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ABSTRACT Electrofishing is commonly used by fisheries professionals to assess fish assemblage structure and species abundance in streams. Accurate estimates of fish abundance and, consequently assemblage metrics, are typically generated with mark-recapture or maximum-likelihood depletion techniques, but doing so requires considerable sampling effort. Less intensive sampling approaches may be beneficial to fisheries managers, particularly in cases where frequent sampling of many streams is preferred. We used regression and Spearman rank-order correlation analyses to compare species catch rates and the assemblage metrics generated from single-pass electrofishing samples with multiple-pass depletion abundance estimates in Nebraska streams. We examined the influence of instream habitat features on the regression residuals to further examine the effectiveness of single-pass electrofishing. Our results suggest that single-pass electrofishing is suitable for wadeable prairie streams with relatively little habitat diversity. With few exceptions, fish species were detected and captured in similar quantities regardless of electrofishing effort, suggesting that single-pass sampling can be used to quickly assess species occurrence and relative abundance. The single- and multiple-pass electrofishing methods generated slightly different values for each assemblage metric; however, these values were not significantly different. Abundance was over- or underestimated in areas where certain species were congregated (e.g., overhanging vegetation: Red Shiner *Cyprinella lutrensis*, Bigmouth Shiner *Notropis dorsalis*, large substrates: Stonecat *Noturus flavus*, and darters) or difficult to sample (e.g., woody debris: Largemouth Bass *Micropterus salmoides* and Western Mosquitofish *Gambusia affinis*) using only one electrofishing pass. Single-pass electrofishing offers a reliable alternative to the more intensive multiple-pass depletion techniques; however, caution should be applied in difficult to sample areas with unique habitats.

KEY WORDS: backpack electrofishing, catch rates, depletion, multiple-pass, wadeable streams.

Methods that adequately sample fish assemblage structure are to effectively assess stream fish communities. Reliable appraisals of stream fish assemblages are necessary to monitor spatial and temporal population dynamics and identify changes to relative abundances of individual species (Reynolds et al. 2003, Reid et al. 2009, Peoples and Frimpong 2011). Although many gears and approaches are available to sample fishes, electrofishing is the most commonly used sampling gear in streams (Larimore 1961, Kruse et al. 1998, Bertrand et al. 2006, Rabeni et al. 2009). Abundance estimates and descriptions of fish assemblage structure (i.e., richness, evenness, diversity) are typically generated using mark-recapture (Pine et al. 2012) or maximum-likelihood depletion techniques which require multiple electrofishing passes at a reach (Zippin 1956, Ricker 1975, White et al. 1982, Price and Peterson 2010). However, these multi-sample protocols are time consuming, can stress stream ecosystems, and may not describe populations and assemblages better than more rapid methods (Reynolds et al. 2003, Peterson et al. 2004, Peoples and Frimpong 2011, Pritt and Frimpong 2014).

Because resources are commonly limited for stream fisheries evaluations, less intensive alternatives (i.e., single-pass electrofishing) are being used more frequently (Jones and Stockwell 1995, Kruse et al. 1998, Patton et al. 2000, Bertrand et al. 2006, Peoples and Frimgong 2011). Single-pass electrofishing may allow fisheries managers to characterize fish assemblages across larger spatial areas or with increased frequency. Although several studies have evaluated the suitability of single-pass electrofishing in different regions and habitats (Jones and Stockwell 1995, Kruse et al. 1998, Edwards et al. 2003, Bateman et al. 2005, Bertrand et al. 2006, Reid et al. 2009, Peoples and Frimpong 2011), this effectiveness has been rarely tested for small streams in the Great Plains. Before single-pass estimations can be used on a broader scale, research is needed to determine whether these methods are effective in prairie stream environments (Simmons and Lyons 1995, Pusey et al. 1998, Meador 2003, Bertrand et al. 2006, Peoples and Frimpong 2011, Vehanen et al. 2012).

To better understand the applications of single-pass electrofishing in diverse prairie streams, we: (1) investigated the relationship between individual species and taxonomic group catch rates and the assemblage metrics generated from single-pass electrofishing samples and multiple-pass depletion abundance estimates; and (2) described the relative influence of instream habitat variability on the effectiveness of single-pass sampling. To be effective, single-pass electrofishing must detect a majority of the species present and provide accurate relative abundance estimates for individual species in diverse habitats.

METHODS

We sampled 18 wadeable prairie stream reaches across Nebraska from July – August 2011 to describe the local fish assemblage (Fig. 1). Four stream reaches were sampled twice during the study for a total of 22 sampling events. The repeated sampling events were considered independent, as they were conducted >14 days following the first sampling effort. Each sampling reach was delineated as 40 times the average wetted stream width measured at five randomly selected points; however, a minimum of 150 m and maximum of 300 m was established (Patton et al. 2000, Reynolds et al. 2003). Fixed block-nets were established at the up- and downstream endpoints of the sampling reaches. Multiple-pass (up to four passes), depletion sampling without replacement was conducted, and sampling was terminated when no new species were captured during a pass. The first pass was used to represent a single-pass electrofishing effort. Depletion abundance estimates were generated from the number of individuals removed during successive passes using the FSA (Fisheries Stock Analysis) package developed by Ogle (2018). All sampling protocols followed those described and approved by the Institutional Animal Care and Use Committee at the University of Nebraska at Kearney (Approval #041100).

We quantified aspects of instream habitat that we hypothesized influence fish immobilization, detection, and collection during electrofishing to examine the relative importance of these factors on the effectiveness of single-pass electrofishing (Bain and Sorenson 1999). We measured instream habitat characteristics along 11 equally spaced transects at each stream reach during every sampling event. Along each transect, we measured wetted width (m), depth (cm), and water velocity (cm/s) at five equally spaced points. Water velocity was measured at the water's surface and at 60% of the water's depth at each point. The availability of cover habitats (i.e., aquatic macrophytes, small and large woody debris, and overhanging vegetation) was visually

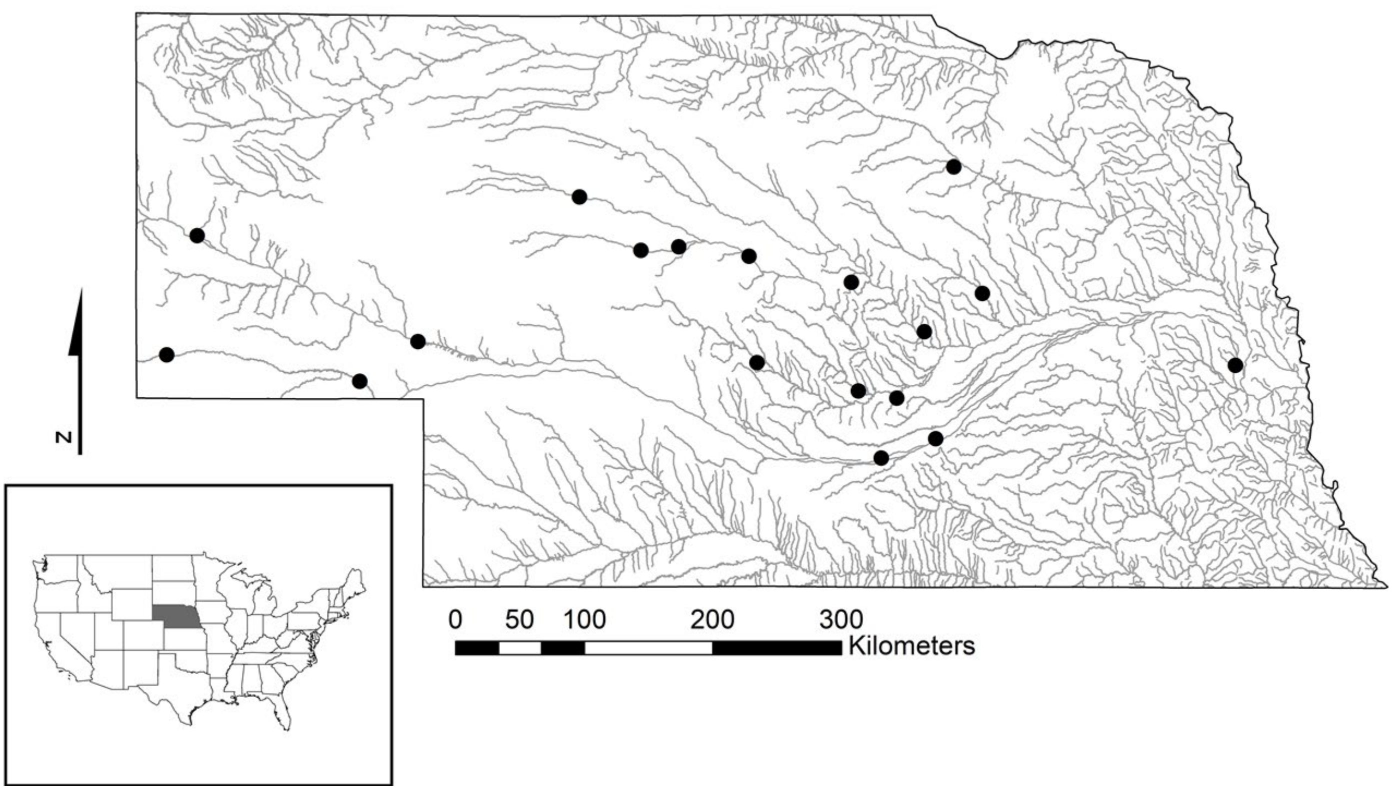

Figure 1. Locations of the wadeable prairie streams in Nebraska used to assess single-pass electrofishing effectiveness to describe species abundance and fish assemblage structure.

estimated within 15 equally spaced sections along each transect and rated using a standard categorical scale: 0 (absent, 0%), 1 (sparse, <10%), 2 (moderate, 10–40%), 3 (heavy, 41–75%), and 4 (very heavy, >75%). Substrate coarseness was visually estimated in the same 15 sections as the percentage composition of silt/muck (<0.06 mm), sand (0.06–2.00 mm), and larger substrates (>2.00 mm). Substrate values were averaged among transects to describe the percent of each substrate class at each sampling site. Means (± one standard error [SE]) were calculated for each continuous environmental variable, whereas median and the range of values were used to characterize each cover habitat index at each sampling reach during each visit.

We used linear regression to compare single-pass electrofishing catch rates (catch/m^2) to the abundance estimates from multiple-pass sampling (fish/m^2) for each individual species and, in rare, combined species taxonomic group. Models with positive slopes that differed significantly from zero indicated a significant relationship between single-pass catch rates and multiple-pass abundance estimates. Fish species that were encountered during fewer than five sampling events (<25% of samples) were not evaluated using the species-specific regression analyses; however, data for closely related species were combined when possible. Catch information on all *Etheostomine* darters was combined as each species of this genus was captured infrequently. A logarithmic transformation was applied to catch rate, estimated abundance, and cover habitat data to produce frequency distributions that better approximated normality. We also compared Shannon-Diversity, evenness, and richness between single- and multiple-pass sampling efforts using Spearman rank-order correlation (Bertrand et al. 2006). These assemblage metrics were calculated using all capture data, including rare species that were captured at fewer than five sites. Linear regression was used to characterize the influence of each environmental parameter on the relationship between single-pass catch rates and multiple-pass abundance estimates. In this analysis, the studentized residuals from each species- or taxon-specific relationship was the response variable and the habitat features were the independent variables. Analyses were conducted using the SAS statistical software (SAS version 9.3). Significance was determined at $\alpha = 0.05$ for each individual species- or taxon-specific hypothesis.

RESULTS

The morphology and the availability of habitats that could influence electrofishing efficiency varied among the sampling reaches. Although the stream reaches were generally shallow (mean ± 1 SE: 28.8 ± 2.86 cm), the wetted widths ranged from relatively narrow (minimum: 1.5 m) to wide (maximum: 44.2 m). Mean discharge was generally low (mean ± 1 SE: 3.1 ± 0.98 cm^3 sec^{-1}) at the predominately shallow and slow-moving streams reaches we sampled. The stream banks at each sampling site were incised (mean ± 1 SE: 47.4 ± 3.90 degrees). Sand (mean ± 1 SE: 66.1 ± 8.06%) and other fine substrates (mean ± 1 SE: 32.2 ± 3.01%) dominated the benthic areas of most sampling reaches, and larger substrates were relatively rare (<2%). Aquatic macrophytes (median index: 1.3, range: 0 – 3.6) and overhanging riparian vegetation (median index: 1.8, range: 0.1 – 3.3) cover was moderate (i.e., 10–40% coverage) at most sampling reaches; however, both habitat features were nearly absent and considered heavy (i.e., 41 – 75%) at some stream reaches. Woody debris was relatively uncommon at each stream (median index: 1.0, range: 0 [absent] – 3.0 [heavy]), but was present 95% of the sampling events.

The number of electrofishing passes required to the deplete the local fish population varied among sampling reaches (mean ± 1 SE: 2.5 ± 0.12 passes) and the electrofishing effort differed slightly among subsequent passes at each site (mean ± 1 SE: 1,017 ± 74.1 s). In total, we captured 6,978 individuals, of which 68% were captured during the first electrofishing pass. We captured 37 species from 10 families across all stream reaches sampled (Table 1). Twenty species were encountered during too few (i.e., <5) sampling events to generate reliable regression parameter estimates and were excluded from the single-species analyses (Table 1). We were unable to generate depletion abundance estimates for 7.4% of capture sequences the rarest species with seemingly low detection probabilities (i.e., 0 captured on first pass) and for 3.7% of capture sequences for very abundant species with populations that we did not deplete. Ultimately, we were able to compare single-pass catch rates and multiple-pass abundance estimates for 88.9% of capture events.

Significant relationships were found between single-pass catch rates and multiple-pass abundance estimates for most (~89%) individual fish species and *Etheostomine* darters (R^2 range: 0.67 – 0.99; Table 1). However, abundance estimates from single-pass electrofishing efforts were not significantly related to those from multiple-pass estimates for Longnose Dace *Rhinichthys cataracta*e ($F_{1, 4} = 5.1$, $P = 0.11$, $R^2 = 0.50$) and Stonecat *Noturus flavus* ($F_{1, 5} = 6.7$, $P = 0.06$, $R^2 = 0.53$).

Although fish community metrics generated from single-pass catch data and multiple-pass abundance estimates differed, the magnitude of the differences were not significant (Fig. 2). Richness estimates from single-pass electrofishing efforts were lower than multiple-pass estimates during ~41% of the samples. The difference in richness estimates was generally small (mean ± 1 SE: 0.73 ± 0.23, range: 1 – 4 species), and estimates from both sampling methods were significantly related ($r = 0.93$, $P < 0.01$). Assemblage evenness was estimated, on average, to be ~6.1% higher when using only the single-pass data (Fig. 2); however, the values generated from the different electrofishing methods were significantly related ($r = 0.79$, $P < 0.01$). Similarly, estimates of Shannon-Diversity were approximately 3.0% higher (Fig.

Table 1. Relationships between single-pass electrofishing catch rates (catch per m^2) and depletion abundance estimates (fish per m^2) for fish captured throughout Nebraska. Regression parameters are back-transformed as raw data was transformed using a logarithmic function in order to approximate a normal distribution of the data.

Common Name[a]	**Species**	**Number of Sites**	**Inter-cept**	**Slope**	**R^2**	**F value**	**P value**
Cyprinidae							
Bigmouth Shiner	*Notropis dorsalis*	9	23.5	19.9	0.92	94.5	<0.01
Brassy Minnow	*Hybognathus hankinsoni*	10	2.9	13.6	0.88	64.4	<0.01
Common Carp	*Cyprinus carpio*	14	1.8	10.6	0.94	188.9	<0.01
Creek Chub	*Semotilus atromaculatus*	10	2.1	11.0	0.95	160.7	<0.01
Fathead Minnow	*Pimephales promelas*	19	1.7	9.6	0.92	203.3	<0.01
Longnose Dace	*Rhinichthys cataractae*	5	30.9	19.5	0.50	5.1	0.11
Red Shiner	*Cyprinella lutrensis*	10	2.9	9.9	0.67	19.1	<0.01
Catostomidae							
River Carpsucker	*Carpiodes carpio*	5	1.5	11.0	0.99	1623.0	<0.01
White Sucker	*Catostomus commersonii*	9	2.0	10.4	0.93	101.7	<0.01
Ictaluridae							
Channel Catfish	*Ictalurus punctatus*	6	0.3	6.5	0.85	28.9	<0.01
Stonecat	*Noturus flavus*	6	0.4	6.9	0.53	6.7	0.06
Fundulidae							
Plains Topminnow	*Fundulus sciadicus*	7	1.1	8.6	0.98	264.5	<0.01
Poeciliidae							
Western Mosquitofish	*Gambusia affinis*	7	1.8	9.9	0.89	76.4	<0.01
Centrachidae							
Bluegill	*Lepomis macrochirus*	7	6.3	0.97	208.5	208.5	<0.01
Green Sunfish	*Lepomis cyanellus*	13	3.0	0.97	359.9	359.9	<0.01
Largemouth Bass	*Micropterus salmoides*	9	3.5	0.90	74.2	74.2	<0.01
Percidae							
Darters	*Etheostoma* spp.	9	2.0	10.4	0.93	101.7	<0.01

[a]Twenty species were captured during fewer than 5 sampling events are were not included in regression analyses to describe the relationship between single-pass and depletion methods. These species are: Black Bullhead, Brook Stickleback, Brown Trout, Central Stoneroller, Emerald Shiner, Flathead Chub, Gizzard Shad, Grass Pickerel, Iowa Darter, Johnny Darter, Longnose Sucker, Northern Pike, Orangethroat Darter, Plains Killifish, Rainbow trout, Redear Sunfish, Shorthead Redhorse, Western Silvery Minnow, Yellow Bullhead, and Yellow Perch.

2), but statistically equivalent, between the single-pass data and the multiple-pass estimates (r = 0.90, P < 0.01).

The accuracy of single-pass electrofishing was influenced by local habitat features for only six (33.3%) species (Table 2). Increased densities of woody debris in the sampling reach resulted in underestimates of Western Mosquitofish *Gambusia affinis* ($F_{1, 5}$ = 9.4, P = 0.03) and Largemouth Bass *Micropterus salmoides* ($F_{1, 7}$ = 5.3, P = 0.05) abundance (Table 2). Our catch data tended to overestimate the abundances of Red Shiner *Cyprinella lutrensis* ($F_{1, 8}$ = 36.4, P < 0.01; Table 2) and Bigmouth Shiner *Notropis dorsalis* ($F_{1, 7}$ = 5.6, P = 0.05; Table 2) within instream reaches with abundant overhanging vegetation. The abundances of darter species ($F_{1, 5}$ = 32.9, P < 0.01) and Stonecat ($F_{1, 4}$ = 38.8, P < 0.01) were overestimated in areas with higher percentages of large substrates (Table 2).

DISCUSSION

We demonstrated that it may be possible to use single-pass electrofishing in wadeable prairie streams with relatively little habitat diversity in place of depletion sampling efforts that require multiple passes. Although many standardized sampling protocols require multiple electrofishing passes to effectively estimate population parameters (Kruse et al. 1998, Kennard et al. 2006, Rabeni et al. 2009), we generated similar estimates of fish density for most species regardless of the number of electrofishing passes. Additionally, the single-pass and multiple-pass depletion electrofishing methods resulted in similar values for the assemblage metrics. Although our research demonstrates that single-pass electrofishing may be a suitable alternative for many prairie stream fishes in Nebraska, caution should be applied

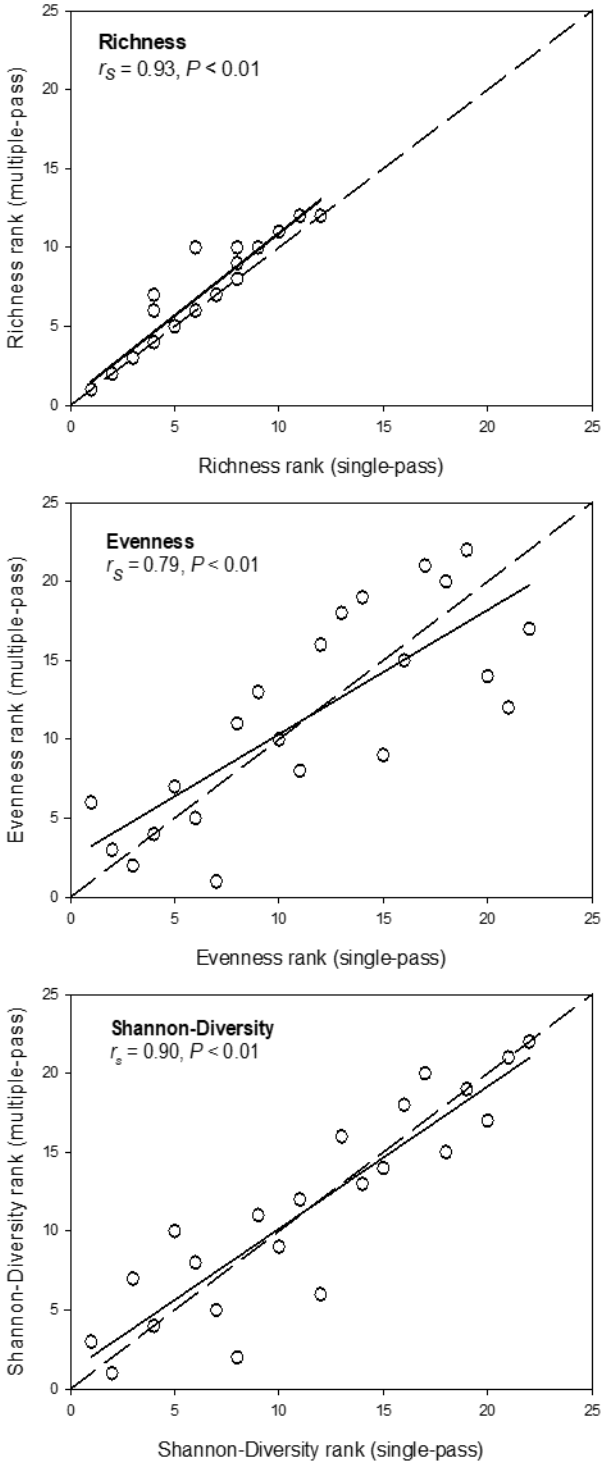

Figure 2. Relationship between ranked species richness (top), evenness (middle), and Shannon-Diversity (bottom) estimated from single-pass and multiple-pass depletion electrofishing samples collected from wadeable prairie streams across Nebraska. Spearman rank correlations are shown for single-pass versus multiple-pass estimates (open circles, solid least-squares line) and the dotted line represents the 1:1 relationship.

if targeting certain species in relatively heterogeneous habitats.

Care should be taken when using single-pass electrofishing methods to describe the population structures of some species that are difficult to detect as the accuracy may be influenced by inherent differences in their population abundances, physical characteristics, behaviors, or habitat preferences (Rabeni et al. 2009, Reid and Haxton 2017). For example, single-pass electrofishing failed to accurately estimate Longnose Dace and Stonecat abundances in the current study. Although these species occurred during >20% of the sampling events, neither were captured in high abundances and often the number of individuals captured varied little among electrofishing passes. Both species are cryptic, with color patterns similar to the benthic habitats they occupy (Mullen and Burton 1995, Armbruster and Page 1996). Although Stonecat and other madtom species (*Noturus* spp.) are commonly considered difficult to sample in wadeable streams due to their reclusive (Shearer and Berry 2003, Gibson-Reinemer et al., 2016, Reid and Haxton 2017), comparable single-pass electrofishing efforts for Longnose Dace have largely provided more accurate depictions of abundance (Peoples and Frimpong 2011, Reid and Haxton 2017).

Our inability to capture individuals of present species and tendencies to over- and underestimate the abundances of relatively rare and very abundant species with single-pass electrofishing likely influenced our estimates of assemblage composition (Simonson and Lyons 1995, Pusey et al. 1998, Meador et al. 2003). Similar to research conducted in different regions, each of our estimates of assemblage structure were only slightly influenced by the number of electrofishing passes (Edwards et al. 2003, Meador et al. 2003, Bertrand et al. 2006, Reid et al. 2009, Vehanen et al. 2012). However, despite relatively few species (~15) occupying the sampled streams, we were not always able to collect at least one representative of each species on the first pass. On average, about one species was missed during the first electrofishing pass; however, for some sampling events, this number was as high as four. Typically, the missed species were small (e.g., Brook Stickleback *Culaea inconstans*), benthic (e.g., darters), cryptic (e.g., Stonecat), or occupied mid-channel habitats (e.g., Flathead Chub *Platygobio gracilis* and Shorthead Redhorse *Moxostoma macrolepidotum*). Imperfect detection of riverine species during rapid sampling exercises is commonly noted and creates concern for assessing populations with fewer electrofishing passes (Peoples and Frimpong 2011, Reid and Haxton 2017). If species are not encountered on the first electrofishing pass or populations of common species are not depleted during subsequent passes, the generated abundance estimates are unreliable. No matter the number of passes conducted, we were unable to estimate the abundance of these species (i.e., 11.1% of all fish captures).

Table 2. Relative influence of instream habitat variability on the standardized residuals of electrofishing catch rates (catch per m^2) and depletion abundance estimates (fish per m^2) abundance estimates for fish species in which significant relationships were identified ($P < 0.05$).

	Species	Influence on single-pass catch data	F value	P value
Instream Habitat				
Gravel substrate (%)	Darters (Etheostoma spp.)	Overestimated	32.9	<0.01
	Stonecat (Noturus flavus)	Overestimated	38.8	<0.01
Available Cover (Indices)				
Woody debris	Largemouth Bass (*Micropterus salmoides*)	Underestimated	5.3	<0.05
	Western Mosquitofish (*Gambusia affinis*)	Underestimated	9.4	0.03
Overhanging Vegetation	Red Shiner (*Cyprinella lutrensis*)	Overestimated	36.4	<0.01
	Bigmouth Shiner (*Notropis dorsalis*)	Overestimated	5.6	<0.05

The relationship between single-pass catch rates and multiple-pass abundance estimates appeared to be strongly influenced by local habitat heterogeneity for six species. Little is known about the specific fish-habitat relationships that seemed to alter our single-pass electrofishing proficiency (Bohlin and Sundström 1977, Kennedy and Strange 1981, Kruse et al. 1998, Meador et al. 2003, Peterson et al. 2004, Reid et al. 2009, Pritt and Frimpong 2014). Six species were over- or underestimated in complex or difficult to sample habitats when using only one electrofishing pass. Although each of these species were usually detected during the first electrofishing pass, our catch rates were either positively or negatively influenced by certain habitat features (i.e., woody debris, overhanging vegetation, and large substrates). Abundances were generally overestimated when physical habitats had the potential to congregate minnows (i.e., Red Shiner and Bigmouth Shiner) near overhanging cover or, for benthic species (i.e., Stonecat and darters), near large substrates that were rare in the sampling reaches. Thus, the utilization of overhanging vegetation by mid-water column minnow species (Talmage et al. 2002) and preference of large substrates by Stonecat (Hrabik et al. 2015) and Orangethroat Darter *Etheostoma spectabile* (Lee et al. 1980), the most common darter species we encountered, potentially concentrated individuals in areas that were relatively easy to sample. Single-pass electrofishing underestimated species abundances when habitat features limited our ability to consistently detect or collect immobilized individuals (Thompson and Rahel 1996, Peterson et al. 2004, Bertrand et al. 2006). Abundant woody debris negatively influenced our ability to collect Western Mosquitofish during our single-pass electrofishing efforts (Angermeier and Karr 1984, Pyke 2005, Crook and Robertson 1999). During subsequent passes, it is possible that these individuals were encountered further from the woody debris or in the downstream block nets. With few exceptions, single-pass electrofishing offered a reliable alternative to the more intensive multiple-pass depletion sampling techniques.

MANAGEMENT IMPLICATIONS

Using a single-pass protocol, we generally obtained representative relative abundance data in approximately three fewer hours per site. Managers can expect to effectively capture the majority of species present with one electrofishing pass in proportions reflective of their estimated abundance when sampling wadeable prairie streams. However, single-pass electrofishing may unreliably detect rare species, and abundance estimates be biased by particular habitats that potentially congregate or facilitate the escape of mobile individuals (Vehanen et al. 2012). Single-pass electrofishing provides a suitable method to rapidly describe occurrence patterns of many species in prairie streams with little habitat diversity, but managers sampling streams with many difficult to sample areas or abundant cover habitats should consider multiple-pass depletion electrofishing methods.

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