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ARTICLE

Quantitative Assessment of Yield, Precision, and Cost-Effectiveness of Three Wetland Invertebrate Sampling Techniques

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Abstract Macroinvertebrates are increasingly used as indicators of wetland integrity and productivity. However, accurate interpretation of biological information depends on effective sampling methods, which are also preferably cost-effective. We compared sampling yield, precision, and cost-effectiveness of two traditional wetland sampling methods (dipnet, stove pipe corer) to a dipnet combined with a dropframe in wetlands in the Platte River Valley, USA. The dropframe method was designed to be more quantitative than standard dipnet techniques and to maximize capture of mobile taxa. We compared measures of macroinvertebrate community structure (e.g., abundance, richness, diversity) and function (functional structure, habitat associations), as well as processing time for each sampling technique in vegetated and non-vegetated habitats. Vegetated habitats harbored higher richness, diversity, abundance, and biomass of most invertebrates. The dipnet consistently yielded the lowest values in vegetated and non-vegetated habitats, suggesting that sampling with a dipnet alone can greatly underestimate macroinvertebrate populations and diversity. The corer and the dropframe yielded similar results, but the dropframe produced significantly higher richness values. While the dropframe appeared to be a good choice for sampling in these wetlands, sample processing times for this method were more than two times longer than the other methods. Results provide a basis for informed decisions regarding quantitative sampling of wetland macroinvertebrates.

Keywords Corer · Dipnet · Diversity · Drop trap · Emergent macrophytes · Riparian · Sampling methods

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Introduction

Macroinvertebrates can be critical to freshwater ecosystem function because they influence vital processes such as organic matter decomposition and nutrient cycling (e.g., Batzer and Wissinger 1996; Wallace and Webster 1996). Macroinvertebrates are also useful indicators of aquatic system health because resident assemblages reflect habitat conditions ranging from water chemistry to thermal and hydrologic regimes (Hilsenhoff 1988, Rosenberg and Resh 1993; Barbour et al. 1999). Thus, sampling and analysis of macroinvertebrate populations can provide valuable insight into freshwater ecosystem integrity.

The usefulness and accuracy of macroinvertebrate datasets for assessing issues such as ecosystem integrity depend on the sampling methods used. Sampling methods for any system must account for the diversity of habitat or substrate types in the system, distributions and sizes of invertebrate taxa, and the motility of the invertebrates. Wetlands in particular pose sampling challenges because of the predominance of soft substrata and vegetation. Some investigators have compared efficiency and associated effort of various sampling methods in wetlands (Kaminski and

Murkin 1981; Murkin et al. 1983; Cheal et al. 1993; Anderson and Smith 1996; Brinkman and Duffy 1996, Turner and Trexler 1997), and these studies have produced somewhat conflicting results, depending on the types of samplers compared and the habitats sampled.

Large-diameter benthic coring devices (e.g., stove pipe corers, ~20 cm diameter), which can sample the water column, vegetation, and substrata, have been used to quantitatively examine wetland invertebrate communities (e.g., Whiles and Goldowitz 2005), but samples collected with these devices require considerable time to process (Batzer et al. 2001). In contrast, samples collected with small diameter sediment corers (e.g., 6–10 cm.) can require much less effort to process, but these generally do not account for water column taxa, highly mobile taxa, and those associated with vegetation. Many investigators have used dipnets in wetland sampling regimes (Batzer et al. 2001), but this method has been criticized for being less quantitative. Also, highly mobile taxa (adult Coleoptera and Hemiptera) can easily evade the net during capture, and burrowing taxa are likely underestimated.

The purpose of this research was to compare the sampling yield, precision, and cost-effectiveness of a dropframe technique (a drop trap combined with a dipnet) that we developed for sampling wetlands in the Platte River Valley (Meyer and Whiles 2008) with two commonly used techniques, a benthic corer and dipnet. Additionally, we compared results of samplers in vegetated and non-vegetated areas. We predicted that the dropframe method would yield samples with higher diversity, abundance, and biomass of macroinvertebrates compared to the other samplers, but might require relatively long processing times.

Methods

Study Region

All samples were collected from a natural, semi-permanent linear wetland slough in the Platte River Valley, located ~15 km southwest of Grand Island, Nebraska (lat. 40°47′ 45.2″N, long. 98°26′39.6″W). This slough was chosen because it has relatively uniform substrata and water depths, thereby providing a large area of homogeneous habitat from which to sample. This wetland slough is part of a large wet-meadow complex located on Shoemaker Island, in Hall County. Wet meadows are large, herbaceous-dominated (e.g., *Carex emoryi* Dewey, *Carex molesta* Mackenzie ex Bright, *Spartina pectinata* Bosc ex Link, *Verbena hastata* L., *Alisma subcordatum* Raf.) mesic grass and sedge complexes with meandering linear sloughs in low-lying areas. Substrata within these sloughs are predominantly sand and silt, and vegetation cover ranges from 0 to 100% (Meyer et al. 2008, 2010). Sloughs in this region range from ephemeral to perennial, depending on evapotranspiration, precipitation, and groundwater connections to Platte River channels (Wesche et al. 1994; Whiles and Goldowitz 1998). Regional climate is temperate (summer daily average temperature=24°C, winter daily average temperature=−7°C).

Benthic Invertebrate Sampling and Processing

During the first week of June 2005, we collected five macroinvertebrate samples with each of three sampling devices, a stovepipe corer, a dipnet, and the dropframe in each of two vegetation types: non-vegetated and vegetated (50–75% vegetative cover of primarily *Schoenoplectus* spp., *Eleocharis* spp., and *Ranunculus* spp.). Because of the morphology of this particular wetland site, water depth was relatively constant between sampling locations and substrata were similar throughout the system. Thus, we are confident that differences in macroinvertebrate metrics are primarily related to differences in vegetation at individual sampling locations. Mesh size (500-μm) was constant among sampler types to avoid size-related sampling bias. We carefully and quickly placed the sampling devices in undisturbed areas of the wetland to decrease the possibility of swimming invertebrates evading capture. Although sampling area differed for each method, we standardized most measures on an areal basis (per m^2).

Sampler Types

Corer The coring device we used was a 90-cm length of 0.6-mm thick tin stovepipe (20-cm diameter, 314-cm^2 sampling area). This device is relatively large in diameter compared to other benthic coring devices used in wetland macroinvertebrate sampling (e.g., 9.8-cm diameter in Cheal et al. 1993), and it samples water-column and vegetation-associated taxa in addition to benthic assemblages. Sampling was achieved by plunging the corer through the water and into the substrata at least 20 cm, which was possible because of the predominance of sand, silt, and soft organic substrata in the wetland. We removed water, substrata, and associated invertebrates and organic materials to a depth of 10 cm with a tin cup (10-cm diameter, 10-cm deep). In rare cases when water refilled the corer during sampling, a small (10 cm by 12.5 cm) 500-μm net was used to remove suspended materials from the water, thereby ensuring that the majority of macroinvertebrates were captured. All materials were placed into a 20-L bucket and poured through a 500-μm sieve. Materials retained on the sieve were washed into plastic

bags and preserved in 8% formalin with phloxine B dye to facilitate sorting.

Dipnet The dipnet method involved sweeping a 500-μm D-frame net (34 cm wide) along the substrate for 0.5 m (distance verified with floating meter stick) while vigorously agitating the substrate. We chose this method based on recommendations of Turner and Trexler (1997), who found that this method yielded high numbers of invertebrates with relatively low inter-sample variability. We rinsed collected materials through the net with clean water and preserved them using the same methods as for the core.

Dropframe In the dipnet coupled with a box-type frame (drop trap) sampling method, the drop trap (43-cm wide, 50-cm long, 100-cm tall frame made from 2.2-cm wide PVC piping, made slightly larger than the net width so that the net could be easily maneuvered, and covered on four sides with 500-μm Nitex™ mesh (Nitex, Geneva, Switzerland)) was used to standardize sampling area and minimize avoidance of the dipnet by highly mobile invertebrate taxa (Hemiptera, adult Coleoptera, etc.). We sampled by agitating the substrate for five horizontal sweeps in alternating (180°) directions. During this process, if the net became clogged with organic matter, it was emptied into a bucket between sweeps. All material was then rinsed (500 μm), and collected materials were preserved using the same methods as for the core.

It should be noted that each sampler type employs different effort (surface area covered, sample depth). However, all three capture water-column taxa, vegetation-associated taxa, and benthic taxa to some extent. Thus, they all may be considered for similar research questions in freshwater wetlands.

Sample Processing

In the laboratory, we rinsed samples through nested sieves to divide them into coarse (>1 mm) and fine (<1 mm, >0.5 mm) fractions. We used dissecting microscopes to separate invertebrates from debris in coarse fractions, and we subsampled invertebrates in fine fractions with a Folsom wheel sample splitter. We identified invertebrates to the lowest practical taxonomic level (generic level for most insects and other taxa; class for oligochaetes and some crustaceans), enumerated them and measured their body length (mm) excluding terminal appendages. We assigned taxa to functional feeding groups and habitat preferences (benthic, water column associated, vegetation associated) based on Merritt and Cummins (1996); Smith (2001), or our knowledge of local fauna. These groups were used to test whether the efficacy of sampler types differed according to behavioral attributes of the taxa. We estimated biomass (ash-free dry mass [AFDM]/m^2) of individuals using length-mass relations (Bottrell et al. 1976; Benke et al. 1999). To avoid experimental bias in the processing time analyses, the same person processed all samples.

Analysis of Macroinvertebrate Data

We tested for main treatment effects (habitat type, sampler type) and interactions (habitat x sampler type) using PROC MIXED (SAS 2003). This procedure uses Satterthwaite's method to estimate denominator degrees of freedom (Littell et al. 1996). Orthogonal contrast statements were used to perform pairwise a priori mean comparisons (α= 0.05, P-values<0.10 are reported because of high variability and low replication). We performed pairwise comparisons of sampling devices (corer vs. dipnet, corer vs. dropframe, dipnet vs. dropframe) within each vegetation type, and we compared vegetation types (vegetated vs. nonvegetated) for each sampling device. Prior to analyses, we log-transformed ($\log_e(x+1)$) data when needed, as determined by PROC UNIVARIATE, to decrease heteroscedasticity and satisfy normality assumptions.

We tested for differences in total abundance, total biomass, total taxon richness, Shannon Diversity (H′, base *e*), and sample processing time. We also tested for differences in abundance and biomass of functional feeding groups as well as abundance and biomass of habitat preference groups. To test for differences at finer taxonomic scales, we compared groups that accounted for a substantial portion (≥4%) of wetland samples, which included Nematoda, Oligochaeta, Gastropoda, Ostracoda, Haliplidae, Dytiscidae, Hydrophilidae, and Chironomidae. To test precision (consistency of results among individual samples) of sampler types, we compared coefficient of variation (CV= measured as ((standard deviation/mean) * 100)) of total abundance, total biomass, average richness, diversity, and processing time.

Community Composition

We used non-metric multidimensional scaling (NMDS) (Minchin 1987) to compare macroinvertebrate community structure based on each sampling type. Ordinations were performed separately for data from vegetated and non-vegetated locations, and for abundance and biomass measures. We standardized the output to unit maxima to give equal weight to each macroinvertebrate taxon. We calculated dissimilarities using the Bray-Curtis Index (Bray and Curtis 1957) and performed the analyses in one to six dimensions, with 100 random starts.

We used analysis of similarity (ANOSIM, Clarke and Green 1988) to test for differences between data from each

sampler type for both abundance and biomass. ANOSIM is calculated by the following equation:

$$R = (r_B - r_W)/(M/2)$$

where r_B = the rank similarity between groups, r_W = the rank similarity within groups, M = n(n-1)/2, where *n* = the number of sampling units. ANOSIM values range from −1 to 1; R approaches 1 if samples are more similar within groups than among groups. We used DECODA software (Minchin 1989) to perform all NMDS and ANOSIM procedures.

Results

Sampler Precision and Cost-Effectiveness

Sample processing time was higher for vegetated samples compared to non-vegetated ($F_{1,24}$=11.6, P=0.002), and also differed by sampler type ($F_{2,24}$=31.7 P<0.001) (Table 1). The corer and dipnet processing times were similar ($F_{1,24}$= 0.7, P=0.423), ranging from 2–5 hrs. per sample (Table 1). Dropframe sample processing time exceeded that of the corer ($F_{1,24}$=42.6, P<0.001) and dipnet ($F_{1,24}$=53.6, P<0.001) by at least 5 h per sample for both habitat types (Table 1).

The CV values associated with macroinvertebrate measures ranged from 10.5 to 60.6 for samples from non-vegetated habitats and 4.8 to 66.1 for vegetated habitats (Table 1). In non-vegetated habitats, the dropframe produced the highest sample CV for total abundance, while CV's for total biomass, richness, and diversity were all highest for dipnet samples (Table 1). In the vegetated habitat, the corer produced the highest CV's for both total abundance and biomass (Table 1). The CV values for richness and diversity in vegetated habitats were highest for the dipnet samples (Table 1).

Sampler Yield: Macroinvertebrate Abundance, Biomass, and Diversity

Total macroinvertebrate abundance differed by habitat ($F_{1,24}$= 10.8, P=0.003) and sampler type ($F_{2,24}$=8.9, P=0.001) (Table 1). Likewise, total macroinvertebrate biomass was more than three times higher in vegetated habitats ($F_{1,24}$= 60.7, P<0.001) and also differed by sampler type ($F_{2,24}$= 11.6, P<0.001) (Table 1). The corer and dropframe yielded similar total abundance ($F_{1,24}$=0.5, P=0.502) and biomass ($F_{1,24}$=0.7, P=0.409), and both consistently captured higher abundance (corer vs. dipnet: $F_{1,24}$=15.6, P<0.001; dropframe vs. dipnet: $F_{1,24}$=10.6, P=0.003) and biomass values (corer vs. dipnet: $F_{1,24}$=20.5, P<0.001; dropframe vs. dipnet: $F_{1,24}$=13.6, P=0.001) than the dipnet (Table 1).

Taxon richness ($F_{1,24}$=162.2, P<0.001) and diversity ($F_{1,24}$=122.8, P<0.001) were both 1.5-2x higher in vegetated habitats than non-vegetated habitats based on all sampling methods (Table 1). Richness estimates differed with sampler type ($F_{2,24}$=20.5, P<0.001), with the dropframe yielding consistently higher richness than either the corer ($F_{1,24}$=37.9, P<0.001) or dipnet ($F_{1,24}$=21.2, P< 0.001). Diversity estimates were similar among sampler types ($F_{2,24}$=0.8, P=0.467) (Table 1).

Individual taxa were consistently more abundant (Table 2) and had higher biomass (Table 3) in vegetated habitats compared to non-vegetated. Abundance (Table 2)

Table 1 Average macroinvertebrate abundance (no./m^2) and biomass (mg ash-free dry mass [AFDM]/m^2), sampling metrics, and processing times of each sampling device in vegetated and non-vegetated habitats of Platte River wetlands. Values are means (1 SE). CV = coefficient of variation. Letters following means denote significant differences between sampler types within a habitat type

Habitat	Core			Dipnet			Dropframe		
	Mean	SE	CV	Mean	SE	CV	Mean	SE	CV
Vegetated									
Total abundance	166,304.0^a	54,933.1	66.1	43,844.1^b	9,252.1	42.2	146,423.9^a	42,580.3	58.2
Total biomass	15,170.9^a	3,665.1	48.3	6,144.1^b	621.8	20.2	15,024.5^a	1,740.2	23.2
Average taxon richness	20.6^a	1.2	11.2	22.2^a	1.4	12.9	31.4^b	0.8	4.8
Shannon diversity (H′)	1.7^a	<0.1	5.4	1.7^a	0.2	18.7	1.5^a	<0.1	6.2
Processing time (hours)	4.9^a	0.6	26.4	3.3^a	0.7	39.9	10.0^b	1.5	29.3
Non-vegetated									
Total abundance	70,265.6^a	13,001.9	37.0	31,913.4^b	6,996.4	43.8	55,303.4^a	13,257.3	47.9
Total biomass	4,833.7^a	423.5	17.5	1,832.2^b	498.7	54.4	3,200.0^a	585.6	36.6
Average taxon richness	9.2^a	0.7	16.1	10.8^a	1.3	24.0	14.4^b	1.0	14.4
Shannon diversity (H′)	1.0^a	0.1	11.2	0.9^a	0.1	20.1	1.0^a	0.1	10.5
Processing time (hours)	2.0^a	0.2	23.4	2.7^a	0.8	60.6	7.9^b	1.0	25.2

Table 2 Macroinvertebrate abundance (no./m^2) captured by each sampler type in vegetated and non-vegetated habitats of Platte River wetlands. Values are means (± SE). Letters following means denote significant differences between sampler types within a habitat type

Taxon	Vegetated						Non-vegetated					
	Core		Dipnet		Dropframe		Core		Dipnet		Dropframe	
Hydra	2,873.6	(2,669.7)^{a}	278.4	(211.2)^{a}	2,500.8	(1,303.7)^{b}	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)
Dugesiidae	0.0	(0.0)^{a}	0.0	(0.0)^{a}	1.9	(1.3)^{b}	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)
Nematoda	17,568.0	(7,050.9)^{a}	4.0	(4.5)^{b}	1,063.9	(953.6)^{c}	249.6	(130.7)^{a}	2.7	(3.0)^{b}	12.1	(3.9)^{c}
Oligochaeta	17,945.6	(8,924.4)^{a}	4,223.8	(576.2)^{b}	18,693.0	(6,057.6)^{a}	2,444.8	(578.2)^{a}	387.6	(106.7)^{b}	2,374.3	(762.6)^{a}
Hirudinea	1,145.6	(382.6)^{a}	53.3	(52.2)^{b}	503.1	(175.0)^{a}	70.4	(44.4)	14.7	(7.6)	28.8	(12.6)
Gastropoda	45,088.0	(13,366.0)^{a}	15,853.5	(5,934.4)^{b}	38,243.5	(10,297.7)^{a}	3,500.8	(696.9)	2,061.9	(648.3)	3,174.1	(955.3)
Bivalvia	524.8	(437.1)	273.1	(194.7)	739.4	(812.3)	0.0	(0.0)	1.3	(1.5)	120.0	(134.1)
Acari	6.4	(7.2)	0.0	(0.0)	0.0	(0.0)	6.4	(7.2)	1.3	(1.5)	1.9	(1.3)
Copepoda	6.4	(7.2)^{a}	191.8	(95.3)^{b}	0.0	(0.0)^{a}	102.4	(114.5)	0.0	(0.0)	0.0	(0.0)
Ostracoda	8,774.4	(4,293.4)^{a}	3,612.4	(1,778.7)^{b}	8,344.9	(3,162.5)^{ab}	19,212.8	(6,297.6)	8,474.2	(1,887.0)	17,065.5	(6,469.9)
Amphipoda	4,537.6	(2,798.9)	895.1	(242.9)	2,145.5	(675.0)	409.6	(457.9)	0.0	(0.0)	0.0	(0.0)
Collembola	409.6	(457.9)	121.2	(133.7)	365.5	(266.6)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)
Coenagrionidae	102.4	(114.5)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	42.6	(47.7)	0.0	(0.0)
Corixidae	0.0	(0.0)^{a}	1.3	(1.5)^{a}	9.3	(2.8)^{b}	25.6	(17.5)^{ab}	6.7	(4.7)^{a}	21.4	(7.5)^{b}
Haliplidae	96.0	(49.3)^{a}	227.8	(120.9)^{a}	844.4	(164.2)^{b}	121.6	(118.3)	10.7	(3.0)	13.0	(4.2)
Dytiscidae	5,657.6	(4,243.9)	1,610.4	(771.3)	2,965.8	(902.7)	57.6	(55.9)	5.3	(1.5)	20.5	(7.5)
Hydrophilidae	160.0	(100.6)	134.5	(109.1)	172.1	(133.6)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)
Hydraenidae	0.0	(0.0)^{a}	1.3	(1.5)^{ab}	3.7	(3.0)^{b}	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)
Pyralidae	0.0	(0.0)^{a}	0.0	(0.0)^{a}	1.9	(1.3)^{b}	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)
Ceratopogonidae	198.4	(119.4)^{a}	25.3	(16.0)^{b}	16.7	(9.7)^{b}	211.2	(103.4)	75.9	(31.4)	212.0	(161.2)
Chironomidae	61,126.4	(20,067.5)^{a}	15,897.4	(3,272.8)^{b}	69,438.5	(23,690.0)^{a}	43,846.4	(8,937.8)^{a}	20,828.5	(6,644.4)^{b}	32,259.8	(8,885.8)^{ab}
Psychodidae	0.0	(0.0)^{a}	0.0	(0.0)^{a}	120.0	(132.8)^{b}	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)
Stratiomyidae	6.4	(7.2)^{a}	16.0	(5.6)^{b}	29.8	(4.8)^{b}	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)
Sciomyzidae	57.6	(32.8)^{a}	309.0	(97.9)^{b}	50.2	(11.8)^{a}	6.4	(7.2)	0.0	(0.0)	0.0	(0.0)
Ephydridae	19.2	(21.5)^{a}	106.6	(106.4)^{a}	167.4	(128.9)^{b}	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)

Table 3 Macroinvertebrate biomass (mg ash-free dry mass [AFDM]/m^2) captured by each sampler type in vegetated and non-vegetated habitats. Values are means (± SE). Letters following means denote significant differences between sampler types within a habitat type

Taxon	Vegetated						Non-vegetated					
	Core		Dipnet		Dropframe		Core		Dipnet		Dropframe	
Hydra	23.6	(21.9)^{a}	2.3	(1.7)^{a}	20.5	(10.7)^{b}	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)
Dugesiidae	0.0	(0.0)^{a}	0.0	(0.0)^{a}	0.2	(0.2)^{b}	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)
Nematoda	12.3	(4.9)^{a}	<0.1	(<0.1)^{b}	0.7	(0.7)^{b}	0.2	(0.1)	<0.1	(<0.1)	<0.1	(<0.1)
Oligochaeta	340.0	(102.3)^{a}	21.2	(5.3)^{b}	110.4	(40.6)^{c}	32.4	(9.6)^{a}	5.9	(1.6)^{b}	22.3	(8.6)^{a}
Hirudinea	98.9	(28.3)^{a}	7.8	(6.7)^{b}	36.7	(8.4)^{a}	55.1	(34.4)	12.0	(6.1)	19.9	(8.1)
Gastropoda	3,125.0	(693.2)	2,493.2	(449.4)	2,479.1	(319.9)	762.5	(174.0)^{a}	350.8	(127.4)^{b}	618.7	(113.8)^{a}
Bivalvia	48.1	(19.7)^{a}	8.7	(4.2)^{b}	18.2	(16.0)^{b}	0.0	(0.0)	0.1	(0.1)	2.4	(2.7)
Acari	<0.1	(<0.1)	0.0	(0.0)	0.0	(0.0)	<0.1	(<0.1)	<0.1	(<0.1)	<0.1	(<0.1)
Copepoda	<0.1	(<0.1)^{a}	0.2	(0.1)^{b}	0.0	(0.0)^{a}	0.1	(0.1)	0.0	(0.0)	0.0	(0.0)
Ostracoda	45.5	(22.3)	18.7	(9.2)	43.3	(16.4)	99.6	(32.7)	43.9	(9.8)	88.5	(33.6)
Amphipoda	487.9	(218.1)^{a}	73.2	(28.6)^{b}	335.3	(127.2)^{a}	6.8	(7.6)	0.0	(0.0)	0.0	(0.0)
Collembola	15.5	(17.4)	3.9	(4.3)	10.0	(6.7)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)
Coenagrionidae	0.5	(0.6)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.2	(0.2)	0.0	(0.0)
Corixidae	0.0	(0.0)^{a}	0.7	(0.8)^{a}	4.4	(1.5)^{b}	9.9	(7.3)	1.5	(1.5)	5.6	(3.2)
Haliplidae	254.8	(123.7)	265.3	(113.5)	641.0	(151.6)	255.4	(123.0)	34.0	(22.6)	80.7	(42.5)
Dytiscidae	8,847.4	(2,480.8)	2,689.1	(750.5)	9,581.5	(1,376.2)	17.6	(17.0)^{a}	13.2	(6.6)^{a}	180.4	(84.7)^{b}
Hydrophilidae	515.7	(227.1)^{a}	169.5	(73.1)^{b}	595.8	(156.7)^{a}	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)
Hydraenidae	0.0	(0.0)^{a}	1.2	(1.3)^{ab}	3.6	(3.6)^{b}	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)
Pyralidae	0.0	(0.0)	0.0	(0.0)	0.1	(0.1)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)
Ceratopogonidae	46.3	(35.8)^{a}	2.5	(1.4)^{b}	4.0	(2.0)^{b}	94.4	(46.2)	31.7	(12.3)	50.3	(33.5)
Chironomidae	1,274.3	(403.7)^{a}	245.1	(83.7)^{b}	1,000.2	(332.3)^{a}	3,493.2	(328.4)^{a}	1,338.8	(466.7)^{b}	2,131.5	(442.6)^{ab}
Psychodidae	0.0	(0.0)^{a}	0.0	(0.0)^{a}	2.4	(2.6)^{b}	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)
Stratiomyidae	6.4	(7.2)^{a}	79.2	(43.0)^{b}	100.5	(23.0)^{b}	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)
Sciomyzidae	27.9	(12.8)	34.4	(8.2)	27.3	(11.2)	6.6	(7.4)	0.0	(0.0)	0.0	(0.0)
Ephydridae	0.7	(0.8)^{a}	6.0	(4.6)^{b}	9.1	(4.4)^{b}	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)

and biomass (Table 3) of individual taxa also varied with sampler type, with the drop frame and corer generally yielding higher estimates than the dipnet.

Sampler Yield: Macroinvertebrate Habitat Preference and Functional Groups

Total abundance values of taxa of all habitat preference types were higher in vegetated habitats compared to non-vegetated (benthic taxa: $F_{1,24}$=8.4, P=0.008; water-column taxa: $F_{1,24}$=80.3, P<0.001; vegetation-associated taxa: $F_{1,24}$=64.3, P<0.001) (Fig. 1). Additionally, total abundance of benthic taxa ($F_{2,24}$=8.6, P=0.002) and water-column taxa ($F_{2,24}$=7.6, P=0.003) differed with sampler type (Fig. 1). In both cases, the corer and dropframe yielded similar numbers, but the dipnet captured significantly fewer benthic taxa (corer vs. dipnet: $F_{1,24}$=14.9, P<0.001; dropframe vs. dipnet: $F_{1,24}$=10.6, P=0.003) and water-column taxa (corer vs. dipnet: $F_{1,24}$=14.9, P<0.001; dropframe vs. dipnet: $F_{1,24}$=5.7, P=0.026) (Fig. 1).

Total biomass of each habitat preference group was higher in vegetated habitats compared to non-vegetated (benthic taxa: $F_{1,24}$=3.6, P=0.069; water-column taxa: $F_{1,24}$=67.8, P<0.001; vegetation-associated taxa: $F_{1,24}$=51.4, P<0.001) (Fig. 1). Biomass of vegetation-associated taxa did not differ with sampler type, but benthic ($F_{2,24}$=7.2, P=0.005) and water-column taxa ($F_{2,24}$=7.2, P=0.004) did (Fig. 1). Each sampler type yielded significantly different biomass estimates of benthic taxa (corer vs. dipnet: $F_{1,24}$=14.4, P=0.001; corer vs. dropframe: $F_{1,24}$=3.3, P=0.082; dipnet vs. dropframe: $F_{1,24}$=3.9, P=0.059) (Fig. 1). The dipnet consistently produced lower estimates of water column taxa biomass than the other two samplers (corer vs. dipnet: $F_{1,24}$=12.0, P=0.002; dipnet vs. dropframe: $F_{1,24}$=9.5, P=0.005) (Fig. 1).

Collector-gatherer abundance did not differ by habitat type, but did differ by sampler type ($F_{2,24}$=9.9, P<0.001)

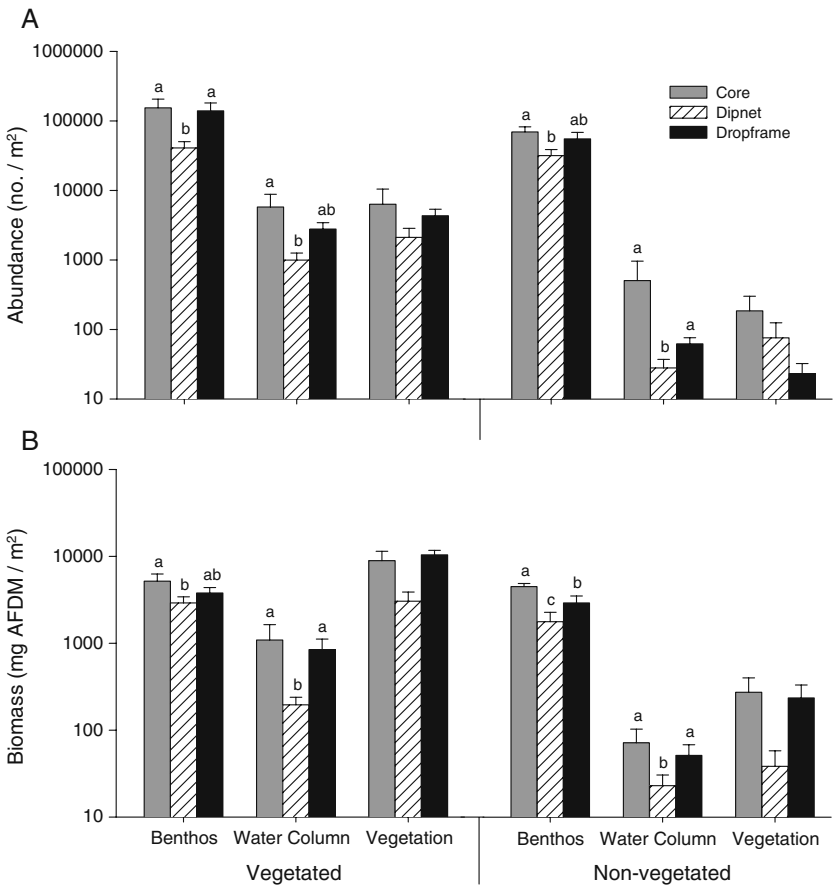

Fig. 1 Mean macroinvertebrate abundance (**a**) and biomass (**b**) (+1 SE) collected by each sampler in areas of dense and sparse vegetation within the same wetland. Macroinvertebrates are grouped according to habitat preference and presented on a log scale. Letters above bars denote significant differences between sampler types for each habitat preference within a habitat type

(Fig. 2). The dipnet yielded consistently lower collector-gatherer abundance estimates than either the corer ($F_{1,24}$=16.3, P<0.001) or the dropframe ($F_{1,24}$=13.2, P=0.001) (Fig. 2). Collector-gatherer biomass was higher in non-vegetated habitats compared to vegetated ($F_{1,24}$=9.8, P=0.005), and also differed with sampler type ($F_{2,24}$=15.1, P<0.001) (Fig. 2). The dipnet yielded consistently lower collector-gatherer biomass than either the corer ($F_{1,24}$=28.3, P<0.001) or the dropframe ($F_{1,24}$=14.8, P<0.001) (Fig. 2).

Collector-filterer abundance, composed solely of sphaeriid clams, was higher in the vegetated habitat ($F_{1,24}$=23.8, P<0.001), but did not differ by sampler type (Fig. 2). Collector-filterer biomass was higher in the vegetated habitat ($F_{1,24}$=35.2, P<0.001), but did not differ by sampler type (Fig. 2). A weak interaction existed between habitat and sampler type in herbivore-piercer abundance measures ($F_{2,24}$=2.5, P=0.105); the dropframe collected higher abundances of herbivore piercers than either the corer ($F_{1,24}$=8.1, P=0.009) or the dipnet ($F_{1,24}$=4.5, P=0.045) in vegetated habitats (Fig. 2). Herbivore-piercer biomass was influenced by an interaction between habitat and sampler type ($F_{2,24}$=3.4, P=0.049); herbivore-piercer biomass collected by the dropframe exceeded that of the corer ($F_{1,24}$=11.9, P=0.002) and the dipnet ($F_{1,24}$=6.9, P=0.015) in vegetated habitats (Fig. 2).

Abundance of predators was considerably higher in vegetated habitats compared to non-vegetated ($F_{1,24}$=107.2, P<0.001), and also differed overall with sampler type ($F_{2,24}$=4.0, P=0.032), with the corer yielding higher abundance than the dipnet ($F_{1,24}$=7.8, P=0.010) (Fig. 2). Predator biomass in vegetated habitats exceeded that of non-vegetated habitats by at least an order of magnitude ($F_{1,24}$=308.7, P<0.001) (Fig. 2). Biomass estimates of predators also differed with sampler type ($F_{2,24}$=13.6, P<0.001), with the dipnet consistently yielding lower estimates than either the corer ($F_{1,24}$=14.5, P=0.001) or the dropframe ($F_{1,24}$=25.0, P<0.001) (Fig. 2).

Scraper abundance, which consisted of *Physa* and *Fossaria* snails, was also higher in vegetated habitats ($F_{1,24}$=63.1, P<0.001) and differed with sampler type ($F_{2,24}$=2.9, P=0.076). The dipnet captured fewer scrapers than either the corer ($F_{1,24}$=4.9, P=0.036) or the dropframe ($F_{1,24}$=3.6, P=0.070) (Fig. 2). Shredder abundance showed an interaction between habitat and sampler type ($F_{2,24}$=2.8, P=0.079), with the dropframe capturing more shredders than either the corer ($F_{1,24}$=8.1, P=0.009) or the dipnet ($F_{1,24}$=4.3, P=0.050) in vegetated habitats (Fig. 2). The

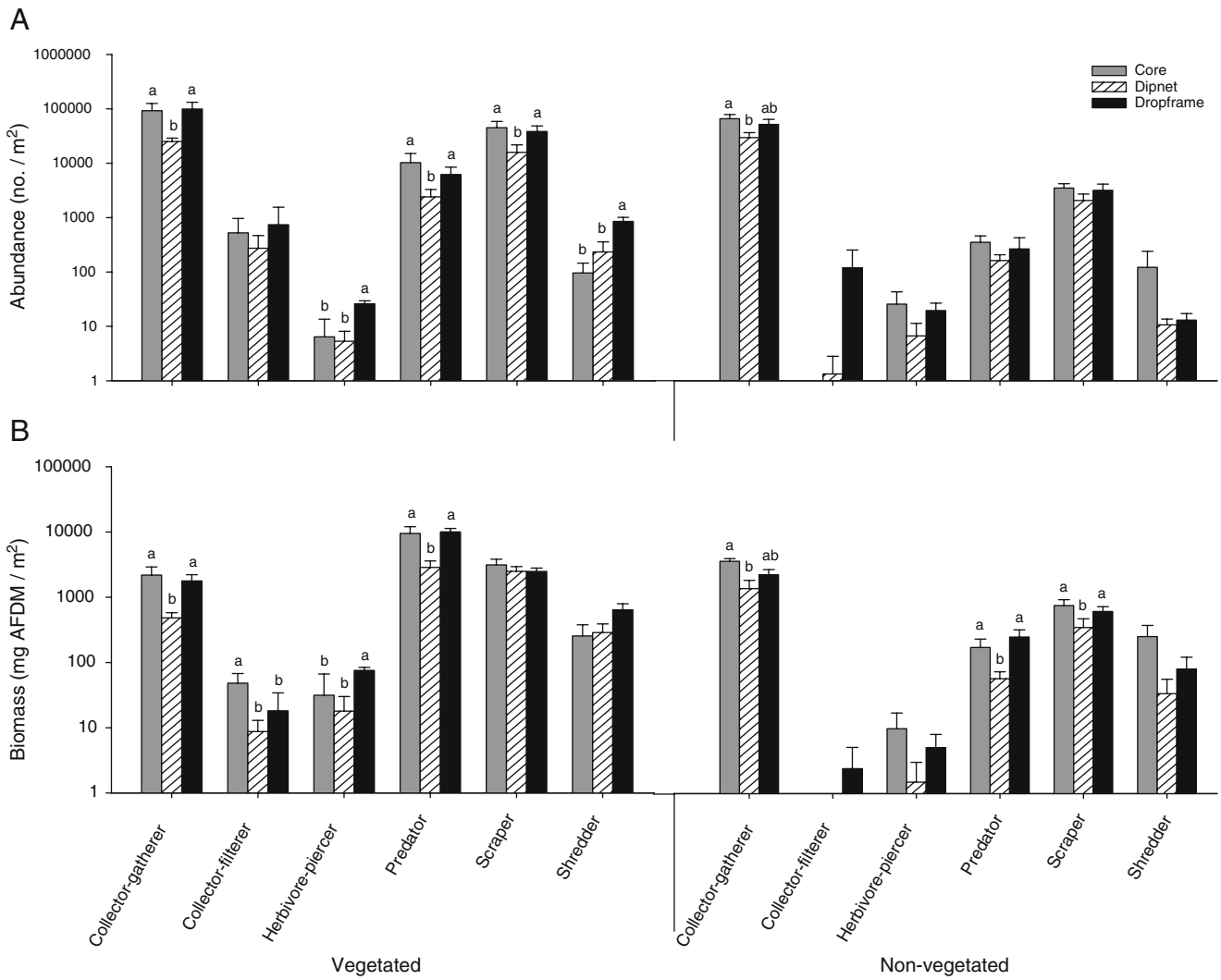

Fig. 2 Mean macroinvertebrate abundance (**a**) and biomass (**b**) (+1 SE) collected by each sampler in areas of dense and sparse vegetation within the same wetland. Macroinvertebrates are grouped according to functional feeding groups and presented on a log scale. Letters above bars denote significant differences between sampler types for each habitat preference within a habitat type

biomass of both scrapers ($F_{1,24}$=65.7, P<0.001) and shredders ($F_{1,24}$=10.5, P<0.004) was highest in vegetated habitats. However, biomass estimates for both groups did not differ with sampler type.

Sampler Yield: Macroinvertebrate Community Structure

Two-dimensional NMDS solutions were used for all ordinations, based on relative decreases in stress from one to two dimensions. The ordination based on total abundance in non-vegetated habitats (stress=0.183) showed separation among sampling types. Additionally, ANOSIM results revealed significant compositional differences based on sampler type (R=0.22, P=0.001) (Fig. 3). Pairwise comparisons showed that the corer samples produced significantly different communities than the other sampler types based on abundance (corer vs. dipnet: R=0.31, P=0.008; corer vs. dropframe: R=0.24, P=0.009; dipnet vs. dropframe: R=0.12, P=0.133) (Table 4). However, the ordination based on total biomass estimates in non-vegetated habitats (stress=0.151) did not show separation among sampler types. Results of ANOSIM also failed to show significant differences among sampler types (R=0.01, P=0.351) (Fig. 3).

Ordination of abundance data from vegetated habitats (stress=0.160) and corresponding ANOSIM results (R=0.24, P<0.001) showed separation among sampler types (Fig. 3). All three sampler types yielded significantly different community composition (corer vs. dipnet: R=0.19, P=0.006; corer vs. dropframe: R=0.24, P=0.009; dipnet vs. dropframe: R=0.20, P=0.008) (Table 4). The ordination based on biomass in vegetated habitats and the ANOSIM (R=0.03, P=0.204) showed no significant differences among sampler types.

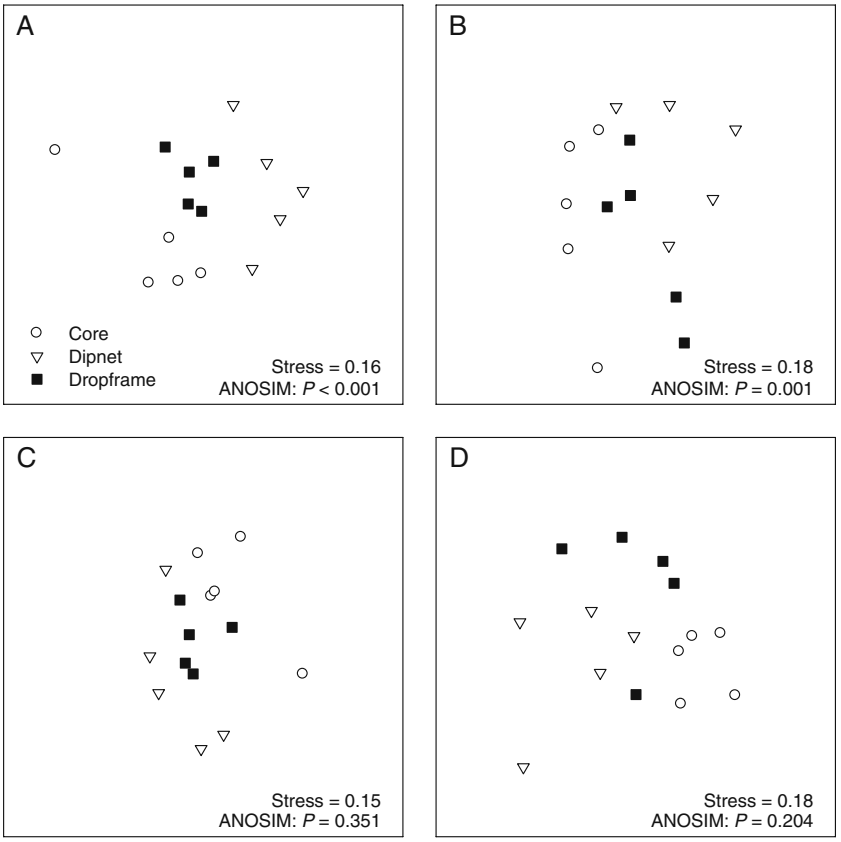

Fig. 3 Non-metric multidimensional scaling (NMDS) ordination of macroinvertebrate community structure using abundance and biomass in vegetated (**a** and **c**, respectively) and non-vegetated (**b** and **d**) habitats. Analysis of similarity (ANOSIM) was used to detect significant differences between sampler types

Discussion

Habitat Differences

Vegetated habitats we sampled had consistently higher macroinvertebrate diversity, abundance, and biomass, including for most individual taxa, as well as functional and habitat preference groups. Vegetation cover and diversity have been shown to affect macroinvertebrate abundance and diversity in freshwater systems, and individual taxa may respond differentially to vegetation presence and type (e.g., Scheffer et al. 1984; de Szalay and Resh 2000; Wright et al. 2002; Kostecke et al. 2005; Davis and Bidwell 2008). Hence, a stratified sampling approach should be considered when differences in vegetation are present.

Positive responses of all habitat preference groups and most functional groups suggest that wetland vegetation can enhance populations of macroinvertebrates through a variety of direct and indirect mechanisms (e.g., food, structural habitat, cover). Collector-gatherer abundance was the only measure that did not differ by habitat type, and the biomass of this group was actually higher in non-vegetated habitats. Collector-gatherer assemblages in both habitats were dominated by non-tanypodine chironomids, and higher chironomid biomass in non-vegetated habitats resulted in the difference in collector-gatherer biomass and indicated larger-bodied midges were present in the open habitats (because abundance did not differ). Although counter to patterns observed in our study and numerous others (e.g., generally positive invertebrate responses to vegetation), this result is in agreement with a recent study in Mississippi River floodplain wetlands, where chironomid biomass, particularly of larger midge taxa, was higher in open habitats compared to vegetated habitats (Flinn et al. 2005).

Table 4 Pairwise comparisons showing differences in macroinvertebrate community structure collected by each sampler in both habitat types as measured by non-metric multidimensional scaling (NMDS). Comparisons made using analysis of similarity (ANOSIM)

	Vegetated R, (*P*)	Non-vegetated R, (*P*)
Abundance		
Core × Dipnet	0.19, (0.006)[a]	0.31, (0.008)[a]
Core × Dropframe	0.24, (0.009)[a]	0.24, (0.009)[a]
Dipnet × Dropframe	0.20, (0.008)[a]	0.12, (0.133)
Biomass		
Core × Dipnet	0.05, (0.225)	0.06, (0.169)
Core × Dropframe	0.02, (0.220)	0.09, (0.108)
Dipnet × Dropframe	0.08, (0.092)	−0.08, (0.632)

[a] denotes significant differences between sampler type

Given the importance of larger-bodied midges as prey for target management species such as fishes and waterfowl (Batzer et al. 1993), their apparent preference for open habitats in floodplain wetlands along the Platte and the Mississippi warrants further investigation and experimentation to identify mechanisms. Because our study included low sample size and limited temporal scope, more intensive investigations may be warranted to more thoroughly understand macroinvertebrate responses to vegetation in these systems.

Sampler Precision and Cost-Effectiveness

Because wetland macroinvertebrate sampling is time and labor-intensive, and time is money, an important consideration in any comparison of sampler types is processing times. The dropframe samples were substantially more laborious to process than the other samples. This occurred because samples taken with the dropframe were substantially more voluminous than both other methods. Higher volume in samples resulted from a dropframe sampling area that exceeded that of the corer by almost seven-fold and the dipnet by 1.3-fold, and also because a single sweep with the dipnet yielded much less organic material and substrata than did multiple sweeps with the dropframe. Sampler comparisons in the Florida Everglades showed that samples taken with stovepipe corer took 6 h and dipnet samples took 4 h to process (Turner and Trexler 1997). These processing time estimates were higher than ours, perhaps because Turner and Trexler (1997) used a larger-diameter stovepipe corer, and possibly due to habitat-related differences between our study site and theirs (e.g., differences in amount of algae, organic materials, etc.). Nonetheless, results of their investigation and ours indicate that some methods require substantial processing time, which may be prohibitive for poorly funded investigations. Likewise, those initiating investigations of wetland invertebrates should be aware of time required to process samples collected with the most effective sampling devices.

The precision of various types of samplers is another important consideration, as this is related to variability estimates and ultimately influences power and outcomes of statistical tests. Measures of aquatic macroinvertebrate abundances and biomass are notoriously variable, and thus any procedures that can minimize variability are desirable, as long as effectiveness is not compromised. The CV values we generated indicated the dropframe produced the most variable abundance estimates in non-vegetated habitats, but the dipnet produced higher variability in most cases. In vegetated habitats, abundance and biomass measures were most variable with the stovepipe corer, and richness and diversity measures were most variable with the dipnet. Taking all comparisons into account, stovepipe corer samples were most precise, followed by the dropframe and then the dipnet, although CV values were highly dependent on habitat type.

Variability estimates in our study were low compared with other published estimates using similar sampling devices. Turner and Trexler (1997) estimated that CVs of eight sampling devices used in the Florida Everglades ranged from 43 to 211%. Their estimates for stovepipe corers and dipnet (sweep net) samples were 76 and 56, respectively, which are slightly higher but within the range of our estimates for the same samplers. The slightly higher CVs of Turner and Trexler's study (1997) may be related to differences in vegetation or structural characteristics between Florida Everglades and Platte River wetlands.

Sampler Yield

The purpose of the dropframe technique was to develop a quantitative technique with high yield, especially for highly mobile taxa such as adult beetles and bugs that might evade capture by other methods. Thus, we expected abundance, biomass, and diversity measures produced with the dropframe to exceed those of the other methods, particularly for taxa in the water column habitat group. While the dropframe yielded the highest richness values, dropframe and corer samples were equivalent in most other measures, including abundance and biomass of water column taxa. This is surprising, considering that the corer has a much smaller sampling area and samples deeper in the substrata than the dropframe. However, measures of specific water column taxa, including dytiscid biomass and haliplid abundance, were highest with the dropframe. These results indicate that the level of taxonomic resolution required and the target assemblages of a given investigation should be considered when selecting sampling methods; if accurate measures of individual water column taxa are required, a dropframe or similar sampling device may be preferable.

Perhaps it is not surprising that the dropframe and corer yielded more macroinvertebrates than the dipnet, because substantially less effort is involved in dipnet sampling. However, relatively low yield of the dipnet in our study is an important consideration given the widespread use of dipnet sampling in studies of wetland macroinvertebrates (Batzer et al. 2001). Lower yield in dipnet samples in the current study is also important because of evidence of the effectiveness of dipnets in other comparison studies. For example, Turner and Trexler (1997) compared eight active and passive collecting techniques and found that dipnet and stovepipe methods yielded the highest diversity and lowest variability of all methods chosen. Kaminski and Murkin (1981) found no differences in capture between a dipnet (referred to as a sweep net in their study) and a box trap (similar to our dropframe), although they considered only

nektonic invertebrates. Cheal et al. (1993) found that a sweep net consistently produced higher richness values than either a benthic corer or plankton net. However, large differences in relative sample area (e.g., 9.8-cm dia. cores vs. 10-m net sweeps) likely inflated differences between dipnet and corer estimates. The effectiveness of various sampler types likely varies with specific wetland habitats; in Platte River floodplain wetlands and similar systems, we caution against the use of dipnet sampling without a dropframe (and multiple sweeps per sample), because of the likelihood of greatly underestimating invertebrate abundance, biomass, and diversity.

Sampler type may influence the suite of taxa sampled from a given wetland. Our ordinations revealed that community composition based on abundances was affected by sampler type, while biomass-based estimates showed no differences. Although we found no other studies that used biomass-based ordinations to compare wetland macroinvertebrate community composition, Turner and Trexler (1997) also found that taxonomic composition based on abundances differed substantially with sampler type. Thus, if a particular group of invertebrates is targeted, sampler choice should be based on the relative yield for that group. If the goal is a comprehensive survey of taxa, employing multiple sampler types may improve results (see Turner and Trexler 1997). If the goal is to compare communities between sites, plots, treatments, etc., other factors may weigh heavily in the decision of sampler type.

Conclusions

The final choice of sampler type should be based on the specific goals and hypotheses of a given study, and should account for sampler yield, precision, and cost-effectiveness, as well as type of habitats sampled and target taxa, functional groups, etc. Although, as suggested by previous authors, it would be ideal for wetland studies to incorporate multiple sampler types (see Turner and Trexler 1997), it may be cost-prohibitive for researchers with time or budgetary constraints to employ more than one sampling device. In these cases, it would greatly benefit researchers to be informed of sampler yield, precision, and cost-effectiveness of possible sampler choices. We found that the dropframe and benthic corer yielded consistently similar, higher estimates of various common measures of macroinvertebrate populations and diversity. If accurate richness and/or sampler precision is a prime concern, the dropframe method appears preferable. However, the relatively long processing time of dropframe samples might be a deterrent, in which case benthic stovepipe corers may be a better option. Further, our ordinations suggested different samplers target different components of invertebrate assemblages, and thus use of multiple sampler types may be best if a comprehensive analysis of communities is an objective.

Regardless of individual project goals, we have shown that use of a dipnet without the aid of a dropframe yields consistently low estimates of invertebrate populations and diversity in both vegetated and non-vegetated habitats of Platte River wetlands. We therefore caution that single-sweep dipnet sampling, despite evidence of its relative effectiveness when sampling for abundance-based measures in some systems, may significantly underestimate richness and biomass-based measures of aquatic macroinvertebrates in others. Ultimately, pre-testing samplers in a target habitat might be the best approach.

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