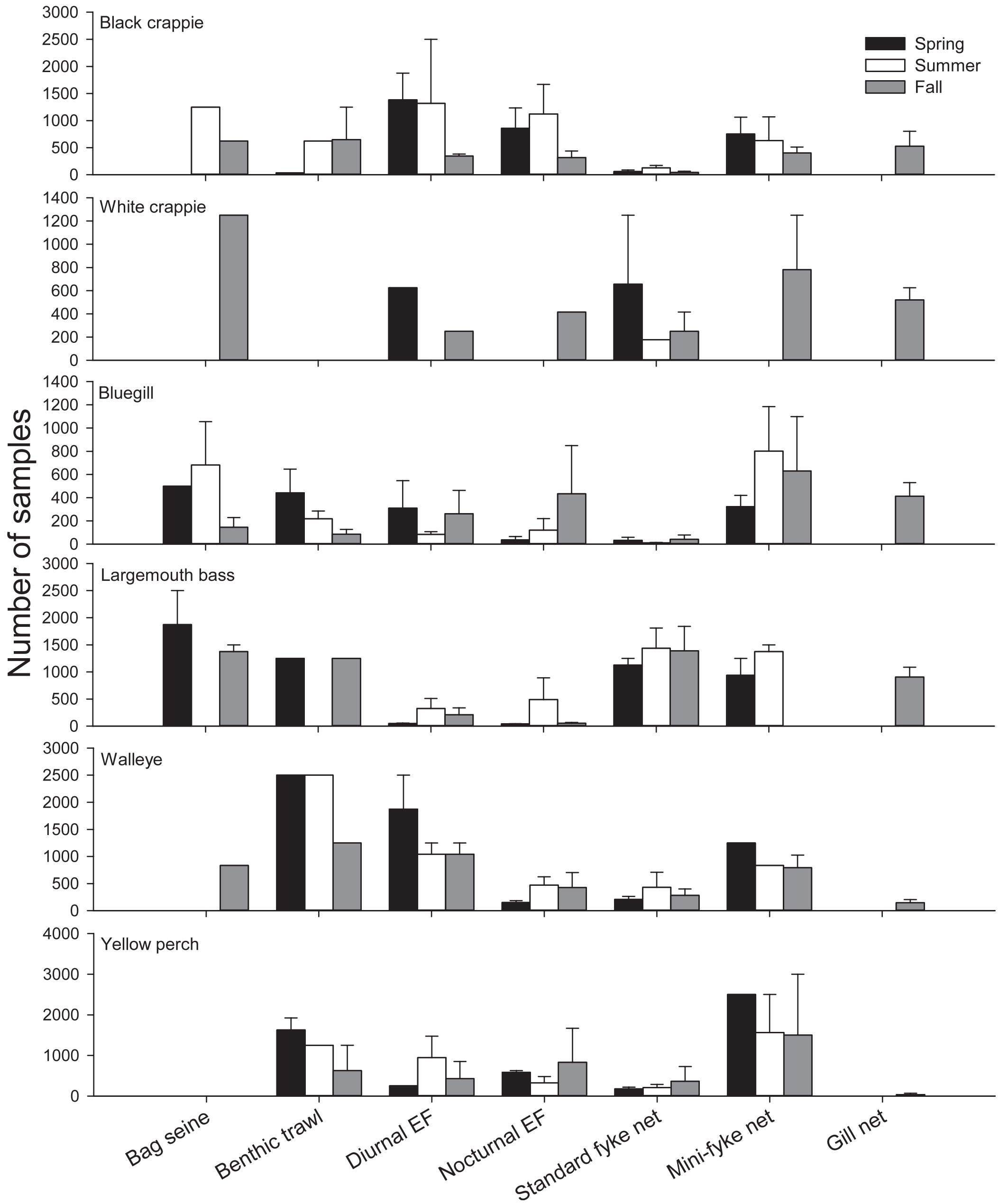

Figure 4. Mean minimum numbers of samples (i.e., 5-min electrofishing runs, deployments, net sets, hauls) necessary to sample 125 stock-length common carp *Cyprinus carpio*, black bullhead *Ameiurus melas*, yellow bullhead *Ameiurus natalis*, channel catfish *Ictalurus punctatus*, white bass *Morone chrysops*, bluegill *Lepomis macrochirus*, largemouth bass *Micropterus salmoides*, white crappie *Pomoxis annularis*, black crappie *Pomoxis nigromaculatus*, yellow perch *Perca flavescens*, walleye *Sander vitreus*, and freshwater drum *Aplodinotus grunniens* from seasonal sampling with a bag seine, benthic trawl, diurnal and nocturnal electrofishing (EF), standard modified fyke nets (Standard fyke net), mini-modified fyke nets (Mini-fyke net), and sinking experimental gill nets (Gill net) in six lakes and impoundments in Iowa, 2008. Error bars represent 1 SE.

abundance. However, capture efficiencies of seining are often highly variable due to snags (e.g., woody debris, boulders) and high macrophyte densities (Pierce et al. 1990). Miranda and Boxrucker (2009) did not recommend sampling methods that directly targeted small-bodied or age-0 fish in large standing waterbodies, but Pope et al. (2009) recommended seining during summer for small-bodied species (e.g., minnows) and age-0 fish in small-standing waterbodies. We attempted to evaluate seasonal influences on estimates of seining, while providing similar comparisons for alternative methods (i.e., mini-modified fyke nets and a benthic trawl). Mini-modified fyke nets constructed with small mesh (e.g., ≤6 mm) have been commonly used to sample age-0 sport fish and small-bodied species (Weaver et al. 1993; Fago 1998; Ruetz et al. 2007). Small-mesh fyke nets often sample more individuals and species than seining (Gritters 1994; Clark et al. 2007). In our evaluation, mean CPUE of substock-length individuals of bluegill, yellow perch, and freshwater drum was highest with mini-fyke nets. An

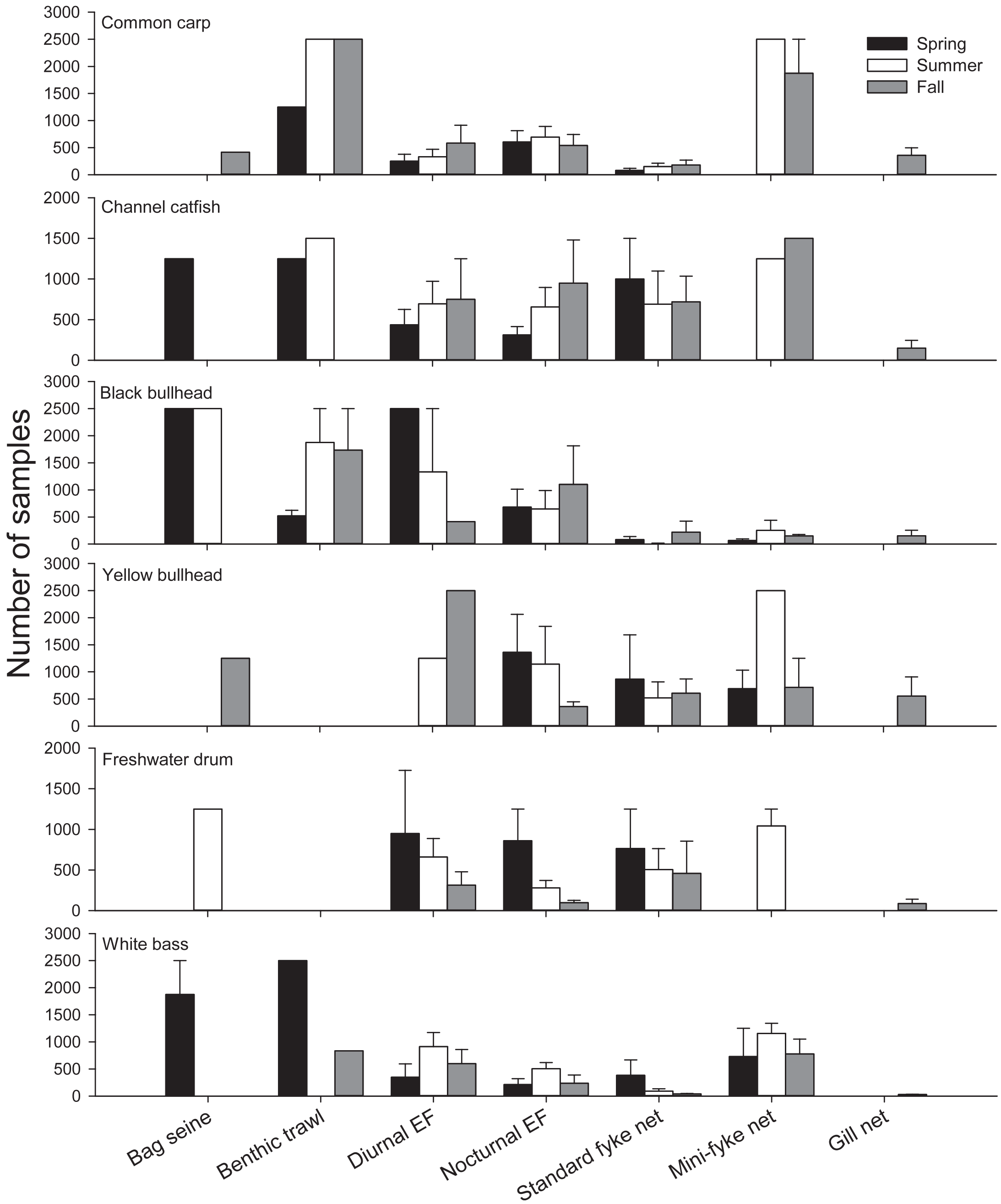

Figure 4. Continued.

additional gear type that has proved productive in sampling previously undocumented small-bodied species is the mini-Missouri trawl (Herzog et al. 2005, 2009; Neebling and Quist 2008). Although trawling is most commonly employed in lotic ecosystems, most trawls require a powerful vessel with multiple personnel to operate safely (Hayes et al. 1996) and was not recommended by Pope et al. (2009) or Miranda and Boxrucker (2009) to sample standing waterbodies. We used a small benthic trawl that could sample littoral areas and provide comparable information to other littoral fish sampling methods. The trawl used in our study was particularly effective at sampling substock-length black crappie and yellow perch during summer. Although seining was effective at sampling largemouth bass in summer and bluegill in fall, catch rates with the seine were substantially more variable (i.e., >50% of hauls yielded zero fish) compared with those obtained with the benthic trawl and mini-modified fyke net. Furthermore, the trawl could be used to sample lentic ecosystems without multiple trips (i.e., deployment and retrieval) that are required for passive gear types set overnight.

Understanding seasonal variation of sampling data is important to the interpretation of fish population and assemblage estimates by fisheries managers. The disproportionate contribution of older individuals due to sampling bias can make interpretation of dynamic rate functions (e.g., recruitment and mortality) difficult or impossible (Ricker 1969). For example, Cross et al. (1995) observed increased CPUE of age-2 bluegill and decreased CPUE of age-4 and older bluegill as the year progressed due to differences in reproductive behavior. Seasonal differences in sampling bias generally result in peaks in the spring and fall and are often attributed to a variety of factors, including changes in physical conditions (e.g., water temperature, macrophyte growth), fish behavior (e.g., spawning, changes in prey resources), and recruitment of smaller individuals to the sampling method as a result of somatic growth (Pope and Willis 1996). Bimodal patterns in abundance and size structure of fish have long been observed for freshwater species sampled seasonally with a single sampling method (Kelly 1953; Congdon 1968). We observed peaks in mean CPUE in the spring and fall for several of the species evaluated. For instance, largemouth bass (stock length), walleye (stock and substock length), yellow perch (stock and substock length), black bullhead (stock and substock length), and white bass (stock length) exhibited lower catch rates in the summer with one or more gear types. Like CPUE, size structure commonly peaks in the spring and fall (Pope and Willis 1996), and bimodal patterns in PSD have long been observed in fish population assessments for largemouth bass (Carline et al. 1984; Gilliland 1985; Bettross and Willis 1988), bluegill (Bettross and Willis 1988), yellow perch (Lott and Willis 1991), and walleye (Mero and Willis 1992). Peaks in PSD during the spring and fall were only observed for black crappie sampled with fyke nets. Mean PSD for bluegill was similar for spring and summer, but was lowest in the fall for both electrofishing and fyke net samples. Mean PSD of largemouth bass also decreased from spring through fall with nocturnal electrofishing. Therefore, sampling in the spring and fall can often increase catch rates, but potential bias (e.g., size and age structure) associated with sample timing should be considered to ensure representativeness of the targeted populations. Ultimately, sampling methods that reduce biases caused by differing capture efficiencies for various ages and sizes are desirable when selecting methods to monitor fish populations.

In addition to differences associated with sampling at various times of the year, diel period can influence fish population and assemblage assessments because of changes in habitat use and potential gear avoidance during the day. Numerous studies have evaluated the influence of diel period on littoral fish assemblage assessments with electrofishing (e.g., Paragamian 1989; Pierce et al. 2001) and seining (Pierce et al. 2001; Riha et al. 2011). Mean CPUE in our study was consistently higher for electrofishing at night compared with electrofishing conducted during the day for stock- and substock-length individuals. However, this may have been due to the majority of the lakes sampled having high water clarity (i.e., >1.5-m Secchi depth; Table 1). McInerny and Cross (1996) observed increased CPUE of largemouth bass greater than 200 mm with electrofishing at night compared with daytime electrofishing when Secchi depths were greater than 2 m. Therefore, estimates of size structure from samples conducted at different times may be biased and not accurately represent the population. Although we were limited in our ability to compare diurnal and nocturnal electrofishing estimates of mean PSD, our results suggested that mean PSD of bluegill collected with day and night electrofishing were similar for spring and summer samples. In addition to size selectivity, diel period can influence species selectivity and capture efficiency. Pierce et al. (2001) observed greater CPUE and species richness with electrofishing and seining during the night compared to similar methods during the day. Although seining at night may have been more productive than during the day, we only seined during the day due to safety concerns. Generally, increases in abundance and species richness observed from night sampling are attributed to the increased use of littoral habitats that make fish more susceptible to sampling (Pierce et al. 2001; Riha et al. 2011). Not only can diel period have implications for sampling with a single gear, but also it may influence comparisons of different sampling methods. For example, Gritters (1994) attributed the increased number of species and individuals sampled with mini-modified fyke nets relative to seining conducted during the day to differences in behavior. Therefore, passive gear types that are set overnight (e.g., standard modified fyke net, gill net) may be more effective than active methods at sampling nocturnal species.

Although comparisons of multiple sampling methods are often difficult due to differences in the unit (e.g., number per net-night, number per hour of effort), our estimation of the sample size required to sample 125 stock-length individuals provides a useful comparison of sampling methods across seasons. Fisheries managers and researchers are often interested in describing populations with estimates of mean length or indices of size structure. However, the number of samples needed to adequately estimate length distributions of fish populations is rarely quantified (e.g., Miranda 1993; Vokoun et al. 2001; Miranda 2007). Although the estimated number of samples needed to collect 125 stock-length individuals in our study are useful, their interpretation should be applied with caution. For example, the effort to sample 125 stock-length bluegill or largemouth bass would be minimized in the spring with use of standard modified fyke nets and nocturnal electrofishing, respectively. However, estimates of size structure for bluegill and largemouth bass sampled during the spring or early summer would likely overestimate true size structure due to the disproportionate sampling of spawning individuals (Novinger and Legler 1978). McInerny and Cross (1996) observed selectivity for largemouth bass greater than 200 mm with nocturnal electrofishing in spring and increased CPUE of bluegill occurred when gonad development was greatest (Cross et al. 1995). Despite seasonal biases associated with spawning behavior, the mean number of samples required to sample 125 stock-length individuals was minimized for 5 of the 12 species sampled with sinking experimental gill nets in fall. Although gill nets were constructed of multiple sizes of mesh, gill nets generally sampled larger individuals than fyke nets used in the same season. As such, mean PSD was higher with gill nets relative to fyke nets for white bass, yellow perch, and walleye. Differences in mean PSD between gear types may have also been due to differences in habitat use by smaller individuals, because gill nets were set in deeper habitats (i.e., >2 m of water) to ensure that the net was fully deployed. Therefore, sampling regimes that attempt to assess the relative abundance and size structure of multiple species in lake and reservoir ecosystems will likely require a combination of gear types and seasons.

Management implications

Ultimately, sampling methods used to assess freshwater fishes will be the compromise between objectives, logistical constraints (e.g., cost, labor), and tradition. It is important however for fisheries scientists to understand how interpretations of assessments may be influenced by different sampling methods used at various times of the year to optimize sampling objectives and benefit from comparable data across larger and larger spatial and temporal scales. Furthermore, the advancement of fisheries science, management, and conservation has already been slowed by the lack of standard sampling methods, and further refinement of the guidelines recommended by Bonar et al. (2009) will undoubtedly increase the understanding of complex freshwater systems. Potential research areas that could increase data comparability include the comparison of sampling methods recommended at different times of years for different freshwater systems. For example, Miranda and Boxrucker (2009) recommended standard fyke nets in the fall for large standing waters (>200 ha), whereas Pope et al. (2009) recommended standard fyke nets in the spring for small standing waters (<200 ha). Although there may be justifiable and logical reasons to sample different sizes of waterbodies in separate seasons, data collected with similar gear types in different seasons may not be directly comparable without additional research. Therefore, future refinement of standard sampling methods for freshwater fish will require additional research on the optimal sampling methodologies for more freshwater species. Our results substantially increase the number of lentic fish species of which seasonal dynamics in population assessments have been estimated. Specifically, we observed seasonal patterns in relative abundance and size structure that can guide sampling recommendations intended to maximize the number of individuals encountered while minimizing bias toward sexually mature individuals. The fewest samples required to obtain 125 stock-length individuals were observed in the fall with sinking experimental gill nets, electrofishing at night, and standard modified fyke nets for 11 of the 12 species evaluated in Iowa lakes and impoundments. Similarly, CPUE of substock-length fish peaked in the summer or fall for the bag seine, benthic trawl, and mini-modified fyke net for half of focal species. In addition to providing relative comparisons of sampling methods for numerous commonly occurring lentic species, our study provides a relative framework for comparing data collected with various sampling methods across seasons for multiple species. Such information for additional species and sampling methodologies will ultimately be needed to further develop standardized sampling methods and further advance fisheries science.

Supplemental Material

Please note: The *Journal of Fish and Wildlife Management* is not responsible for the content or functionality of any supplemental material. Queries should be directed to the corresponding author for the article.

Reference S1. Congdon JC. 1968. The fish population of Lake Poinsett, South Dakota, as indicated by four types of gear. M.S. thesis, South Dakota State University, Brookings.

Found at DOI: http://dx.doi.org/10.3996/082013-JFWM-054.S1; also available at http://pubstorage.sdstate.edu/wfs/thesis/Congdon-James-C-M-S-1968-3.pdf (4059 KB PDF).

Reference S2. Gritters SA. 1994. Comparison of fish catch between a mini fyke net and a 10.7-meter bag seine in the upper Mississippi River. National Biological Survey, Environmental Management Technical Center, Special Report 94-S008, Onalaska, Wisconsin.

Found at DOI: http://dx.doi.org/10.3996/082013-JFWM-054.S2; (1266 KB PDF).

Reference S3. Kelly DW. 1953. Fluctuation of trap net catches in the upper Mississippi River. U.S. Fish and Wildlife Service, Special Scientific Report, Fisheries Number 101.

Found at DOI: http://dx.doi.org/10.3996/082013-JFWM-054.S3; also available at http://spo.nmfs.noaa.gov/SSRF/SSRF101.pdf (1800 KB PDF).

Reference S4. McInerny MC, Cross TK. 1996. Seasonal and diel variation in electrofishing size-selectivity and catch-per-hour of largemouth bass in Minnesota lakes. Investigational report 451. Minnesota Department of Natural Resources, Hutchinson.

Found at DOI: http://dx.doi.org/10.3996/082013-JFWM-054.S4; also available at http://files.dnr.state.mn.us/publications/fisheries/investigational_reports/451.pdf (655 KB PDF).

Reference S5. McInerny MC, and Cross TK. 2004. Comparison of day electrofishing, night electrofishing, and trap netting for sampling inshore fish in Minnesota Lakes. Special publication 161. Minnesota Department of Natural Resources, Hutchinson.

Found at DOI: http://dx.doi.org/10.3996/082013-JFWM-054.S5; also available at http://archive.leg.state.mn.us/docs/2005/other/050135.pdf (366 KB PDF).

Table S1. Worksheet that includes the length (TL, mm), season, gear, and lake for common carp *Cyprinus carpio*, black bullhead *Ameiurus melas*, yellow bullhead *Ameiurus natalis*, channel catfish *Ictalurus punctatus*, white bass *Morone chrysops*, bluegill *Lepomis macrochirus*, largemouth bass *Micropterus salmoides*, white crappie *Pomoxis annularis*, black crappie *Pomoxis nigromaculatus*, yellow perch *Perca flavescens*, walleye *Sander vitreus*, and freshwater drum *Aplodinotus grunniens* sampled with multiple sampling methods (i.e., standard modified fyke net, mini-modified fyke net, sinking experimental gill net, seine, benthic trawl, nocturnal and diurnal boat-mounted electrofisher) from six Iowa natural lakes and reservoirs in spring, summer, and fall 2008.

Found at DOI: http://dx.doi.org/10.3996/082013-JFWM-054.S6; (2008 KB PDF).

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References

Allen MS, Hale MM, Pine III WE. 1999. Comparison of trap nets and otter trawls for sampling black crappie in two Florida lakes. North American Journal of Fisheries Management 19:977–983.

Anderson RO, Neumann RM. 1996. Length, weight, and associated structural indices. Pages 447–482 in Murphy BR, Willis DW, editors. Fisheries techniques. 2nd edition. Bethesda, Maryland: American Fisheries Society.

Barko VA, Herzog DP, Hrabik RA, Scheibe JS. 2004. Relationship among fish assemblages and main-channel-border physical habitats in the unimpounded upper Mississippi River. Transactions of the American Fisheries Society 133:371–384.

Bettross EA, Willis DW. 1988. Seasonal patterns in sampling data for largemouth bass and bluegills in a northern Great Plains impoundment. Prairie Naturalist 20:193–202.

Bister TJ, Willis DW, Brown ML, Jordan SM, Neumann RM, Quist MC, Guy CS. 2000. Proposed standard weight (*Ws*) equations and standard length categories for 18 warmwater nongame and riverine fish species. North American Journal of Fisheries Management 20:570–574.

Bonar SA, Hubert WA, Willis DW. 2009. Standard sampling methods for North American freshwater fishes. Bethesda, Maryland: American Fisheries Society.

Bonvechio TF, Pouder WF, Hale MM. 2008. Variation between electrofishing and otter trawling for sampling black crappies in two Florida lakes. North American Journal of Fisheries Management 28:188–192.

Boxrucker J, Michaletz P, Van Den Avyle MJ, Vondracek B. 1995. Overview of gear evaluation study for sampling gizzard shad and threadfin shad populations in reservoirs. North American Journal of Fisheries Management 15:885–890.

Burkhardt RW, Gutreuter S. 1995. Improving electrofishing consistency by standardizing power. North American Journal of Fisheries Management 15:375–381.

Carline RF, Johnson BL, Hall TJ. 1984. Estimation and interpretation of proportional stock density for fish populations in Ohio impoundments. North American Journal of Fisheries Management 4:139–154.

Clark SJ, Jackson JR, Lochmann SE. 2007. A comparison of shoreline seines with fyke nets for sampling littoral fish communities in floodplain lakes. North American Journal of Fisheries Management 27:676–680.

Congdon JC. 1968. The fish population of Lake Poinsett, South Dakota, as indicated by four types of gear. Master's thesis. Brookings: South Dakota State University (see *Supplemental Material*, Reference S1, http://dx.doi.org/10.3996/082013-JFWM-054.S1); also available: http://pubstorage.sdstate.edu/wfs/thesis/Congdon-James-C-M-S-1968-3.pdf (March 2014).

Cross TK, McInerny MC, Schupp DH. 1995. Seasonal variation in trap-net catches of bluegill in Minnesota lakes. North American Journal of Fisheries Management 15:382–389.

Fago D. 1998. Comparison of littoral fish assemblages sampled with a mini-fyke net or a combination of electrofishing and small-mesh seine in Wisconsin lakes. North American Journal of Fisheries Management 18:731–738.

Fischer JR, Quist MC. 2014. Characterizing lentic freshwater fish assemblages using multiple sampling methods. Environmental Monitoring and Assessment 186:4461–4474.

Gabelhouse DW. 1984. A length-categorization system to assess fish stocks. North American Journal of Fisheries Management 4:273–285.

Gilliland E. 1985. Evaluation of Oklahoma's standardized electrofishing in calculating population structure indices. Proceedings of the Annual Conference of Southeastern Associations of Fish and Wildlife Agencies 39:277–287.

Gritters SA. 1994. Comparison of fish catch between a mini fyke net and a 10.7-meter bag seine in the upper Mississippi River. National Biological Survey, Environmental Management Technical Center, Special Report 94-S008, Onalaska, Wisconsin (see *Supplemental Material*, Reference S2, http://dx.doi.org/10.3996/082013-JFWM-054.S2).

Guy CS, Braaten PJ, Herzog DP, Pitlo J, Rogers RS. 2009. Warmwater fish in rivers. Pages 59–84 in Bonar S, Hubert W, Willis D, editors. Standard sampling methods for North American freshwater fishes. Bethesda, Maryland: American Fisheries Society.

Guy CS, Neumann RM, Willis DW, Anderson RO. 2007. Proportional size distribution (PSD): a further refinement of population size structure index terminology. Fisheries 32:348.

Guy CS, Willis DW, Schultz RD. 1996. Comparison of catch per unit effort and size structure of white crappies collected with trap nets and gill nets. North American Journal of Fisheries Management 16:947–951.

Hayes DB, Ferreri CP, Taylor WW. 1996. Active fish capture methods. Pages 193–220 in Murphy BR, Willis DW, editors. Fisheries techniques. 2nd edition. Bethesda, Maryland: American Fisheries Society.

Herzog DP, Barko VA, Scheibe JS, Hrabik RA, Ostendorf DE. 2005. Efficacy of a benthic trawl for sampling small-bodied fishes in large river systems. North American Journal of Fisheries Management 25:594–603.

Herzog DP, Ostendorf DE, Hrabik RA, Barko VA. 2009. The mini-Missouri trawl: a useful methodology for sampling small-bodied fishes in small and large river systems. Journal of Freshwater Ecology 24:103–108.

Hubert WA. 1996. Passive capture techniques. Pages 157–192 in Murphy BR, Willis DW, editors. Fisheries techniques. 2nd edition. Bethesda, Maryland: American Fisheries Society.

Jackson JR, Noble RL. 1995. Selectivity of sampling methods for juvenile largemouth bass in assessments of recruitment processes. North American Journal of Fisheries Management 15:408–418.

Kelly DW. 1953. Fluctuation of trap net catches in the upper Mississippi River. U.S. Fish and Wildlife Service, Special Scientific Report, Fisheries Number 101 (see *Supplemental Material*, Reference S3, http://dx.doi.org/10.3996/082013-JFWM-054.S3; also available: http://spo.nmfs.noaa.gov/SSRF/SSRF101.pdf (March 2014).

Lee DS, Gilbert CR, Hocutt CH, Jenkins RE, McAllister DE, Stauffer JR Jr. 1980. Atlas of North American Fishes. Raleigh: North Carolina Biological Survey.

Lott JP, Willis DW. 1991. Gill net mesh size efficiency for yellow perch. Prairie Naturalist 23:139–144.

McInerny MC, Cross TK. 1996. Seasonal and diel variation in electrofishing size-selectivity and catch-per-hour of largemouth bass in Minnesota lakes. Investigational report 451. Minnesota Department of Natural Resources, Hutchinson (see *Supplemental Material*, Reference S4, http://dx.doi.org/10.3996/082013-JFWM-054.S4); also available: http://files.dnr.state.mn.us/publications/fisheries/investigational_reports/451.pdf (March 2014).

McInerny MC, Cross TK. 2004. Comparison of day electrofishing, night electrofishing, and trap netting for sampling inshore fish in Minnesota Lakes. Special publication 161. Minnesota Department of Natural Resources, Hutchinson (see *Supplemental Material*, Reference S5, http://dx.doi.org/10.3996/082013-JFWM-054.S5); also available: http://archive.leg.state.mn.us/docs/2005/other/050135.pdf (March 2014).

Mero SW, Willis DW. 1992. Seasonal variation in sampling data for walleye and sauger collected with gill nets form Lake Sakakawea, North Dakota. Prairie Naturalist 24:231–240.

Miranda LE. 1993. Sample sizes for estimating and comparing proportion-based indices. North American Journal of Fisheries Management 13:383–386.

Miranda LE. 2007. Approximate sample sizes required to estimate length distributions. Transactions of the American Fisheries Society 136:409–415.

Miranda LE. 2009. Standardizing electrofishing power for boat electrofishing. Pages 223–230 in Bonar S, Hubert W, Willis D, editors. Standard sampling methods for North American freshwater fishes. Bethesda, Maryland: American Fisheries Society.

Miranda LE, Boxrucker J. 2009. Warmwater fish in large standing waters. Pages 29–42 in Bonar S, Hubert W, Willis D, editors. Standard sampling methods for North American freshwater fishes. Bethesda, Maryland: American Fisheries Society.

Neebling TE, Quist MC. 2008. Observations on the distribution and status of western sand darter, spotted gar, and skipjack herring in Iowa rivers. Journal of the Iowa Academy of Science 115:24–27.

Novinger GD, Legler RE. 1978. Bluegill population structure and dynamics. Pages 37–49 in Novinger GD, Dillard JG, editors. New approaches to the management of small impoundments. North Central Division, Special Publication 5. Bethesda, Maryland: American Fisheries Society.

Paragamian VL. 1989. A comparison of day and night electrofishing: size structure and catch per unit effort for smallmouth bass. North American Journal of Fisheries Management 9:500–503.

Pierce CL, Corcoran AM, Gronbach AN, Hsia S, Mularkey BJ, Schwartzhoff AJ. 2001. Influence of diel period on electrofishing and beach seining assessments of littoral fish assemblages. North American Journal of Fisheries Management 21:918–926.

Pierce CL, Rasmussen JB, Leggett WC. 1990. Sampling littoral fish with a seine: corrections for variable capture efficiency. Canadian Journal of Fisheries and Aquatic Sciences 47:1004–1010.

Pope KL, Neumann RM, Bryan SD. 2009. Warmwater fish in small standing waters. Pages 13–28 in Bonar S, Hubert W, Willis D, editors. Standard sampling methods for North American freshwater fishes. Bethesda, Maryland: American Fisheries Society.

Pope KL, Willis DW. 1996. Seasonal influences of freshwater fisheries sampling data. Reviews in Fisheries Science 4:57–73.

Quist MC, Bonvechio KI, Allen MS. 2009. Statistical analysis and data management. Pages 171–194 in Bonar S, Hubert W, Willis D, editors. Standard sampling methods for North American freshwater fishes. Bethesda, Maryland: American Fisheries Society.

Rabeni C, Lyons J, Mercado-Silva N, Peterson J. 2009. Warmwater fish in wadeable streams. Pages 43–58 in Bonar S, Hubert W, Willis D, editors. Standard sampling methods for North American freshwater fishes. Bethesda, Maryland: American Fisheries Society.

Reynolds JB. 1996. Electrofishing. Pages 221–253 in Murphy BR, Willis DW, editors. Fisheries techniques. 2nd edition. Bethesda, Maryland: American Fisheries Society.

Ricker WE. 1969. Effects of size-selective mortality and sampling bias on estimates of growth, mortality, production, and yield. Journal of the Fisheries Research Board of Canada 26:479–541.

Riha M, Kubecka J, Prchalova M, Mrkvicka T, Cech M, Drastik V, Frouzova J, Hohausova E, Juza T, Kratochvil M, Peterka J, Tuser M, Vasek M. 2011. The influence of diel period on fish assemblage in the unstructured littoral of reservoirs. Fisheries Management and Ecology 18:339–347.

Robillard SR, Kassler T, Marsden JE. 1995. Yellow perch population assessment in southwestern Lake Michigan, including evaluation of sampling techniques. Aquatic Ecology Technical Report 95/9. Champaign: Illinois Natural History Survey.

Ruetz CR, Uzarski DG, Krueger DM, Rutherford ES. 2007. Sampling a littoral fish assemblage: comparing small-mesh fyke netting and boat electrofishing. North American Journal of Fisheries Management 27:825–831.

Sammons SM, Isermann DA, Bettoli PW. 2002. Variation in population characteristics and gear selection between black and white crappies in Tennessee reservoirs: potential effects on management decisions. North American Journal of Fisheries Management 22:863–869.

Sanders RE. 1992. Day versus night electrofishing catches from near-shore waters of the Ohio and Muskingum Rivers. Ohio Journal of Science 92(3):51–59.

Swingle HS. 1956. Appraisal of methods of fish population study, part 4: determination of balance in farm fish ponds. Transactions of the North American Wildlife Conference 21:298–322.

Vokoun JC, Rabeni CF, Stanovick JS. 2001. Sample-size requirements for evaluating population size-structure. North American Journal of Fisheries Management 21: 660–665.

Weaver MJ, Magnuson JJ, Clayton MK. 1993. Analyses for differentiating littoral fish assemblages with catch data from multiple sampling gears. Transactions of the North American Fisheries Society 122:1111–1119.

Willis DW, Murphy BR. 1996. Planning for sampling. Pages 1–15 in Murphy BR, Willis DW, editors. Fisheries techniques. 2nd edition. Bethesda, Maryland: American Fisheries Society.

Willis DW, Murphy BR, Guy CS. 1993. Stock density indices: development, use, and limitations. Reviews in Fisheries Science 1:203–222.

Yoder CO, Smith MA. 1998. Using fish assemblages in a state biological assessment and criteria program: essential concepts and considerations. Pages 17–56 in Simon TP, editor. Assessing the sustainability and biological integrity of water resources using fish communities. Boca Raton, Florida: CRC Press.