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ARTICLE

Comparison of Boat Electrofishing, Trawling, and Seining for Sampling Fish Assemblages in Iowa's Nonwadeable Rivers

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Abstract

The effect of reach length on species richness (estimated with boat-mounted electrofishing, a modified Missouri trawl, and a bag seine) was evaluated in Iowa's nonwadeable river systems. In 2007 and 2008, 21 reaches were sampled on 16 nonwadeable rivers throughout Iowa; reaches were 3 or 5 km in length, depending on stream order. A total of 21,197 fish from 83 species were sampled in this study. Electrofishing produced the highest number of species (65), followed by trawling (60) and seining (54). Forty-seven percent of all the species sampled in this study were captured by all three gears. Four species were captured only by the seine, 8 only by the trawl, and 13 only by electrofishing. Fish sampling data were used to evaluate gears and estimate the number of samples required to observe specified percentages of the total number of species in each reach. The minimum effort necessary to sample 90% of the species in a reach with 95% confidence was determined using a resampling procedure. Sampling with a seine was considered ineffective in nonwadeable rivers and did not substantially reduce the effort necessary to sample 90% of the species in a reach. In 3-km-long reaches, the minimum effort necessary to sample 90% of the species observed was fifteen 100-m electrofishing runs and twenty-four 50-m-long trawls. Twenty-five 100-m electrofishing runs and forty-two 50-m-long trawls were necessary to sample 90% of the species observed in 5-km-long reaches.

Flowing waters can be defined as belonging to one of three groups: small wadeable streams, larger nonwadeable rivers, and large boatable rivers, also called "great rivers" (e.g., Columbia or Mississippi rivers). A nonwadeable river can be defined as a 5th- to 7th-order stream that cannot be effectively or safely sampled with backpack- or barge-mounted electrofishing equipment during most of the year (Flotemersch et al. 2006). While small streams and great rivers pose difficulty with regard to sampling, nonwadeable rivers are among the most difficult to sample because they are often too shallow to be navigated with propeller-driven boats, but are interspersed with deeper areas that cannot be safely waded. Many sampling protocols have been developed for assessing the fish assemblage in both wadeable streams and great rivers (Barbour et al. 1999; Yoder and Smith 1999; Angradi 2006); few, however, are available for nonwadeable rivers, particularly in the Midwestern USA (Hughes et al. 2002; Maret and Ott 2004; Hughes and Herlihy 2007).

Few studies have been conducted to evaluate sampling gears in large rivers (i.e., nonwadeable and great rivers) other than boat electrofishing, the most common gear used for sampling fishes in great rivers (Maret et al. 2007). Guy et al. (2009) recommend seven gears for sampling warmwater fish in both nonwadeable and great rivers: (1) bag seine, (2) large-mesh bottom trawl, (3) small-mesh bottom trawl, (4) boat electrofishing, (5) drifting trammel net, (6) "catfish" hoop net, and (7) "buffalo" hoop net. While some of these sampling gears sample a variety of species and sizes of fish, many are highly selective for a few species or sizes. For example, trammel nets are selective for large-bodied species (e.g., common carp, bigmouth buffalo) and species with sharp projections (e.g., shovelnose sturgeon; White 1959; Hayes

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et al. 1996; Guy et al. 2009), and hoop nets are selective for ictalurids and some catostomids (Hubert 1996; Flammang and Schultz 2007). In selecting gears for the current study, those most likely to be used by natural resource managers and those that do not require multiple days of sampling (i.e., hoop nets) were selected. In addition, gears that had a high probability of sampling a diversity of species and habitats were used instead of those known to be highly selective for a few species. The three gears selected for this study were similar to the gears recommended by Guy et al. (2009): (1) boat electrofishing, (2) benthic trawl (modified Missouri trawl), and (3) bag seine. Boat electrofishing was selected because it is a gear commonly selected for sampling great rivers and because electrofishing and seining are common gears used successfully to sample fish assemblages in a variety of freshwater ecosystems (Reynolds 1996; Bayley and Herendeen 2000). Trawling too has been used to effectively sample fish assemblages in both lentic and lotic habitats (Kjelson and Johnson 1978; Stockwell et al. 2007). The modified Missouri trawl used in this study is a benthic trawl that is particularly useful for sampling small-bodied fishes in large river systems (Herzog et al. 2005). This trawl is constructed with an inner trawl body of larger mesh and an outer cover of smaller mesh. The result is a large-mesh trawl body inside a small-mesh trawl body that prevents smaller specimens from being damaged by larger specimens or debris. Designed as a benthic trawl, it also captures small midwater species in shallow water. The Missouri Department of Conservation has successfully used this trawl for several years (Herzog et al. 2005) to sample small-bodied species that were not regularly sampled with electrofishing or a larger trawl. This trawl is also being used extensively by other state and federal agencies (R. Hrabik, Missouri Department of Conservation, personal communication).

Guidance as to selecting reach lengths is also limited for large river systems. Of the research that has been conducted, most has focused on great rivers. Yoder and Smith (1999) recommended either two 500-m sampling reaches (one on each bank) or one 1,000-m sampling reach (sampling only one bank) to sample fish assemblages in the Ohio River. Similarly, Angradi (2006) recommended a 500-m sample reach (sampling only one bank) for sampling in great rivers. In addition to recommendations for great rivers, a few studies have provided guidance on reach length for rivers in the western USA. For example, Maret and Ott (2004) recommended 30–40 mean stream widths (MSW) for sampling large river reaches in Idaho. Hughes et al. (2002) recommended 85 MSW to "accurately estimate species richness," and Hughes and Herlihy (2007) recommended 50 MSW to estimate Index of Biotic Integrity scores in raftable rivers in Oregon. Flotemersch et al. (in press) provides a thorough review of reach length selection in boatable rivers. Although guidance is available for some lotic systems, reach lengths appropriate for these systems may not be appropriate for nonwadeable warmwater rivers (i.e., 5th to 7th order) characteristic of the Midwestern USA.

In Iowa, nonwadeable river systems are generally 5th order or greater. Iowa has over 115,000 km of streams and rivers within its borders (IDNR 2007), of which approximately 5,500 km are considered nonwadeable (i.e., excluding the Mississippi and Missouri rivers). The limited sampling that has focused on the "entire" fish assemblage (i.e., not just sport fishes) in Iowa's nonwadeable rivers has used boat electrofishing almost exclusively, and sampling reaches have varied from lengths of about 500 m in 5th-order systems to about 1,000 m in 6th- and 7th-order rivers (reach length measured as length of shoreline along one bank; G. Gelwicks, IDNR, personal communication). These reach lengths have been used because of recommendations in the literature (e.g., Yoder and Smith 1999; Angradi 2006, Flotemersch et al. in press) and because they were thought to provide an adequate representation of the fish assemblage in Iowa rivers with a minimal amount of effort.

Given the importance and increasing interest in nonwadeable rivers and their fish assemblages, a better understanding of sampling methods is needed. Such knowledge is critical for the proper management and conservation of nonwadeable rivers, particularly with regard to assessment of water quality and ecological integrity and to conservation of sensitive species. As such, the objective of this research was to determine the most effective (i.e., sampling the greatest number of species) and efficient (i.e., requiring the smallest amount of sampling effort to sample a given proportion of the total number of species observed) gear type(s) and reach length for adequately characterizing fish assemblages in nonwadeable rivers throughout Iowa.

METHODS

Reach selection.—Twenty-one reaches on 16 different rivers were sampled in the summers of 2007 and 2008 (Figure 1; Table 1). Sampling reaches were 3 km long in 5th-order rivers and 5 km long in 6th- and 7th-order rivers (stream order determined at the 1:100,000 map scale). In the current study, reach lengths were selected to be long enough to "oversample" the fish assemblage while being short enough to minimize the influence of major tributaries and dams. Ten 3-km-long reaches and eleven 5-km-long reaches were sampled. Habitat was highly variable among reaches (Table 1). For example, mean depth varied from 0.71 to 2.80 m and mean wetted channel width varied from 30.9 to 76.9 m among reaches. Several reaches had substrates dominated by sand, while others were dominated by large rocky substrates (i.e., boulders, riprap). Instream cover varied among reaches but typically was dominated by woody debris. Further details on the sampling reaches can be found in Neebling and Quist (2010). Sampling reaches were selected based on prior knowledge of the rivers and proximity to viable access points. Sampling generally began upstream from an access point and progressed downstream. When this was not possible because of obstructions (e.g., woody debris, extensive areas of shallow

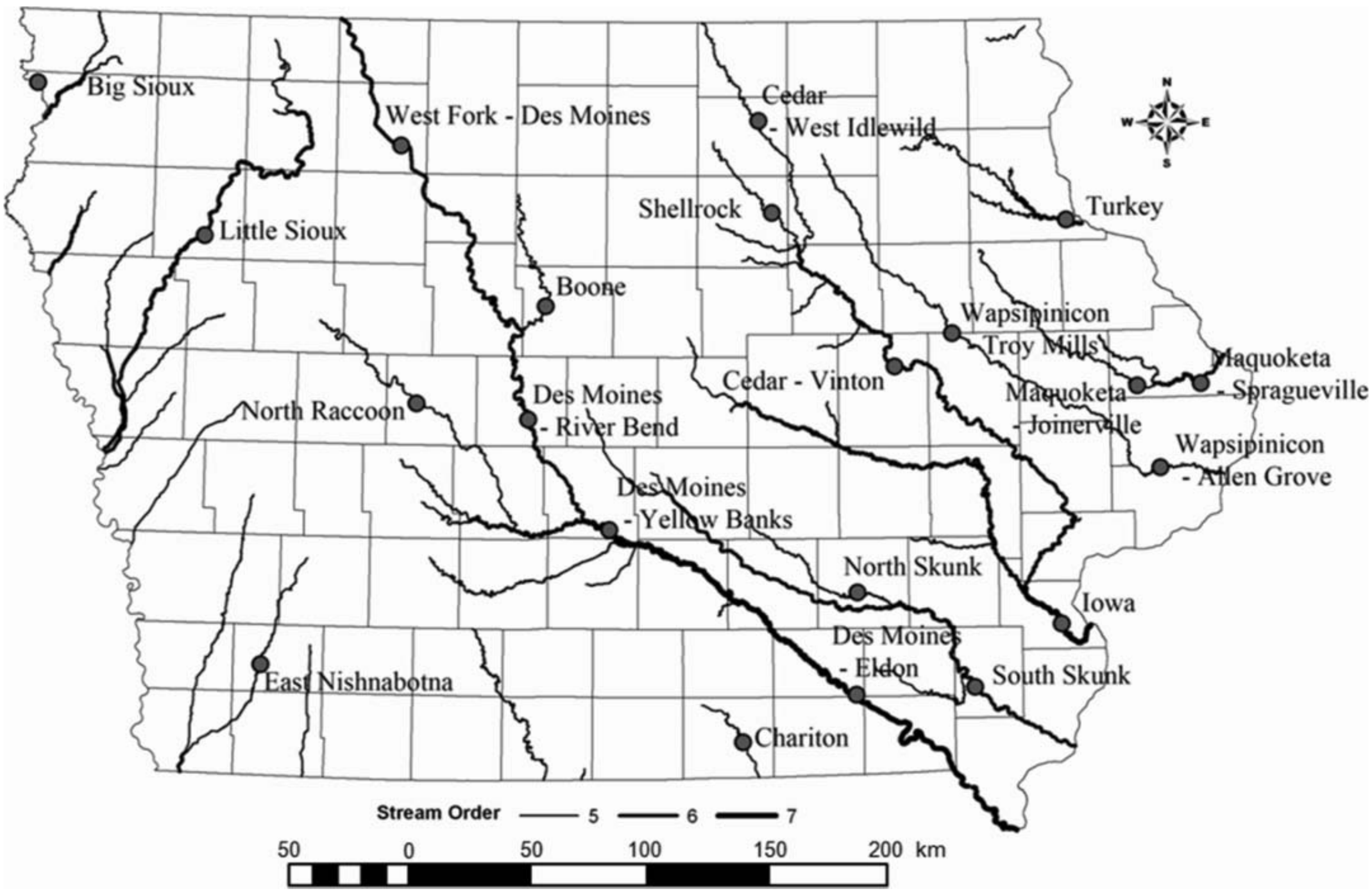

FIGURE 1. Locations of the 21 reaches sampled in 16 nonwadeable rivers in Iowa, 2007–2008. Stream order is indicated by line thickness.

water, dams), the starting point was moved downstream. Reaches were never within 1.5 km of a dam or the entry of another nonwadeable river. Beginning at the upper terminus of each reach, the reach was divided into 100-m-long sections. The length of each section was measured along the thalweg by using a global positioning system (GPS) receiver. This design resulted in 30 sections on 5th-order rivers and 50 sections on 6th- and 7th-order rivers.

After defining and uniquely identifying the 100-m-long sections, a random number generator was used to select half of the sections (i.e., 15 sections in 5th-order rivers, 25 sections in 6th- and 7th-order rivers). Selected sections were sampled with a modified Missouri trawl and a bag seine. The remaining sections were sampled with boat-mounted electrofishing. All work was conducted from a 4.9-m-long, flat-bottomed, aluminum work boat, powered by a jet-drive outboard motor.

Fish sampling methods.—The modified Missouri trawl headrope was 2.4 m long, the footrope was 3.7 m long, and the uprights were 0.6 m long. The inner trawl was made of 1.0-mm-diameter (no. 7) multifilament nylon twine sewn at 34.9-mm stretch bar in the body and 1.2-mm-diameter (no. 12) multifilament nylon twine sewn at 31.8-mm stretch bar in the doors. The outer cover was made of 6.3-mm delta-style, knotless mesh dipped with a protective coating for ultraviolet, rot, and abrasion resistance. Further detail on the design and development of this style of trawl can be found in Herzog et al. (2005).

Towlines on the trawl were 21.7 m long, which allowed for a 7:1 drop ratio at our expected maximum depth of about 3.1 m. Towlines were 22.2-mm twisted nylon ropes, attached to the boat with screw-gate carabiners. Connected to the cod end of the trawl was a 7.6-m-long, 6.3-mm-diameter braided nylon rope with a float attached to the end; the float allowed the trawl position to be monitored and aided in retrieval when the trawl became snagged. Keeping the trawl open were 52-cm-long, 32-cm-tall otter doors, weighing 6.0 kg. Attached to the footrope was 1.8 m of 4.7-mm-diameter chain, which ensured the footrope was in constant contact with the river's bottom.

Trawls were pulled from the bow in a downstream direction (i.e., the boat traveled downstream in reverse), with three trawl hauls in each 100-m section. Each individual trawl continued until it became snagged or until 50 m had been fully trawled. Fifty meters was selected as the sampling distance because it allowed the trawl to be fully deployed, fished, and retrieved without extending past the 100-m boundary. Distance was

TABLE 1. Summary of habitat variables measured in 21 reaches of 16 nonwadeable rivers in Iowa, 2007–2008.

Variable	Mean	SD	Minimum	Maximum
Channel morphology and flow				
Mean depth (m)	1.44	0.54	0.71	2.80
Mean bank angle (degrees)	53.25	11.56	30.93	76.89
Mean wetted channel width (m)	76.54	55.41	23.39	229.47
Mean bank-full width (m)	92.18	57.32	32.77	262.87
Mean current velocity (m/s)	0.40	0.19	0.16	0.85
Substrate (mean proportion)				
Clay	0.10	0.28	0.00	1.15
Silt	8.35	9.04	0.00	32.86
Sand	70.44	19.76	17.79	96.22
Gravel	10.31	9.31	0.55	35.13
Cobble	8.91	14.35	0.00	59.86
Boulder	1.58	3.92	0.00	16.98
Bedrock	0.27	0.95	0.00	4.15
Instream cover				
Tree fall (%)	36.98	31.97	0.00	98.78
Submerged tree (%)	0.77	1.83	0.00	7.70
Log pile (%)	53.12	33.48	0.32	97.68
Boulder (%)	3.47	10.13	0.00	38.90
Riprap (%)	3.91	9.63	0.00	38.54
Other (%)	1.74	6.19	0.00	28.40
Instream woody debris (mean volume [m^3])	122.17	159.58	17.36	774.10
Instream rock (mean volume [m^3])	7.27	12.59	0.00	41.52
Canopy and bank characteristics				
Mean canopy cover (%)	16.86	11.29	3.04	38.75
Proportion of total bank cover				
Tree fall	12.81	14.68	0.00	42.14
Roots	12.93	10.38	1.10	34.37
Log pile and debris dam	19.67	22.51	0.00	79.00
Riprap	11.07	11.25	0.00	43.47
Willow	7.71	16.40	0.00	64.21
Nonwoody vegetation	35.73	24.92	2.19	93.41
Other	0.09	0.35	0.00	1.59
Bank woody debris (mean volume [m^3])	108.60	106.62	7.00	479.47
Bank rock (mean volume [m^3])	17.11	17.07	0.00	62.00

measured with a GPS receiver, beginning once the trawl was fully deployed. If a trawl was snagged before it sampled 35 m, a new haul was conducted and data from the snagged trawl were not recorded. The first haul sampled the thalweg area and the other two hauls sampled nonthalweg areas with random starting points. Fish were identified and measured after each individual haul.

The seine was 3.6 m long and 1.2 m deep. The headrope was constructed of 9.5-mm-diameter braided float line with seven equally spaced 135-mm $\times$ 89-mm foam floats. The footrope was constructed of a braided lead line with internal leads, plus 18 equally spaced 113-g external leads along the bottom of the seine. The body of the seine was made of 6.3-mm delta-style, knotless mesh. A 0.9-m-diameter round bag, 0.9 m deep, was centered both vertically and horizontally in the seine.

Three 10-m seine hauls were completed per section, covering areas not sampled with the trawl. Ten meters was selected as the sampling distance because it was the distance that could generally be sampled without encountering major snags or deep water habitats preventing efficient seining. The seine was pulled, by hand, in a downstream direction parallel to the shore. Fish were identified and measured from each individual seine haul in the same manner as those sampled by the trawl.

A VVP-15B electrofisher (Smith-Root, Inc., Vancouver, Washington) powered by a 5,000-W generator was used for electrofishing. Power was transferred to the water by using two

TABLE 2. Number of fish species and individuals sampled by each of three gears (E = electrofishing, S = seining, and T = trawling) from 21 reaches in 16 nonwadeable rivers in Iowa, 2007–2008.

		Species				Individuals			
Reach	Streamorder	Total	E	S	T	Total	E	S	T
Big Sioux	7	27	20	11	14	2,138	266	358	1,514
Boone	5	27	19	8	18	1,184	415	113	656
Cedar, Vinton	6	40	29	17	14	2,224	1,070	568	586
Cedar, West Idlewild	5	27	19	17	15	1,772	477	271	1,024
Chariton	5	25	23	10	10	358	289	33	36
Des Moines, Eldon	7	36	30	14	11	559	409	73	77
Des Moines, River Bend	6	26	21	9	12	741	232	359	150
Des Moines, Yellow Banks	7	32	23	14	21	1,577	603	645	329
East Nishnabotna	5	19	13	9	8	377	63	163	151
Iowa	7	33	26	12	16	924	209	131	584
Little Sioux	6	16	13	9	9	370	174	83	113
Maquoketa, Joinerville	5	23	19	4	14	334	210	16	108
Maquoketa, Spragueville	6	25	19	7	5	257	148	53	56
North Raccoon	5	25	14	15	10	1,269	82	1,053	134
North Skunk	5	22	18	8	8	532	78	106	348
Shellrock	5	34	24	15	16	2,262	484	156	1,622
South Skunk	6	29	20	8	12	1,066	132	143	791
Turkey	6	32	22	9	17	754	197	53	504
Wapsipinicon, Allen Grove	5	36	24	9	18	507	269	84	154
Wapsipinicon, Troy Mills	5	29	21	14	16	1,552	454	413	685
West Fork Des Moines	6	21	10	17	8	440	137	266	37

Smith-Root standard fiberglass booms and two AUA-6 electrode arrays mounted on a removable shocking rail, with the boat's hull serving as the cathode. Electrofishing consisted of a single pass with two netters. Electrofishing proceeded in a downstream direction and sampled thalweg and edge-channel habitat (e.g., banks, woody debris, logs, holes) in each section. Power output was standardized to 3,000 W based on water conductivity and dropper exposure. Electroshock response in fishes appeared optimal and similar among reaches with these settings. Fish were netted by using dip nets with 6.3-mm delta-style, knotless mesh. All fish from a single electrofishing run were processed (as above), along with the time spent electrofishing (i.e., "current-on" effort). Time sampled was recorded because although each electrofishing run sampled a 100-m section, the true distance electrofished could not be measured. "Current-on" effort varied from 62 to 470 s per 100-m section (mean ± SD, 258 ± 74 s).

Five voucher specimens, as well as any unidentified species, were killed in tricaine methanesulfonate (MS-222), preserved in a 10% formalin solution, and transported to the laboratory for identification. Threatened, endangered, or other protected species were not retained. Species that were too large to be preserved were extensively photographed and then released.

Data analysis.—The number of species sampled by each of the three gear types was calculated within each reach. A Venn diagram was developed to illustrate the occurrence of fishes among sampling gears. To determine whether species richness differed between gears or reach lengths, analysis of variance (ANOVA) was used, performed with SAS version 9.1 (SAS Institute 2005).

The most appropriate reach length for sampling fish assemblages in Iowa's nonwadeable rivers was evaluated using a resampling procedure similar to that described in Patton et al. (2000), Quist et al. (2007), and Fischer and Paukert (2009). For each sampling gear, 1,000 samples were selected at random and the number of species sampled was calculated. For example, 5-km-long reaches had 75 trawls. A single trawl sample was randomly selected and the number of species sampled was recorded; this process was repeated 1,000 times. Two trawls were then selected at random, with replacement, and the number of species sampled by the two trawls was recorded; 1,000 iterations were completed. This process continued until all 75 trawls were sampled, each 1,000 times. Then, the number of times out of the 1,000 iterations that a given effort sampled a certain proportion of the total number of species sampled by that gear was calculated. This study focused on the effort necessary to sample 50, 75, 90, 95, and 100% of the species sampled by a given gear with 95% confidence. This procedure was performed for each reach. The two reach lengths (i.e., 3 km and 5 km) were then evaluated separately to examine whether reach length

TABLE 3. Fishes sampled from 21 reaches in 16 nonwadeable rivers in Iowa, 2007–2008. The number of individuals captured by each gear type (E = electrofishing, S = seining, and T = trawling), the total number of individuals, and the frequency of occurrence (percentage of reaches in which they were found) are included. Minimum, maximum, and average total length (mm, TL), and SD of lengths are also provided (Min., Max., Aver., and SD).

Family and species	E	S	T	Total	Frequency (%)	Min.	Max.	Aver.	SD
Acipenseridae									
Shovelnose sturgeon *Scaphirhynchus platorynchus*	27		13	40	24	38	660	524	142
Lepisosteidae									
Spotted gar *Lepisosteus oculatus*	2			2	10	247	502	374	180
Longnose gar *Lepisosteus osseus*	42	1		43	19	148	868	646	136
Shortnose gar *Lepisosteus platostomus*	57			57	38	278	715	543	108
Hiodontidae									
Goldeye *Hiodon alosoides*	22	1		23	29	87	396	309	57
Mooneye *Hiodon tergisus*	15			15	14	185	341	269	37
Clupeidae									
Skipjack herring *Alosa chrysochloris*	1			1	5	341	341	341	
Gizzard shad *Dorosoma cepedianum*	558	526	26	1,110	48	37	375	73	40
Cyprinidae									
Central stoneroller *Campostoma anomalum*	1	9	2	12	14	51	154	85	33
Grass carp *Ctenopharyngodon idella*	2			2	5	150	661	405	361
Red shiner *Cyprinella lutrensis*	308	290	29	627	33	29	87	53	11
Spotfin shiner *Cyprinella spiloptera*	851	1,499	159	2,509	86	30	103	61	12
Common carp *Cyprinus carpio*	379	17	8	404	100	32	836	486	143
Gravel chub *Erimystax x-punctatus*	5	50	259	314	10	39	125	88	18
Western silvery minnow *Hybognathus argyritis*		2		2	10	70	82	76	8
Brassy minnow *Hybognathus hankinsoni*		6	2	8	10	38	69	50	9
Mississippi silvery minnow *Hybognathus nuchalis*	3	43	40	86	10	35	85	53	6
Plains minnow *Hybognathus placitus*	8		1	9	5	48	103	87	18
Bighead carp *Hypophthalmichthys nobilis*	1			1	5	604	604	604	
Common shiner *Luxilus cornutus*	18	17	2	37	19	38	289	117	41
Shoal chub *Macrhybopsis hyostoma*		3	439	442	57	21	106	50	10
Silver chub *Macrhybopsis storeriana*	7	5	56	68	62	92	190	129	22
Hornyhead chub *Nocomis biguttatus*	1			1	5	66	66	66	
Emerald shiner *Notropis atherinoides*	166	172	53	391	71	30	110	65	12
River shiner *Notropis blennius*	4	23	9	36	10	52	87	69	9
Bigmouth shiner *Notropis dorsalis*	7	210	23	240	33	35	77	60	8
Ozark minnow *Notropis nubilus*		1		1	5	67	67	67	
Carmine shiner *Notropis percobromus*	44	12	1	57	24	35	96	63	10
Sand shiner *Notropis stramineus*	119	919	3,170	4,208	95	24	87	56	7
Mimic shiner *Notropis volucellus*	133	76	100	309	19	29	84	46	6
Channel shiner *Notropis wickliffi*	4	30	137	171	24	27	88	52	7
Suckermouth minnow *Phenacobius mirabilis*			8	8	19	33	77	50	18
Bluntnose minnow *Pimephales notatus*	27	467	119	613	67	25	177	56	12
Fathead minnow *Pimephales promelas*	27	37	19	83	71	31	99	64	15
Bullhead minnow *Pimephales vigilax*	11	129	31	171	48	32	86	55	8
Longnose dace *Rhinichthys cataractae*		1	2	3	10	33	50	39	9
Western blacknose dace *Rhinichthys obtusus*		6		6	5	54	72	61	7
Creek chub *Semotilus atromaculatus*	23	16	5	44	33	32	191	93	27

(*Continued on next page*)

TABLE 3. Continued.

Family and species	E	S	T	Total	Frequency (%)	Min.	Max.	Aver.	SD
Catostomidae									
River carpsucker *Carpiodes carpio*	459	41	3	503	86	48	555	345	107
Quillback *Carpiodes cyprinus*	288	11		299	100	46	474	320	97
Highfin carpsucker *Carpiodes velifer*	109		1	110	43	103	361	275	69
White sucker *Catostomus commersonii*	14	7	4	25	38	34	454	235	163
Blue sucker *Cycleptus elongatus*	5			5	14	154	687	526	212
Northern hog sucker *Hypentelium nigricans*	68	38	68	174	52	31	425	144	103
Smallmouth buffalo *Ictiobus bubalus*	73	1	1	75	57	73	730	485	121
Bigmouth buffalo *Ictiobus cyprinellus*	67			67	57	373	638	501	66
Silver redhorse *Moxostoma anisurum*	6			6	14	206	564	424	162
River redhorse *Moxostoma carinatum*	10		7	17	5	37	387	188	115
Golden redhorse *Moxostoma erythrurum*	720	42	32	794	67	33	596	288	124
Shorthead redhorse *Moxostoma macrolepidotum*	686	27	39	752	100	25	643	304	107
Ictaluridae									
Black bullhead *Ameiurus melas*	2	3		5	14	74	200	123	64
Yellow bullhead *Ameiurus natalis*	6		1	7	10	27	197	141	65
Channel catfish *Ictalurus punctatus*	235	156	2,480	2,871	95	8.5	595	76	92
Stonecat *Noturus flavus*			482	482	57	17	158	54	23
Flathead catfish *Pylodictis olivaris*	78	2	5	85	62	67	1,225	307	165
Esocidae									
Northern pike *Esox lucius*	8	1		9	19	194	654	356	154
Umbridae									
Central mudminnow *Umbra limi*	1			1	5	110	110	110	
Salmonidae									
Rainbow trout *Oncorhynchus mykiss*	1			1	5				
Percopsidae									
Trout-perch *Percopsis omiscomaycus*			1	1	5	54	54	54	
Fundulidae									
Blackstripe topminnow *Fundulus notatus*		1		1	5	57	57	57	
Gasterosteidae									
Brook stickleback *Culaea inconstans*			3	3	5	23	29	26	3
Moronidae									
White bass *Morone chrysops*	103	55	2	160	33	52	422	175	115
Centrarchidae									
Rock bass *Ambloplites rupestris*	16	1	1	18	24	53	206	128	35
Green sunfish *Lepomis cyanellus*	24	2	2	28	48	32	153	82	29
Pumpkinseed *Lepomis gibbosus*	2			2	5	160	160	160	0
Orangespotted sunfish *Lepomis humilis*	10	51	3	64	48	27	98	52	17
Bluegill *Lepomis macrochirus*	90	19	8	117	67	7	202	100	45
Smallmouth bass *Micropterus dolomieu*	187	8	20	215	67	43	514	192	81
Largemouth bass *Micropterus salmoides*	7	5		12	29	40	337	130	90
White crappie *Pomoxis annularis*	9		2	11	24	33	285	197	69
Black crappie *Pomoxis nigromaculatus*	18		2	20	38	24	282	183	70

TABLE 3. Continued.

Family and species	E	S	T	Total	Frequency (%)	Min.	Max.	Aver.	SD
Percidae									
Western sand darter *Ammocrypta clara*			22	22	14	46	59	51	3
Rainbow darter *Etheostoma caeruleum*		3	2	5	10	42	58	51	6
Iowa darter *Etheostoma exile*			1	1	5	27	27	27	
Johnny darter *Etheostoma nigrum*		8	25	33	33	22	64	47	11
Banded darter *Etheostoma zonale*		6	1,342	1,348	29	19	62	41	7
Logperch *Percina caprodes*			1	1	5	82	82	82	
Blackside darter *Percina maculata*	2	5	93	100	19	32	123	58	11
Slenderhead darter *Percina phoxocephala*	1	6	220	227	62	23	98	58	16
River darter *Percina shumardi*			30	30	19	30	60	40	9
Sauger *Sander canadensis*	25		2	27	19	185	508	377	99
Walleye *Sander vitreus*	55	11	7	73	67	34	685	322	165
Sciaenidae									
Freshwater drum *Aplodinotus grunniens*	140	62	34	236	57	34	550	209	140

influenced the effort needed to sample a given proportion of the species sampled.

The optimal combination of gears and appropriate reach length were evaluated by repeating the resampling procedure using combinations of gears. The resampling procedure was identical to the one described above; however, instead of using one gear and increasing the number of samples (i.e., sections) by one at each step, combinations of all three gears were used and samples were increased in steps of five. For instance, the resampling procedure began with 5 electrofishing runs, 5 trawls, and 5 seine hauls, after which the number of seine hauls was increased by 5 until the maximum of 75 was reached. Next, the number of seine hauls was returned to five, but the number of trawls was increased in steps of five until the maximum was reached. The same process was also conducted by varying the number of electrofishing samples. Completing all possible combinations in steps of 5 yielded 1,125 possible sampling combinations. When different combinations of gears resulted in the same number of species sampled with the same effort, the number of electrofishing runs was maximized, the number of seine hauls was minimized, and the number of trawls was allowed to vary. This approach was used because electrofishing sampled the greatest number of species and seining sampled the fewest species. Finally, as part of determining the most effective and efficient gear types, the aforementioned resampling procedure was used to examine the effect of removing the least effective gear on sample size requirements.

RESULTS

A total of 21,197 fish, representing 83 species, was sampled using the three gears (Tables 2, 3). Electrofishing sampled the highest number of species (65) and the second highest number of individuals (6,398). Trawling sampled 60 species and 9,659 individuals, and seining sampled 54 species and 5,140 individuals. Electrofishing sampled 78% of the species observed in this study, trawling sampled 73% of the species observed, and seining sampled 65% of the species observed. Electrofishing sampled 48–92% (mean ± SD, 73 ± 10%) of the total number of species sampled among the 21 reaches, while trawling sampled 17–87% (41 ± 15%) and seining sampled 20–67% (47 ± 12%) of the total number of species sampled. Electrofishing sampled the most species in all but two (i.e., 90%) of the sample reaches; seining sampled the most species in the other two reaches. Electrofishing sampled the greatest number of individuals in 7 of the 21 reaches (i.e., 33%), whereas trawling sampled the greatest number of individuals in 9 of the reaches (i.e., 43%).

Species richness in sampling reaches varied from 16 to 40 species (mean ± SD, 28 ± 6) and total catch varied from 257 to 2,262 individuals (1,009 ± 671; Table 2). The number of species sampled was not significantly different between 3- and 5-km reaches ($F_{1,19} = 0.63$, $P = 0.44$). Similarly, the number of species sampled with trawling (12.9 ± 4.1) was not significantly different from the number sampled with seining (11.2 ± 3.7; $F_{1,40} = 1.98$, $P = 0.17$); however, electrofishing (20.3 ± 5.1) sampled 8.4 more species on average than did trawling ($F_{1,40} = 26.74$, $P = 0.0001$) or seining ($F_{1,40} = 43.84$, $P = 0.0001$). The interaction between reach length and gear type in relation to species richness was not significant ($F_{2,57} = 0.38$, $P = 0.68$).

Forty-seven percent of the species observed were sampled by all three gears (Figure 2). Large-bodied species (e.g., ictalurids, lepisosteids, catostomids) were primarily sampled with electrofishing, while small-bodied species (e.g., darters, cyprinids) were typically sampled with the trawl and seine. Sand shiner

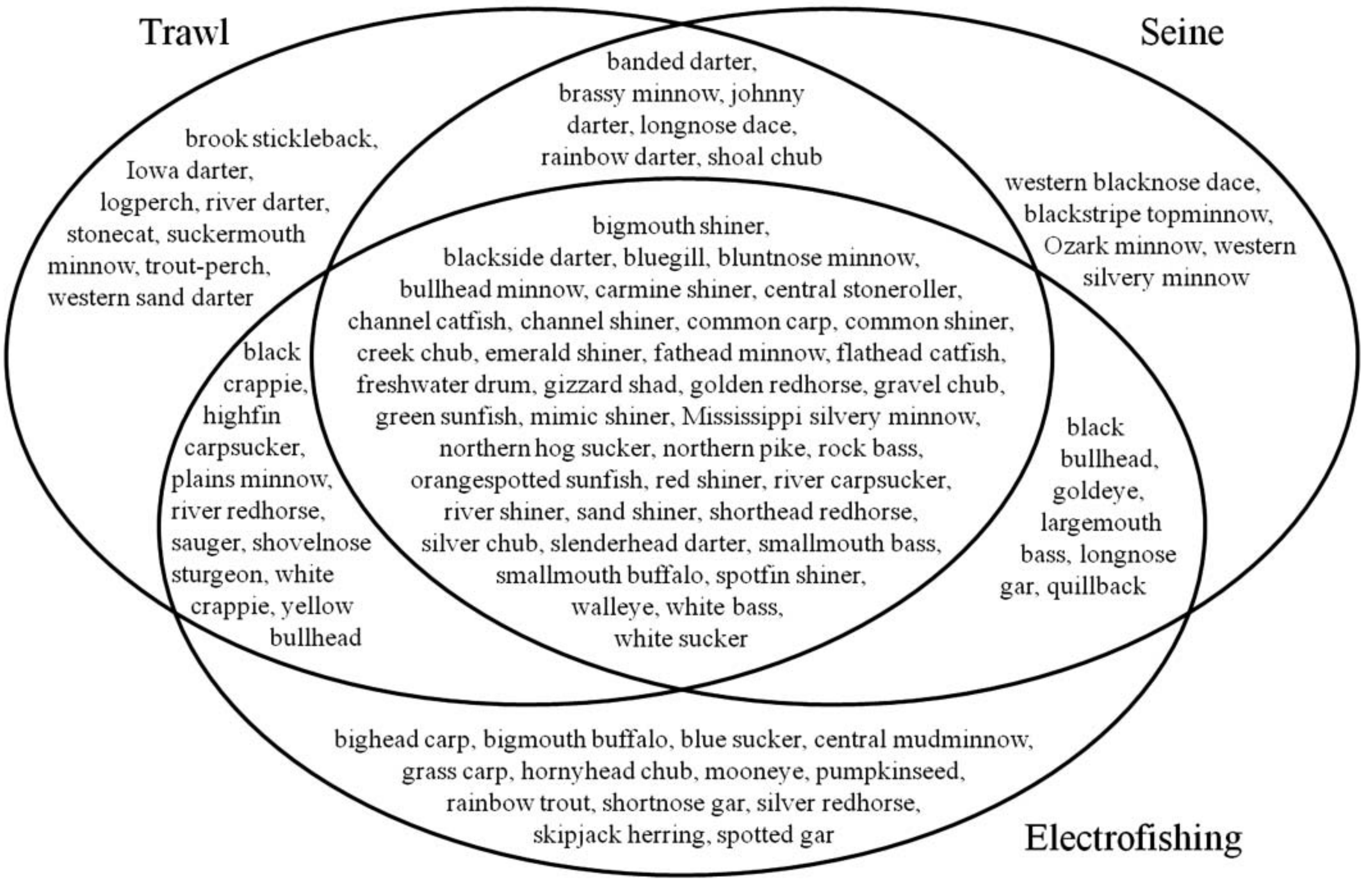

FIGURE 2. Venn diagram of the 83 fish species sampled from 21 reaches in 16 nonwadeable rivers in Iowa, 2007–2008.

was the most numerically abundant species sampled in this study (i.e., all three sampling gears combined), followed by channel catfish, spotfin shiner, banded darter, and gizzard shad (Table 3). The most abundant species sampled with electrofishing were spotfin shiner, golden redhorse, shorthead redhorse, gizzard shad, and river carpsucker. The most abundant species sampled with the trawl were sand shiner, channel catfish, banded darter, stonecat, and shoal chub. Spotfin shiner, sand shiner, gizzard shad, bluntnose minnow, and red shiner were the numerically most abundant species sampled with the seine. Although shorthead redhorse, common carp, and quillback were not among the most abundant species, they were sampled in all reaches (Table 3).

Estimates of sample size indicated that electrofishing would require fewer samples to collect available fish species present at each site than would either trawling or seining. The resampling procedure that used individual gears estimated that in 3-km reaches, the mean number of electrofishing runs necessary to sample 90% of the species observed with 95% probability with electrofishing was fourteen 100-m runs (Figure 3). Trawling required 42 trawls and seining required 43 hauls to sample 90% of the observed species sampled with their respective gears. Sampling 95% or more of the observed species with a 95% probability required the maximum effort (i.e., sampling all sections) for each gear. Sampling 5-km reaches with an individual gear showed patterns similar to those for 3-km reaches (Figure 3). The mean number of electrofishing runs necessary to sample 90% of the observed species sampled with electrofishing was 22 runs. Seventy-three trawls were required to sample 90% of the observed species sampled with the trawl, and 72 seine hauls were necessary to sample 90% of the observed species sampled with the seine. Again, the maximum effort (i.e., sampling all sections) for each gear was required to sample 95% or more of the observed species.

The resampling procedure that used combinations of gears estimated that in 3-km reaches, the sampling regime that resulted in the minimum amount of effort necessary to sample 90% of the observed species was 15 electrofishing runs, 26 trawls, and 17 seine hauls (Figure 4). In 5-km reaches, 24 electrofishing runs, 48 trawls, and 27 seine hauls was the minimum effort necessary to sample 90% of the species observed (Figure 4).

After analyzing the results of the previous resampling procedures and examining the low number of species and individuals sampled by the seine, seining was determined to be the least effective gear tested. To examine the effect that seining had on the overall results, the previous resampling procedure (i.e.,

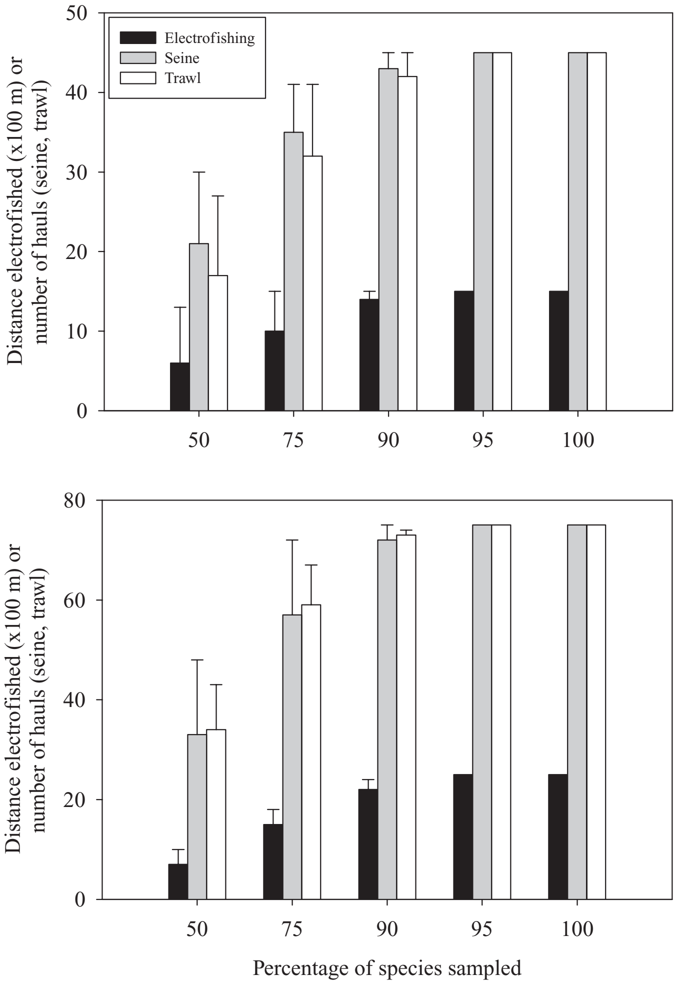

FIGURE 3. Mean number of samples necessary to sample certain percentages of the species observed with one of three gears in 3-km reaches (upper panel) and 5-km reaches (lower panel) in 16 nonwadeable rivers in Iowa, 2007–2008. Each error bar represents the maximum number of samples necessary to sample a certain percentage of the species in a reach.

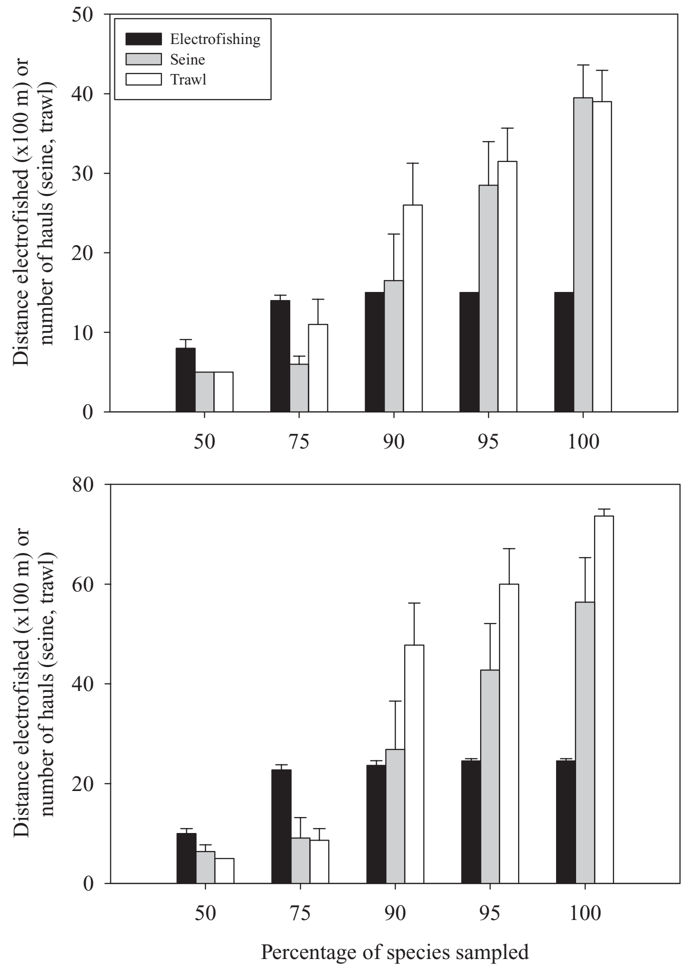

FIGURE 4. Mean minimum number of samples necessary to sample certain percentages of the fish species observed in a given reach when using combinations of three gears (electrofishing, trawling, and seining) in 3-km (upper panel) and 5-km (lower panel) reaches in 16 nonwadeable rivers in Iowa, 2007–2008. Error bars represent SEs.

using combinations of gears) was repeated but excluding the data from seining. Results of this resampling analysis were similar to the results from resampling using all combinations of gears (Figures 4, 5). In 3-km reaches, the minimum effort necessary to sample 90% of the species observed was 15 electrofishing runs and 24 trawls. Twenty-five electrofishing runs and 42 trawls were necessary to sample 90% of the species observed in 5-km reaches (Figure 5).

DISCUSSION

Electrofishing, trawling, and seining sample different habitats; therefore, they sample different species and sizes of fish. This study illustrates how the three sampling gears sample different components of the fish assemblage. Although electrofishing and trawling typically captured the greatest number of species and individuals, including rare and unique species, seining also sampled unique species. As such, the choice of sampling gears is largely dependent on the objectives of sampling and logistical constraints associated with using different sampling techniques.

Several studies have evaluated the effectiveness of electrofishing in large rivers in comparison with other gears and have generally concluded that electrofishing outperforms other techniques with regard to species richness and diversity (Pugh and Schramm 1998; Mercado-Silva and Escandon-Sandoval 2008). Similar results were observed in our study, where electrofishing samples had higher species richness than did trawl or seine samples. However, although electrofishing could be considered the best "all-around" gear used in the current study, electrofishing failed to sample 22% of the species observed in this study.

Trawling has long been an effective sampling gear in marine ecosystems (Hayes et al. 1996), but the use of trawls in freshwater, particularly in rivers, is more recent (Dettmers et al.

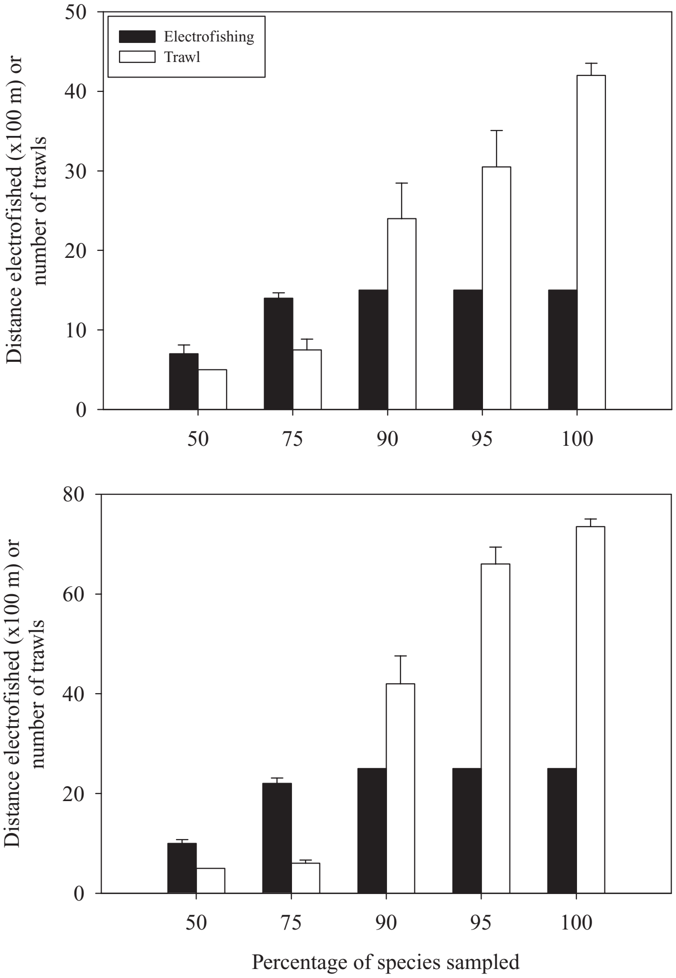

FIGURE 5. Mean minimum number of samples necessary to sample certain percentages of the fish species observed in a given reach when using combinations of electrofishing and trawling in 3-km reaches (upper panel) and 5-km reaches (lower panel) in 16 nonwadeable rivers in Iowa, 2007-2008. Error bars represent SEs.

2001; Herzog et al. 2005). Small-bodied, benthic species are often highly susceptible to towed gears such as trawls (Hayes et al. 1996); however, much of the trawling in rivers has used large mesh trawls (e.g., Dettmers et al. 2001). Consequently, small-bodied species have probably been undersampled in large river systems. Trawling sampled the greatest number of individuals in this study probably because many of the species it sampled have a maximum length of less than 100 mm (e.g., banded darter, rainbow darter, suckermouth minnow; Pflieger 1997), and small-bodied species are likely to be more abundant than larger-bodied species. Moreover, the trawl was able to sample midchannel benthic areas, areas that are not well sampled with traditional gears such as electrofishing.

Seining is a popular sampling gear, but its effectiveness is limited to shallow water habitats free of obstructions (Hayes et al. 1996; Guy et al. 2009). Mercado-Silva and Escandon-Sandoval (2008) found that seining was inadequate for estimating community parameters and assessing biotic integrity in a large river in Mexico. We found similar results: the seine in our study sampled the fewest species and individuals. Additionally, the number of species that were sampled only by seining, and the number of individuals of those species, was extremely low. These results may be attributed to the difficulty of operating a seine in Iowa's nonwadeable rivers. Many Iowa rivers have nearly vertical banks because of channelization or erosion. Steep banks, combined with deep water and large amounts of woody debris, dramatically reduced the ability to effectively seine. The difficulties associated with seining in nonwadeable rivers, combined with the capture of few unique species, suggest that seining may not be a suitable gear in many of Iowa's nonwadeable river systems. Having said that, sampling with a seine may be one of the few available options for sampling when boat access is limited. Therefore, scientists must carefully consider their objectives within the logistical constraints of sampling.

Reach lengths used in this study were considerably longer than the fixed reach lengths recommended in the literature (e.g., Yoder and Smith 1999; Flotemersch et al. 2001), but shorter than recommendations based on MSW (e.g., Hughes et al. 2002). However, the rivers in the current study differed substantially from those in other studies. Moreover, few studies have examined appropriate reach lengths in nonwadeable rivers characteristic of those in the Midwestern USA. Lyons et al. (2001) found that 1,600 m was the point where estimates of species richness were asymptotic and became insensitive to variation in sampling effort. Flotemersch and Blocksom (2005) found that 1,000 m of electrofishing was sufficient for bioassessment of nonwadeable tributaries of the Ohio River. These studies used a single gear (electrofishing). In the current study, however, multiple gears were used to determine "total" species richness, with results higher than would be indicated from sampling with electrofishing alone (i.e., a total of 83 species sampled compared with 65 species sampled with only electrofishing). Additionally, both Lyons et al. (2001) and Flotemersch and Blocksom (2005) calculated total species richness from reaches far shorter than the 3- and 5-km reaches used in this study.

As the amount of area or stream length sampled increases, the number of species encountered typically increases (Fischer and Paukert 2009). This was observed in the current study, where sample size estimates indicated that the maximum or nearly maximum effort was required to sample 95–100% of the species. Iowa's nonwadeable rivers are extremely diverse ecosystems, home to many rare or uncommon species, as evidenced by the fact that 75% of the species made up less than 1% of the total catch. Increasing reach length, and subsequently effort, typically resulted in new species occurrences up to the maximum reach length of this study. This may be partially explained by species–area relationships, where the number of species increases with the area sampled because of an increase in habitat diversity and availability (Williams 1964; Rosenzweig 1995). Another explanation for the continual increase in species richness is the uneven distribution of rare species, which is again often based on habitat availability (Gorman and Karr 1978; Angermeier and Smogor 1995; Fischer and Paukert 2009). As sample reach length increases and the availability of habitats increases, the likelihood of encountering a rare species also increases.

Management Implications

Results from this research suggest that a minimum sampling reach length of 1,500 m is required to sample 90% of the species observed in 5th-order rivers, and 2,500 m is required in 6th- and 7th-order rivers. Additionally, sampling with a single gear should be avoided because even the most effective gear (i.e., electrofishing) sampled only 78% of the species observed. In Iowa, a primary objective of sampling is to maximize the number of species sampled while minimizing the amount of effort. Therefore, sampling twenty-five 100-m electrofishing runs and forty-two 50-m-long trawls (three trawls completed in a 100-m section) in nonwadeable rivers in Iowa maximizes the number of species sampled with a reasonable amount of sampling effort.

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