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Characterizing lentic freshwater fish assemblages using multiple sampling methods

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Abstract Characterizing fish assemblages in lentic ecosystems is difficult, and multiple sampling methods are almost always necessary to gain reliable estimates of indices such as species richness. However, most research focused on lentic fish sampling methodology has targeted recreationally important species, and little to no information is available regarding the influence of multiple methods and timing (i.e., temporal variation) on characterizing entire fish assemblages. Therefore, six lakes and impoundments (48–1,557 ha surface area) were sampled seasonally with seven gear types to evaluate the combined influence of sampling methods and timing on the number of species and individuals sampled. Probabilities of detection for species indicated strong selectivities and seasonal trends that provide guidance on optimal seasons to use gears when targeting multiple species. The evaluation of species richness and number of individuals sampled using multiple gear combinations demonstrated that appreciable benefits over relatively few gears (e.g., to four) used in optimal seasons were not present. Specifically, over 90 % of the species encountered with all gear types and season combinations (N=19) from six lakes and reservoirs were sampled with nighttime boat electrofishing in the fall and benthic trawling, modified-fyke, and mini-fyke netting during the summer. Our results indicated that the characterization of lentic fish assemblages was highly influenced by the selection of sampling gears and seasons, but did not appear to be influenced by waterbody type (i.e., natural lake, impoundment). The standardization of data collected with multiple methods and seasons to account for bias is imperative to monitoring of lentic ecosystems and will provide researchers with increased reliability in their interpretations and decisions made using information on lentic fish assemblages.

Keywords Fish assemblage · Gear comparison · Impoundments · Natural lakes · Sampling techniques · Standardized sampling

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Introduction

Knowledge of fish assemblage composition is critical for the effective management of fisheries and conservation of biodiversity in aquatic ecosystems. The importance of understanding fish assemblage structure is supported by the inclusion of biological components in the 1972 U.S. Clean Water Act (CWA), which focuses on maintaining and restoring ecological integrity of surface waters. A consequence of the CWA's legal mandate to focus on aquatic organisms has been extensive research on the ecology of fishes in streams and rivers. Furthermore, the formative research on fish-based indices of biological integrity (e.g., Karr 1981) have greatly improved the methods and techniques used to monitor fish (e.g., Lyons 1992; Angermeier and Smogor 1995) and furthered our understanding of factors structuring the occurrence, abundance, and composition for lotic fish assemblages (e.g., Angermeier and Schlosser 1989; Poff and Allan 1995) as well as other aquatic organisms. Unfortunately, a similar focus on lacustrine and large river systems has progressed at a much slower rate and lags far behind wadeable lotic systems.

The reasons for the disparity between our understanding of lentic and lotic fish assemblage structure are due, in part, to the physical diversity of lacustrine ecosystems and associated problems with sampling lakes compared to rivers and streams. For example, few methods are generally needed to efficiently sample lotic fishes in stream reaches (e.g., Neebling and Quist 2011), whereas a wide variety of lentic fish sampling methods and techniques have been evaluated for sampling entire lake fish assemblages (e.g., Jackson and Harvey 1997; Whittier et al. 1997; McInerny and Cross 2004; Clark et al. 2007). Vaux et al. (2000) compared the sampling efficacy of multiple electrofishing configurations, seines, minnow traps, trap nets, and experimental gill nets to characterize fish assemblages from northeastern U.S. lakes during summer and determined that even the most efficient gear (backpack electrofishing from a small boat) resulted in less than 80 % of the species encountered with all gears being represented. Even characterizing family richness (i.e., Cyprinidae) in lakes often requires a multiple-gear protocol consisting of minnow traps, trap nets, gill nets, and seines (Whittier et al. 1997). Multiple fish sampling methods are required in lentic habitats because lakes can have distinct physicochemical zones (i.e., littoral, pelagic). Differences in fish habitat use between littoral and pelagic zones can affect the efficiency of sampling methods, requiring the use of multiple gears to characterize fish assemblages. As such, zonation in lentic ecosystems has led to research focused on describing fish assemblages of individual zones (e.g., offshore: McQueen et al. 1986; Gido and Matthews 2000; littoral: Weaver et al. 1993; Ruetz et al. 2007) as opposed to attempts to describe whole-lake assemblages. In contrast, studies of lotic systems have long attempted to describe the structure and function of multiple species that are often considered representative of the fish assemblage. The lack of information regarding sampling of multiple species to characterize entire fish assemblages in lentic habitats is also the result of various classifications as to what is considered lentic (e.g., wetlands, ponds, reservoirs) and few studies have attempted to identify sampling methods for a wide range of lentic systems. Rather, specific sampling gears are often selected based on physical characteristics of the waterbody, such as surface area or water temperature (see Bonar et al. 2009). Perhaps the greatest discrepancy arises from natural lakes and impounded riverine systems (hereafter referred to as impoundments). Impoundments are socially and economically important and provide numerous ecological goods and services that are similar to natural lakes. However, impoundments often have chemical, physical, and biological characteristics that are similar to both lakes and rivers that can also have substantial effects on the efficiency of fish sampling methods.

An additional factor that has contributed to slower progress of developing standard sampling methods in lentic ecosystems is the well-known effects of temporal variation in fish abundance and size structure (Guy and Willis 1991; Pope and Willis 1996). Whereas rivers and streams are commonly sampled at base flow when sampling efficiency is maximized, lentic environments are commonly sampled with different gears at specific times of the year due to temporal patterns of fish use (e.g., summer offshore movement of fish, spawning) and recruitment of fish to sampling gears. For instance, young cohorts of small-bodied species that hatch in spring may not be susceptible to standard methods until the following year, whereas age-0 large-bodied species hatched in spring may be collected during their first fall. The diversity of factors limiting the development of widely accepted lentic fish sampling methods has resulted in the practice of targeted sampling for species or groups of species. Examples of targeted sampling, primarily for sport fishes, in lentic systems are ubiquitous in the literature (e.g., Paragamian 1989; Guy and Willis 1991; Allen et al. 1999; Sammons et al. 2002; Bonvechio et al. 2008). However, describing the influence of multiple sampling techniques on fish assemblage characterization is crucial to understanding complex ecosystems such as lakes and impoundments.

All fish sampling methods are selective (e.g., species, size) due to physical attributes of the gear and (or) the sampling protocol. For example, differences in construction materials and dimensions of fish sampling gears have been repeatedly demonstrated to result in samples of different species and sizes of fish (Henderson and Nepszy 1992; Schultz and Haines 2005; Fischer et al. 2010). The gear-specific sampling protocol (e.g., night versus day electrofishing) can also affect fish assemblage characterization and has received considerable attention (McInerny and Cross 1996; Thurow and Schill 1996; Pierce et al. 2001; Riha et al. 2011). Therefore, the use of multiple methods to reduce bias can account for underrepresentation of species that are hard to detect and is often necessary for a variety of aquatic habitats (e.g., Neebling and Quist 2011) including lakes (Jackson and Harvey 1997). Accurately characterizing assemblage structure is particularly important for biological assessment, where the presence and relative abundance of species and functional groups (e.g., trophic guilds) in a system are crucial to the interpretation and evaluation of ecological impairment. Since all fish sampling methodologies have biases, evaluating the use of multiple sampling methods is important for developing and implementing monitoring designs that represent the biological assemblage of an ecosystem. Additionally, the recent development of standard freshwater fish sampling methods (Bonar et al. 2009) includes different techniques (i.e., gears and seasons) for sampling small (i.e., ≤200 ha; Pope et al. 2009) and large standing waters (i.e., >200 ha; Miranda and Boxrucker 2009). Disparity in techniques would greatly limit comparisons of data collected from different waterbodies. However, we are unaware of previous studies that have evaluated the influence of season on multiple sampling methods for characterizing fish assemblage structure in lentic ecosystems. The goal of our study was to provide researchers and natural resource managers with information on the influence of multiple sampling gears and protocols used to characterize lentic fish assemblages. Specifically, our objectives were to (1) compare several passive and active gears to detect the presence of species sampled seasonally, (2) evaluate the influence of sampling intensity and timing on estimates of species richness using multiple sampling methods, and (3) estimate the potential trade-offs of using multiple sampling gears to characterize lentic fish assemblages while maximizing species richness and number of individuals encountered. Our results provide a relative comparison of both commonly used and novel sampling methods for freshwater fish in lentic habitats. Because sampling was consistent across multiple seasons, the results provide insights on optimizing sampling strategies to characterize fish assemblages in lakes and impoundments.

Methods

Study sites

Lakes and impoundments were selected to represent the wide range of trophic conditions present in the state of IA, USA (Table 1). Three natural lakes and three impoundments of low (e.g., high total phosphorus, low water clarity), intermediate, and high water quality were selected. Water quality designations were based on research by the Iowa Department of Natural Resources and Iowa State University (Downing et al. 2005). The three natural lakes included West Okoboji Lake, Lake Minnewashta, and Silver Lake. All natural lakes were located in northwest IA. Impoundments selected for sampling included Pleasant Creek Lake, Don Williams Lake, and Prairie Rose Lake.

Fish sampling

Sampling gears included a variety of passive and active gears and were selected based on the recommended standard sampling methods for small and large standing waters (i.e., boat electrofishing, modified-fyke nets, gill nets, seine; Bonar et al. 2009). Supplementary gears (e.g., benthic trawl, mini-fyke nets) were also included to maximize the number of species and individuals sampled in each waterbody. Standard modified-fyke nets (1 m×2 m frame, 12.7-mm bar-measure mesh, with a 15.2-m lead; Miranda and Boxrucker 2009) were used to target active species located in littoral habitats (e.g., centrarchids; Hubert 1996). Mini-fyke nets (0.6 m×1.2 m frame, 6.4-mm ace mesh, with a 7.6-m lead) were also used to sample small-bodied species common in

Table 1 Waterbody type, area (ha), mean depth (*Z*; m), sampling effort (number of net nights for passive gears, number of seine hauls, number of 3-min trawls, and number of 5-min electrofishing runs conducted within a season), mean secchi depth (m), mean chlorophyll *a* (Chl-*a*; μg/L) concentration, mean total phosphorus (TP; μg/L) concentrations. Waterbody information obtained from the Iowa Department of Natural Resources Lakes Information Report

Waterbody	Type	Area	*Z*	Sampling effort	Secchi depth	Chl-*a*	TP
Prairie Rose Lake	Impoundment	70	2.7	10	0.7	48	91
Don Williams Lake	Impoundment	60	5.5	10	1.7	24	84
Pleasant Creek Lake	Impoundment	162	4.8	12	2.1	15	40
Silver Lake	Natural lake	432	2.3	20	0.7	37	167
Lake Minnewashta	Natural lake	48	3.1	10	1.7	22	116
West Okoboji Lake	Natural lake	1,557	11.6	20	5.4	4	27

shallow littoral areas (Fago 1998; Barko et al. 2004). Experimental gill nets (i.e., sinking) were used to sample pelagic species that are not commonly sampled with fyke nets. Gill nets were 30.5-m long by 2-m deep with ten 3.1-m long panels in a quasi-random order (127, 38, 57, 25, 44, 19, 64, 32, 51, 102-mm bar-measure mesh) based on recommendations of Miranda and Boxrucker (2009) and Pope et al. (2009). Fyke nets and gill nets were set at dusk and retrieved the following morning. A beach seine (9.1-m long by 2-m deep, 2-m×2-m×2-m bag, 6.4-mm ace mesh) was used to sample littoral fishes in areas conducive for seining (i.e., little aquatic vegetation or woody debris, few large boulders). Quarter-arc seine hauls were conducted during the day. A small-mesh benthic trawl (i.e., mini-Missouri trawl; Herzog et al. 2005) was used to sample small-bodied species and juveniles of larger species from littoral and profundal benthic habitats. The trawl had a headrope length of 2.4 m, footrope length of 3.7 m, and upright height 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 long to allow for a maximum effective depth of 5.4 m with a 7:1 drop ratio. Additional information on the design, development, and specifications of this trawl is provided by Herzog et al. (2005), Guy et al. (2009), and Neebling and Quist (2011). Trawls were towed perpendicular to the shore for 3 min at approximately 3.2 km/h during the day. Pulsed DC electrofishing was used to target littoral fishes not collected with the other sampling gears. Electrofishing efficiency is often affected by diel period (Sanders 1992; Reynolds 1996; McInerny and Cross 2004); therefore, boat electrofishing was conducted during the day and night to evaluate differences in sample timing. Electrofishing efforts were standardized to have a 3,000-W power transfer to fish (Burkhardt and Gutreuter 1995; Miranda 2009). Boat electrofishing was conducted in 5-min runs (i.e., on time) that were conducted parallel to the shoreline with two netters (6.3-mm delta mesh dip nets). All sampled fish were identified to species in the field whenever possible. Unidentified specimens were preserved in 10 % formalin and identified in the laboratory.

Because changes in physical and chemical characteristics (e.g., water temperature, water clarity) and fish behavior throughout year (e.g., spawning, emigration) can influence estimates of population characteristics (e.g., births, recruitment to sampling methods) and assemblage composition (Pope and Willis 1996; Gido and Matthews 2000; Jordon and Willis 2001), fish were sampled seasonally to evaluate the influence of sample timing. Sampling was conducted in the spring (i.e., April 11 to May 31), summer (i.e., late June 22 to July 13), and fall (i.e., September 14 to October 31) of 2008. Gill nets were only used in the fall to minimize mortality. Samples were allocated for each waterbody using a systematic random sampling design to ensure that sampling included a diversity of habitats and that all gears were represented throughout lakes and impoundments. Specifically, the shoreline was divided into segments that included at least one sample with each gear (i.e., seven gears total). The number of shoreline segments, delineated for each lake or impoundment, was based on the effort required for all sampling gears (Table 1). For example, a 75-ha lake included 10 samples of each gear. Shoreline segments were further divided into eight reaches. A total of eight reaches was selected to include an individual reach for each of the seven sampling gears (i.e., mini-fyke, standard fyke, gill net, seine, trawl, day electrofishing, night electrofishing) in addition to an alternative reach that was used to allocate gears that were unable to be deployed in a preselected reach (e.g., enclosed swimming beach). Individual gears were randomly assigned to reaches in each segment. Once a specific gear was assigned to a reach, the gear was used to sample fish in that reach across all seasons.

Data analysis

The mean number of species and individuals sampled with each gear and season was estimated across lakes and impoundments. Additionally, the probability of detecting a species when present in a waterbody was the number of samples where the species was captured divided by the total number of samples conducted. Probability of detection estimates were calculated for gears and seasons individually and across waterbodies where a species was present. The presence of species across seasons in a waterbody was assumed to be constant (i.e., no emigration or immigration). Therefore, the focus of our evaluation was estimating detection probabilities when a species was known to be present in a lake or impoundment and not on estimates of site occupancy with imperfect detection rates (e.g., MacKenzie et al. 2005). For example, if at least one individual of a species was found in a lake, probability of detection was calculated for all gears and seasons regardless of encounters for the species in the lake. Species accumulation curves were constructed for waterbodies, gears, and seasons. Species accumulation curves were used to evaluate the influence of season and increasing number of samples on estimates of species richness. Additionally, species accumulation results were used to assess the correspondence in patterns of assemblage representation among lakes and impoundments. The total number of species and individuals encountered with combinations of gears used in a single season (i.e., with replacement) was plotted to evaluate the gain in species or individuals sampled using multiple methods. Specifically, totals of species and individuals sampled with one gear, two gears, three gears, and up to seven gears used in a single season were combined while allowing seasons to vary by gear (e.g., summer seining and fall modified-fyke nets).

Results

Totals of 43 species and 61,293 fish were sampled from all six waterbodies and three seasons (Table 1; Fig. 1). Thirty-five species and 10,800 individuals were sampled in spring, 40 species and 18,189 individuals in summer, and 36 species and 32,304 individuals in fall. Regardless of season, mini-fyke nets sampled 81 % of the species observed across waterbodies, followed by night electrofishing (79 %), day electrofishing (74 %), fyke nets (67 %), trawling (67 %), seining (65 %), and gill nets (54 %). Modified-fyke nets sampled the greatest number of individuals (24,806) representing 29 species. Mini-fyke nets sampled the second largest number of individuals (10,853) representing 35 species, followed by night electrofishing with 7,234 individuals representing 34 species. Trawling sampled 8,275 individuals across 29 species, seining sampled 4,763 individuals and 28 species, and day electrofishing sampled 2,903 individuals and 32 species. Gill nets sampled the fewest number of species (23) and individuals (2,459), but were only used in the fall. The highest number of species sampled in a season was 29 with night electrofishing (fall) and day electrofishing (fall), while the most individuals sampled in a season was 10,085 with modified-fyke nets (fall). Spring sampling did not produce more species than summer or fall for any of the gears evaluated. However, trawling (24), modified-fyke nets (26), and mini-fyke nets (28) had the highest number of species sampled in summer across all six lakes and impoundments.

Total and unique species by gear

Over 50 % of species were sampled with six or more gears (median=6 gears; Table 2). However, four gears sampled species that were not sampled with other methods. Trout-perch (scientific names provided in Table 2) and sauger were only sampled with the benthic trawl. Night electrofishing was the only gear that sampled emerald shiner. Shorthead redhorse and orangespotted sunfish were only sampled with modified-fyke nets, while the mini-fyke net was the only gear to sample common shiner and tadpole madtom. Common shiner, emerald shiner, tadpole madtom, orangespotted sunfish, and sauger were represented by a single individual, yet accounted for approximately 12 % of the total number of species sampled across all waterbodies and seasons. In contrast, several species

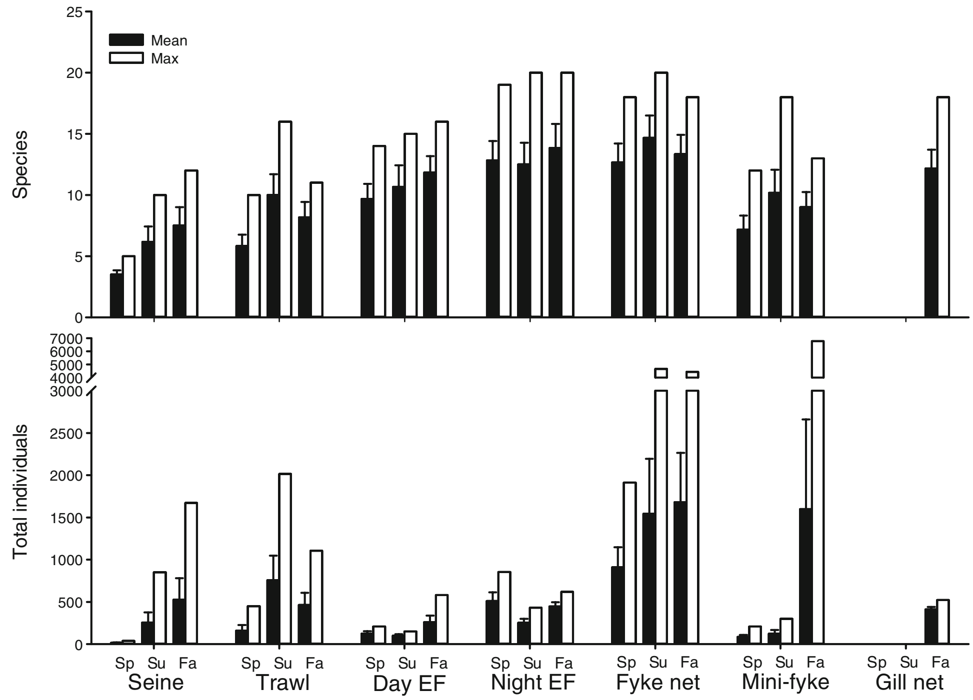

Fig. 1 Mean and maximum number of species and individuals sampled seasonally with seven methods for six IA lakes and impoundments, 2008. *Bars* represent means plus 1 SE

were ubiquitous. Common carp, channel catfish, green sunfish, bluegill, largemouth bass, black crappie, and walleye were sampled in all of the waterbodies included in our study. Of these species, only green sunfish was not sampled with all of the gears (i.e., gill nets). Several other species (i.e., gizzard shad, golden shiner, black bullhead, yellow bullhead, white bass, smallmouth bass, white crappie, yellow perch, freshwater drum) were sampled with every gear in the lakes and impoundments where they were encountered (Table 2).

Probability of detection was consistent among seasons using a single gear for several of the species evaluated. For example, probabilities of detection for common carp, white sucker, and walleye sampled with fyke nets were consistent across seasons (Table 2). In contrast, probabilities of detection of several species decreased in summer and peaked in spring and fall. Probabilities of detection for white bass (night electrofishing), largemouth bass (day and night electrofishing), black crappie (modified-fyke nets), and walleye (night electrofishing) were lowest during summer.

Differences in probabilities of detection between gears were generally large for an individual species, indicating strong gear selectivity for many of the species sampled (Table 2). Nearly half of the species encountered had maximum probabilities of detection with gill nets (10 species) or modified-fyke nets (11 species). In contrast, substantially fewer species had maximum probabilities of detection for the other gears evaluated. Specifically, the number of species sampled with maximum probabilities of detection for night electrofishing (seven species), mini-fyke nets (six species), trawling (six species), seining (four species), and day electrofishing (three species) were all much lower than modified-fyke nets and gill nets.

Species accumulation curves (Fig. 2) indicated that increased sampling effort consistently increased the number of species encountered in individual lakes and impoundments. Nonetheless, consistent patterns in seasonal species accumulations were observed for individual gears. Fall maximized the number of species encountered with seining (67 % of waterbodies), day electrofishing (50 %), and night electrofishing (67 %), while summer maximized species encountered with trawling (83 %), modified-fyke nets (83 %), and mini-fyke nets (50 %). Species richness from gill nets tended to asymptote with fewer samples relative to the other gears for each waterbody sampled. In contrast, species accumulation curves for seining and mini-fyke nets demonstrated the slowest rates of asymptotic species richness.

Table 2 Probability of detection and the number of waterbodies present for seven sampling methods used in the spring, summer, and fall to characterize fish assemblages of six lakes and impoundments in IA, 2008

Family and species	Number fo waterbodies	Seine			Trawl			Day EF			Night EF			Fyke net			Mini-fyke net			Gill net
		Sp	Su	Fa	Sp	Su	Fa	Sp	Su	Fa	Sp	Su	Fa	Sp	Su	Fa	Sp	Su	Fa	Fa
Lepisosteidae																				
Shortnose gar *Lepisosteus platostomus*	3											0.13			0.10			0.08		0.18
Clupeidae																				
Gizzard shad *Dorosoma cepedianum*	2	0.05		0.05			0.23	0.05	0.36	0.64	0.27	0.91	0.59	0.09	0.05	0.14		0.05		0.96
Cyprinidae																				
Spotfin shiner *Cyprinella spiloptera*	2		0.07															0.07		
Common carp *Cyprinus carpio*	6	0.01		0.01	0.05	0.04	0.01	0.26	0.24	0.21	0.27	0.20	0.24	0.57	0.60	0.56	0.01	0.01	0.02	0.45
Common shiner *Luxilus cornutus*	1																0.05			
Golden shiner *Notemigonus crysoleucas*	4			0.08		0.02	0.02			0.19	0.10	0.14	0.08	0.17	0.06	0.04	0.02	0.06	0.06	0.10
Emerald shiner *Notropis atherinoides*	1											0.05								
Spottail shiner *Notropis hudsonius*	4		0.08	0.03	0.03	0.07	0.12		0.03	0.05	0.18		0.05	0.13		0.02	0.05	0.02	0.05	
Bluntnose minnow *Pimephales notatus*	4	0.05	0.17		0.12	0.15	0.13	0.12	0.03		0.15	0.02	0.08				0.03	0.08	0.02	
Fathead minnow *Pimephales promelas*	4	0.03	0.02		0.03	0.03		0.02		0.02	0.02						0.02			
Bullhead minnow *Pimephales vigilax*	3	0.04	0.18	0.04	0.18	0.12	0.10	0.06	0.02	0.08	0.14		0.02				0.04	0.08		
Creek chub *Semotilus atromaculatus*	1													0.30			0.40			
Catostomidae																				
River carpsucker *Carpiodes carpio*	4								0.19	0.06		0.23		0.02	0.15	0.06				0.10
Quillback *Carpiodes cyprinus*	2			0.05					0.05	0.20	0.20		0.10							0.60
White sucker *Catostomus commersonii*	4				0.02	0.02	0.03	0.08	0.08	0.07	0.12	0.13	0.07	0.42	0.43	0.45	0.07	0.08	0.05	0.48
Bigmouth buffalo *Ictiobus cyprinellus*	4					0.05		0.02	0.13	0.08	0.20	0.12	0.07	0.03	0.03	0.18			0.03	0.15
Shorthead redhorse *Moxostoma macrolepidotum*	2														0.03	0.03				
Ictaluridae																				
Black bullhead *Ameiurus melas*	4	0.02	0.02	0.02	0.12	0.08	0.10	0.02	0.18	0.05	0.35	0.30	0.17	0.77	0.83	0.42	0.57	0.47	0.33	0.45
Yellow bullhead *Ameiurus natalis*	5			0.01		0.01	0.01	0.01	0.01	0.01	0.13	0.10	0.13	0.26	0.39	0.22	0.13	0.01	0.08	0.15
Tadpole madtom *Noturus gyrinus*	1																	0.05		
Channel catfish *Ictalurus punctatus*	6	0.01			0.01	0.05	0.01	0.06	0.07	0.07	0.11	0.16	0.16	0.05	0.45	0.06		0.02	0.01	0.63
Flathead catfish *Pylodictis olivaris*	3								0.06			0.03	0.06							
Esocidae																				
Northern pike *Esox lucius*	3	0.02	0.02					0.12	0.08	0.04	0.06	0.04	0.12	0.16	0.32	0.28		0.08	0.02	0.30

Table 2 (continued)

Family and species	Number fo waterbodies	Seine			Trawl			Day EF			Night EF			Fyke net			Mini-fyke net			Gill net
		Sp	Su	Fa	Sp	Su	Fa	Sp	Su	Fa	Sp	Su	Fa	Sp	Su	Fa	Sp	Su	Fa	Fa
Muskellunge *Esox masquinongy*	3							0.02		0.02	0.05		0.07	0.19	0.02	0.05	0.02	0.02		0.02
Percopsidae																				
Trout-perch *Percopsis omiscomaycus*	2					0.10	0.03													
Moronidae																				
White bass *Morone chrysops*	5	0.03		0.06	0.03		0.07	0.26	0.11	0.28	0.51	0.22	0.61	0.54	0.72	0.75	0.11	0.10	0.25	0.94

Sp spring, *Su* summer, *Fa* fall

Plots of total species richness and number of individuals sampled with separate gear combinations illustrated that the use of a single sampling method substantially underrepresented the fish assemblages of the study lakes and impoundments (Fig. 3). In fact, appreciable increases in the total number of species and individuals were not observed until at least three sampling methods were combined. Improvement in the number of species and individuals sampled were substantially less for gear combinations above four methods. Additionally, gear combination results were consistent between natural lakes and impoundments despite differences in the number of species and individuals sampled.

Discussion

Designing protocols and choosing fish sampling methods is ultimately a compromise between logistics (e.g., time, cost) and the precision and accuracy needed to answer research and management questions (Hughes and Peck (2008). Our results indicated that the characterization of lentic fish assemblages was influenced by the selection of sampling gears and seasons. Seasonal patterns in detection probabilities and species accumulations suggested that there were optimal seasons to use each sampling gear when attempting to maximize the number of species sampled. However, the optimal season to use a single gear may change depending on the sampling objectives (e.g., total number of individuals), but did not appear to be affected by lake type (i.e., natural, impoundment). Our study also demonstrated that certain gears used in a single season consistently sampled more species and individuals than others (e.g., night versus day electrofishing). Finally, the use of multiple techniques demonstrated diminishing returns of more than four sampling gears due to strong selectivities and high catch rates of relatively few sampling methods. The consistency of our results for natural lakes and impoundments indicated that similar methods may be adequate for sampling these different ecosystems. Therefore, careful selection of multiple gears and seasons would improve fish assemblage characterization over a single gear.

The dominance of biological communities by relatively few species with the majority of taxa considered rare or uncommon has long been of scientific interest (e.g., Williams 1944). Rare species are often of disproportionally greater management and conservation

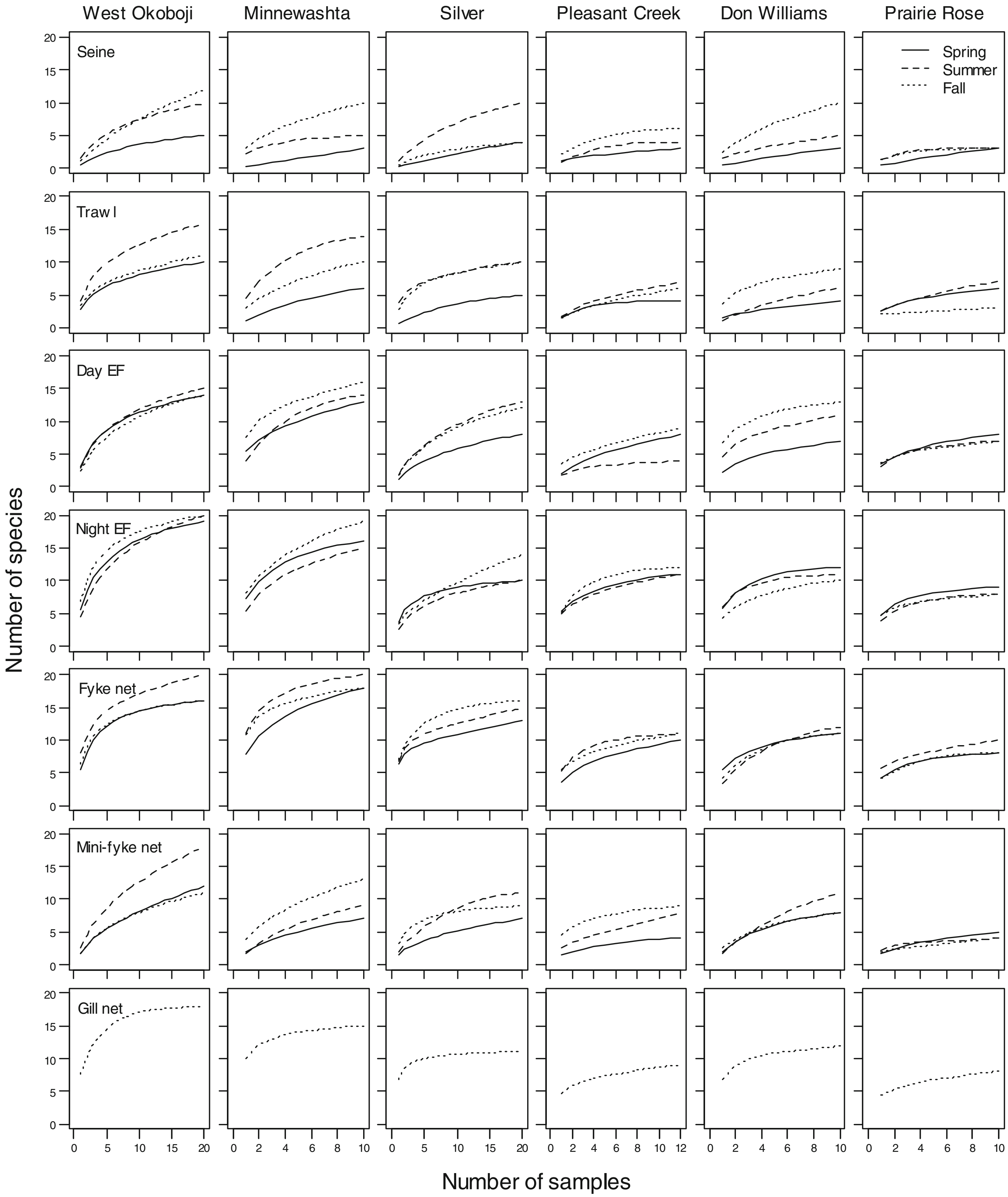

Fig. 2 Species accumulation curves for six lakes and impoundments in IA sampled in 2008 with seven methods

interest due to losses of biodiversity and risk of extinction (e.g., Gaston 1994; Fagan et al. 2002). However, it is unrealistic to assume that all species present in a waterbody can be consistently detected, regardless of

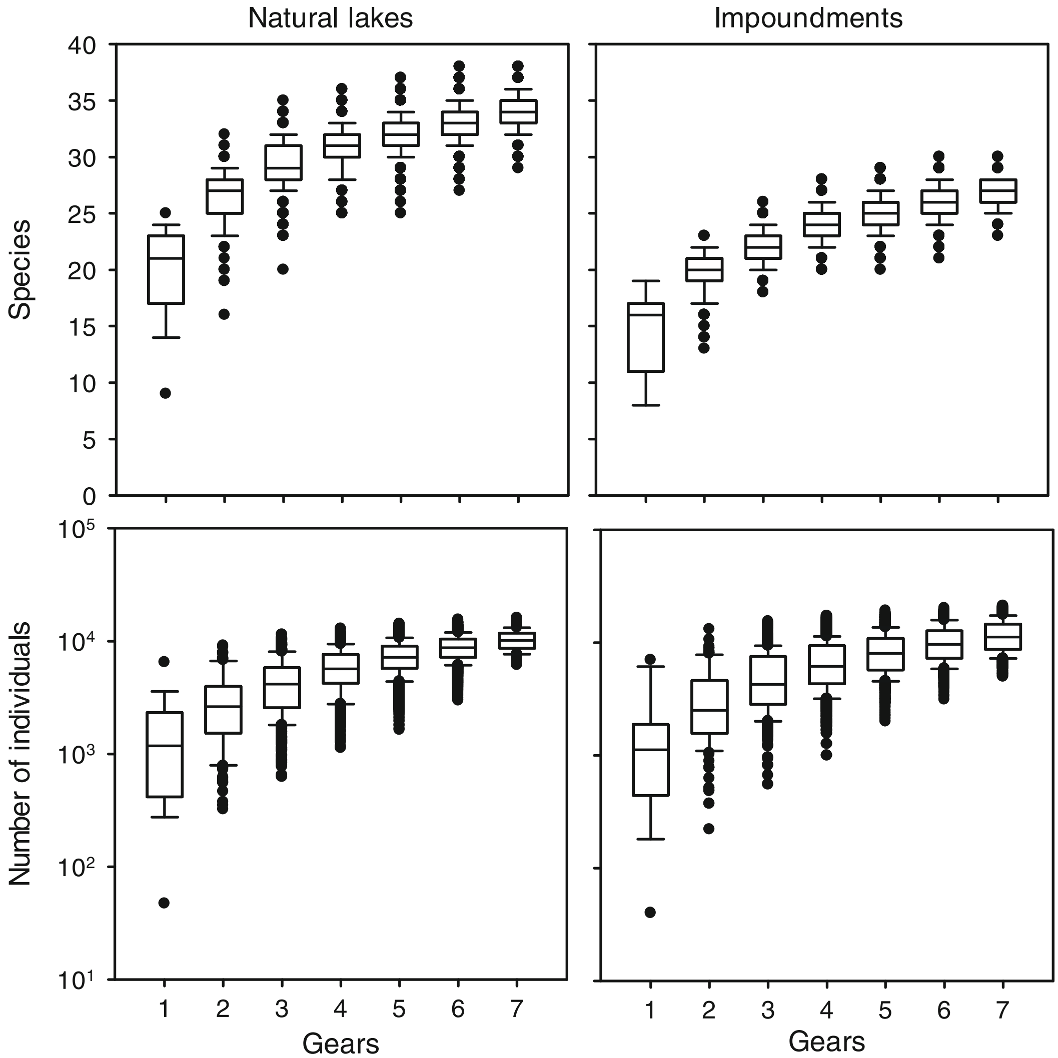

Fig. 3 Box plots of the number of species and individuals sampled with combinations of seven methods (e.g., one gear, two gears) for six IA lakes and impoundments, 2008. *Boxes* represent interquartile range, *bars* represent the 10th and 90th percentiles, and the *line* represents the median

the number sampling methods used and the sampling effort exerted (Krebs 1998). Reliance on a single sampling method has been consistently demonstrated to underestimate species richness in lentic habitats (e.g., Weaver et al. 1993; Jackson and Harvey 1997), further corroborated by our study. Therefore, sampling protocols designed to target biological assemblages are a compromise between effort and the diminishing returns of additional species from additional sampling. Although all sampling methods are biased and no collection of methods can reliably and repeatedly sample all species present, the selection of sampling methods used in our study were considerably more diverse than other published studies focused on lentic fish assemblages. Furthermore, the repeated use of several methods across multiple seasons provided a relative comparison for several commonly used and novel freshwater fish sampling techniques. Our results suggested that relatively few gears can be used to maximize assemblage characterization of lentic habitats. For example, the combination of four methods (fall night electrofishing, summer trawl, summer fyke net, summer minifyke) detected 91 % of the species and 28 % of all individuals sampled with seven gears across all waterbodies and three seasons. The representation of over 90 % of the species encountered with a subset of methods is particularly promising considering 12 % of the species sampled were singletons. Accounting for the majority of species with relatively few sampling methods was likely due to strong species selectivities for the sampling gears and seasons observed. However, the use of more than one gear with strong selectivities is desirable for reducing bias and developing standard fish sampling protocols that characterize assemblages.

Characterizing lacustrine fish assemblages (e.g., species richness) is difficult due to distinct physicochemical zones that vary in location throughout the year. Substantial effects of gears and seasons were observed for the lakes and impoundments included in our research. Therefore, a combination of multiple gears used in more than one season might be necessary to adequately sample lentic fish assemblages. Several direct comparisons between sampling methods provided useful information for the selection of optimal sampling methods. This was most clearly demonstrated by the comparison of day and night electrofishing. Night electrofishing consistently sampled more species and individuals than day electrofishing. Consequently, probabilities of detection were often higher and species accumulation curves tended to asymptote with fewer samples for night relative to day electrofishing. Several other studies that have compared the influence of diel period on electrofishing sampling data (e.g., Paragamian 1989; Pierce et al. 2001; McInerny and Cross 2004) have found similar results. However, the difference between the number of fish and species sampled with day and night electrofishing is likely due to high water clarity observed in the majority of the study lakes.

Sampling small-bodied species or age-0 individuals is often difficult and secondary to monitoring efforts focused on adult sport fish. Beach seines are a commonly used sampling gear for targeting small-bodied species in standing waters (Hayes et al. 1996; Pope et al. 2009). However, capture efficiencies of seines are generally low for benthic species relative to those that inhabit the water column (Lyons 1986; Pierce et al. 1990). Furthermore, seining catch rates can often be inconsistent as a result of obstructions (e.g., woody debris, boulders). The mini-Missouri trawl has been an effective sampling method for small-bodied species in lotic systems (Herzog et al. 2009; Neebling and Quist 2011). For example, Herzog et al. (2009) demonstrated numerous detections of rare species (e.g., shoal chub *Macrohybopsis hyostoma*, sturgeon chub *Macrhybopsis gelida*, crystal darter *Crystallaria asprella*) at previously undocumented locations or rediscovery of species thought to be extirpated throughout lotic habitats in the Mississippi River basin. Neebling and Quist (2008) documented the first collection of western sand darter *Ammocrypta clara* in IA's interior rivers since 1958 using the mini-Missouri trawl. Our results suggest that a mini-Missouri trawl may be an alternative to seining as trout-perch, Iowa darter, and Johnny darter had the highest probabilities of detection with the benthic trawl. We found the mini-Missouri trawl to be an effective sampling gear for littoral areas when towed perpendicular from the shore relative to seining and mini-fyke nets. Specifically, the ability to sample waterbodies in a single visit (i.e., seining, trawling) is often beneficial over passive gears (e.g., mini-fyke nets) when lengthy travel is necessary. Sampling with trawls can also be less physically demanding than seining because the watercraft is used to pull the net through the sampled habitat. Therefore, additional research on the use (e.g., cost, labor) of the mini-Missouri trawl in lentic habitats is warranted given our results.

Like Vaux et al. (2000), the sampling effort allocated in our study increased with increasing lake surface area to account for greater diversity of habitats associated with larger systems (Tonn and Magnuson 1982; Eadie and Keast 1984). Although we attempted to allocate more samples than needed to ensure that the maximum number of species would be encountered with sampling throughout the study (i.e., seven gears, one to three seasons), species accumulation curves indicated that asymptotic species richness was not observed in some systems when only considering a single gear and season. Alternatively, fewer than 10 samples would have been sufficient to detect many species encountered with a single gear in nearly all of the waterbodies (e.g., gill nets). Therefore, our results from combining several active and passive sampling methods suggest that over 90 % of the species would have been encountered with a minimum of 10 to 20 5-min littoral nighttime boat electrofishing runs in the fall, 3-min benthic trawls in summer, and both modified and mini-fyke nets during the summer.

The choice of freshwater fish sampling methods for lentic ecosystems can substantially influence the interpretation of data. For example, the common practice of targeting recreationally important species with a single method will infrequently be representative of the fish assemblage present in a waterbody. Furthermore, data are increasingly collected from aquatic ecosystems to achieve multiple research, management, and conservation objectives (e.g., sport fish, biomonitoring). Although increasing the number of methods to sample more species may not always be justified, a multiple-gear approach provides a more complete characterization of the fish assemblage.

Furthermore, using multiple sampling techniques may afford additional understanding of population characteristics (e.g., recruitment variability) by providing estimates of abundance for different life history stages of particular species. Additional information from multiple gears can be crucial to determining when an insufficient number of fish may limit inferences for targeted populations (e.g., monitoring rare species). Obviously, more samples and gears will always provide more accurate information, but researchers will remain constrained by logistical, social, and economic limitations (e.g., Hughes and Peck 2008). Therefore, developing consistent sampling methods that can be used across a wide variety of lentic systems is desirable to maximize the information gained and provide comparable data across temporal and spatial scales. Our comparison of several sampling techniques provides guidance on the development of fish sampling protocols designed to characterize fish assemblages for biomonitioring lentic ecosystems.

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