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Taxonomic and functional group composition of macroinvertebrate assemblages in agricultural drainage ditches

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Abstract Aquatic macroinvertebrates in drainage ditches may alter rates of nutrient cycling and decomposition of organic matter but have not been accounted for in studies of ditch biogeochemistry. We collected sediment cores from four pairs of field (intermittent) and collection (perennial) ditches on Maryland's Eastern Shore monthly from March 2011 to February 2012 to determine how taxonomic and functional group composition varies among different ditch types. We identified 138 taxa and assigned them to functional groups according to trophic position and modes of burrowing. There was no difference in mean abundance of invertebrates (5821 ind./m^2) between seasons or types of ditches, and species richness peaked in winter (20 taxa/site) compared to other seasons (15 taxa/site), but did not vary between ditch types. Assemblage composition differed between field and collection ditches, but functional group composition did not. Field ditches flow intermittently which may limit the assemblage to early colonists and taxa adapted to survive desiccation. The benthic macroinvertebrate assemblage was dominated by the collector–gatherer functional feeding group (83.6%) and burrowing taxa (97.1%). Bioturbation by burrowing macroinvertebrates is likely an important process contributing to ecosystem-scale functions of drainage ditches, including regulation of biogeochemical processes occurring at the sediment–water interface.

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Introduction

In densely agricultural areas, extensive drainage networks often replace natural headwaters, and serve as conduits for delivering agricultural pollution to larger streams and rivers (Carpenter et al., 1998; Dukes & Evans, 2006; Blann et al., 2009). Drainage ditches are an important component of farming infrastructure for managing soil moisture by enhancing drainage in areas where flat topography and a high water table would otherwise inundate plant roots and cause stress to crops. The interface between ditch sediments and overlying water is an active site of biogeochemical transformations of chemicals such as nitrogen, phosphorus, and pesticides entering into

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ditches (Nguyen & Sukias, 2002; Cooper et al., 2004; Needelman et al., 2007b; Sharpley et al., 2007; Kröger et al., 2008; Shigaki et al., 2008). Therefore, the biogeochemical processes occurring at this interface can control whether pollutants are stored, transformed, or released in water draining from agricultural lands (Hill & Robinson, 2012; Kröger et al., 2013; Usborne et al., 2013).

Drainage ditches also provide habitat to many aquatic species (Williams et al., 2003; Davies et al., 2008; Verdonschot et al., 2011; Leslie et al., 2012). Feeding by aquatic macroinvertebrates can modify rates of transformations and transport of organic matter through aquatic ecosystems, and therefore can have effects on stream function and water quality (Vanni, 2002; Covich et al., 2004). The composition of functional feeding groups (FFGs) in the assemblage may respond to gradients in environmental conditions, and may indicate changes in the functions of stream ecosystems (Vannote et al., 1980; Cummins et al., 2005). Feeding by different functional groups of macroinvertebrates may have similar impacts on ecosystem function such as the breakdown and transport of organic matter in drainage ditches.

Drainage ditches support assemblages of burrowing species that live within the sediment–water interface (Painter, 1999; Langheinrich et al., 2004, Simon & Travis, 2011; Leslie et al., 2012). Bioturbation from burrowing behaviors alters the availability of food resources to below-sediment microbes, changes biogeochemical gradients within sediments, and impacts recruitment of species persisting in dormant stages below the sediment surface in aquatic habitats (Mermillod-Blondin & Rosenberg, 2006; Meysman et al., 2006). In ditches, bioturbation by benthic invertebrates could alter rates of exchange of phosphorus between the sediment and water, denitrification by anaerobic bacteria, decomposition of organic carbon, and suspension of sediment particles. These effects could alter rates of transport and delivery of these materials from agricultural catchments to receiving waters downstream.

Drainage ditch networks are often arranged such that shorter field ditches convey water to longer collection ditches that run between multiple properties (Fig. 1). Field ditches may only hold water following storm events or during periods of seasonally high water table, while collection ditches tend to hold water perennially. Field ditches have a smaller drainage area, and can be

the primary pathway of sediment and nutrients entering the watershed. Collection ditches receive inputs from multiple fields, and can deliver sediment and nutrients to larger receiving waters. In the United States, perennial collection ditches may fall under the jurisdiction of the Clean Water Act, and are subject to water quality regulations, while field ditches are generally exempt from regulation and are treated as farming infrastructure (Grumbles, 1991; ACOE & EPA, 2015). Differences in hydrology and other environmental factors between field and collection ditches could provide an abiotic filter to certain species in the benthic invertebrate assemblage. If macroinvertebrate assemblages differ between different types of drainage ditches, then effects of the benthic assemblage on nutrient cycling and other exchanges across the sediment–water interface may differ as well. Understanding functions of the benthic macroinvertebrate community in ditches could help to manage or mitigate transport of sediment and nutrients from agricultural sources.

The overall goal of this study was to identify patterns in the structure and function of sediment-dwelling macroinvertebrate assemblages in agricultural drainage ditches. We sampled a range of field and collection ditches in an intensively farmed region of Maryland's Eastern Shore across seasons to characterize spatial and temporal differences in the macroinvertebrate assemblage between two types of ditches. We also characterized physical and chemical variables in ditches to determine differences in environmental conditions between different types of ditches. Our hypothesis was that differences in physical and chemical conditions between different types of ditches determine the structure of the macroinvertebrate assemblage and that functional group composition also changes along with taxonomic composition. Further, we hypothesized that habitat conditions change across seasons in different ways between different types of ditches. As a consequence of field ditches drying down completely in summer while collection ditches retain standing water throughout the year, we also expect more turnover in the composition of the macroinvertebrate assemblage in field ditches compared to collection ditches.

Methods

We chose four farm sites within the Choptank watershed in Caroline County on the Eastern Shore

Fig. 1 Map of Maryland's
Eastern Shore, with insets
showing ditch sites in
Caroline County and a
field/collection ditch pair
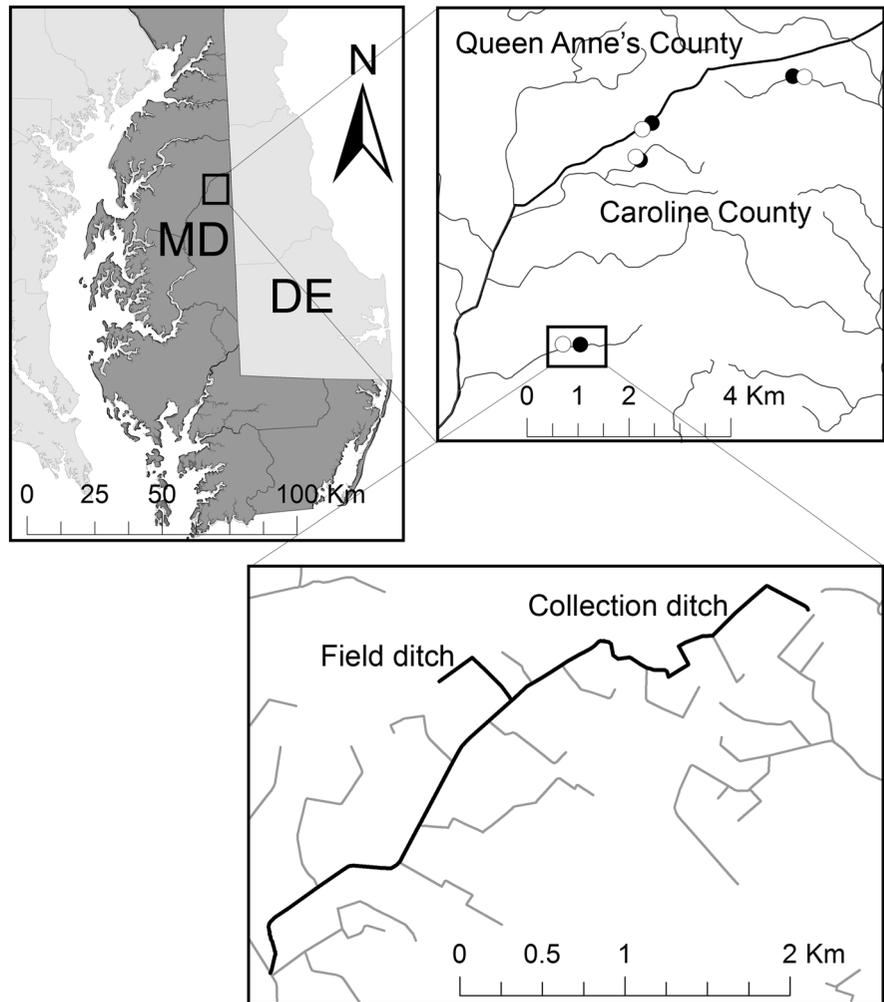
of Maryland to survey (Fig. 1). Much of Maryland's Eastern Shore is characterized by flat topography and a high water table, which creates naturally poorly drained soils that could not support field crops without artificial drainage. Corn and soybeans are the two field crops that comprise the majority of agriculture in Caroline County, and are grown principally as feed for the region's poultry industry. According to the U.S. Department of Agriculture's National Agricultural Statistics Survey, 34,600 ha were planted with corn or soybeans in Caroline County in 2011, comprising 41% of the county. At each farm, one field ditch and one collection ditch were sampled repeatedly on a monthly basis over the course of a year from March 2011 to February 2012. All ditches were maintained by mowing to prevent establishment of weeds and woody vegetation. All ditches supported aquatic vegetation,

such as rice cutgrass (*Leersia oryzoides* (L.) Sw.), common reed (*Phragmites australis* (Cav.) Trin.), and various aquatic sedges (Cyperaceae), but there were no consistent differences in vegetation composition between ditch types. A 50-m reach was demarcated for repeated sampling at both ditch types at each farm. No sampling reach was downstream of another. Sampling was only performed when the ditch contained standing water, which prevented the inclusion of terrestrial macroinvertebrate species.

Measurements of environmental variables were selected to broadly quantify physical and chemical differences between the types of drainage ditches. Specific conductivity was measured at a single downstream point using a handheld meter (YSI 30, YSI Inc., Ohio, USA). A 250 mL water sample was taken from this point and returned on ice to the laboratory to

measure pH (Corning 340, Corning, New York, USA). Wetted width, maximum depth, and flow velocity (Flow Mate Model 200, Marsh McBirney Inc., Colorado, USA) were measured every 10 m along the sampling reach. Sediment and water nutrient levels were not found to be significantly related to macroinvertebrate community composition by Leslie et al. (2012), and were therefore not included in the study. Similarly, dissolved oxygen and temperature were expected to show diel fluctuations, and therefore point measures of these variables would be meaningless for analysis.

Quantitative samples of aquatic invertebrates were collected from sediment cores. A steel ring (18 cm diameter by 5 cm deep) was pushed into the substrate and excavated with a shovel to produce a sediment sample of a fixed volume. Three replicate samples were taken from each ditch on each sampling date. Sample locations within a reach were randomized for each sampling date. For analyses, data from replicate samples for each ditch and date were combined into a single composite sample. Sediment cores were kept in the lab in separate bins with filtered and aerated ditch water to keep macroinvertebrates alive until processing. Sediment cores were rinsed through stacked 4 and 0.5 mm sieves to remove fine sediments. A 0.5-mm sieve was chosen to optimize speed and efficiency of processing large samples, while still retaining many small-bodied organisms. Invertebrates that passed through the sieve were not counted. Coarse, particulate organic matter (CPOM) was removed, dried, and measured as the mass lost on ignition of material retained within the 4-mm sieve. Macroinvertebrates were removed without magnification and stored in 80% ethyl alcohol prior to identification to lowest practical taxonomic units, most to genus or species. Chironomidae larvae and oligochaetes were subsampled such that at least 20% of each morphotype was slide-mounted for identification.

Taxa were assigned to different functional groups based on their functional feeding group and functional bioturbation group based on Stribling et al. (1998), Barbour et al. (1999), Millard et al. (2001), Merritt et al. (2008), and Buchanan et al. (2011). When multiple feeding groups were listed for a single taxon, the primary designation was used. Burrowing modes were chosen from the 3 following categories: (1) 'biodiffusors' randomly scatter surficial sediments, (2) 'conveyors' feed at depth and deposit sediment at the surface, and (3) 'gallery diffusors' build networks of burrows that are actively irrigated (Gerino et al., 2003). Burrowing modes were determined from listed habits for each taxon. Taxa listed as having a sprawling habit are associated with the sediment surface, but do not necessarily excavate defined burrows, and were assigned to the biodiffusor category (e.g., the isopod, *Caecidotea*). Deposit-feeding taxa with a burrowing habit were assigned to the conveyor category (e.g., the oligochaete worm, *Limnodrilus hoffmeisteri* Claparède). Burrowing taxa that feed within their burrows (i.e., collector–gatherer or filter feeder) were assigned to the gallery diffusor category (e.g., larvae of the midge, *Chironomus*). Burrowing taxa that do not feed within burrows (e.g., predators or shredders) were assigned to the biodiffusor category (e.g., larvae of the horse fly, *Tabanus*). Taxa with habits other than burrowing or sprawling were listed as non-burrowers.

We used ANOVA of linear mixed-effects models to test for differences in environmental parameters (pH, flow velocity, specific conductivity, water depth, water width, and CPOM), as well as abundance and taxon richness between field and collection ditches across seasons, using ditch type and season as fixed factors and farm and ditch type as random factors to account for site differences and repeated measures. Macroinvertebrate assemblage and environmental data were pooled across months to give mean seasonal values (Mar–May = spring, Jun–Aug = summer, Sep–Nov = fall, Dec–Feb = winter). We weighted response variables to account for differences in the number of observations contributing to seasonal values when ditches were dry.

We calculated the loss and/or addition of taxa and functional groups (i.e., turnover) before and after summer dry periods to determine whether field ditches experience more turnover across seasons as a result of drying. Jaccard dissimilarity of taxonomic and functional group composition was calculated for all ditches between the last month when all field ditches held water and the first month when all field ditches were refilled from precipitation. To focus the analysis on the persistence and turnover of taxa and functional groups, abundances were transformed to presence–absence data. We used a paired *t* test to determine whether dissimilarity values were higher in field ditches than collection ditches.

We used Dufrêne–Legendre indicator species analysis (IndVal) to determine which taxa tend to be

significantly associated with either field or collection ditches (Dufrêne & Legendre, 1997). This analysis uses the frequency and abundance of taxa in each type of ditch to determine whether the presence and abundance of a species is significantly greater in one type of habitat than the other.

We used distance-based redundancy analysis (dRDA) to determine the effect of ditch type and season on macroinvertebrate assemblage and functional group composition. We calculated a Bray–Curtis dissimilarity matrix for the macroinvertebrate assemblage and functional groups, and ditch type and season were used as explanatory factors in the multivariate models. Farm site was included as a conditional term in the models to account for similarity of pairs of ditches on a single farm. We excluded rare taxa found in only a single sample from these analyses. We used Monte Carlo permutations to test for the significance of the two factors ($\alpha = 0.05$).

All statistical analyses were performed using the statistical program R 3.1.0 (R Core Team, 2014). Linear mixed-effects models were written using the package *nlme* (Pinheiro et al., 2014) and ANOVAs were performed using the *car* package (Fox & Weisberg, 2011). Matrices of contrast coefficients were built using the package *contrast* (Kuhn et al., 2013) and multiple means comparisons were performed using the package *multcomp* (Hothorn et al., 2008). Indicator species analysis was performed using the package *labdsv* (Roberts, 2013). dRDA and Monte Carlo permutations were performed using the package *vegan* (Oksanen et al., 2013). Graphics were produced using the package *ggplot2* (Wickham, 2009).

Results

Environmental measures

There was a significant effect of season on ditch pH (Wald-$\chi^2 = 61.87$, df $= 3$, $P < 0.001$) with no effect of ditch type, and a significant interaction between season and type (Wald-$\chi^2 = 8.10$, df $= 3$, $P = 0.044$). Within field ditches, pH was slightly higher in winter than other seasons. In collection ditches, pH was the same through spring and summer, then dropped in the fall, and increased slightly in the winter (Fig. 2A). Across all sites and seasons, the range in pH values was 5.4–6.9. There were significant effects of season (Wald-$\chi^2 = 37.79$, df $= 3$, $P < 0.001$) and ditch type (Wald-$\chi^2 = 13.66$, df $= 1$, $P < 0.001$) on flow velocity (Fig. 2B). Flow velocities were significantly lower in field ditches than collection ditches, and significantly lower in summer compared to other seasons. There was a significant effect of season (Wald-$\chi^2 = 10.17$, df $= 3$, $P = 0.017$) but not ditch type on specific conductivity (Fig. 2C). Specific conductivity is higher in summer than spring, but does not differ among other seasons. There was a significant effect of season (Wald-$\chi^2 = 7.79$, df $= 3$, $P = 0.051$) but not ditch type on mean water depth (Fig. 2D). Ditches have deeper water in fall than spring, but depth does not differ among other seasons. There was a significant effect of ditch type on mean wetted width (Wald-$\chi^2 = 10.05$, df $= 1$, $P = 0.002$), with collection ditches being wider than field ditches across all seasons (Fig. 2E). There was a significant effect of ditch type on CPOM collected with sediment cores (Wald-$\chi^2 = 22.35$, df $= 1$, $P < 0.001$) and there was also a significant interaction with season (Wald-$\chi^2 = 16.32$, df $= 3$, $P = 0.001$). Pairwise comparison of ditch types across seasons shows that field ditches have more CPOM than collection ditches in summer, fall, and winter, but not spring (Fig. 2F).

Assemblage and functional group composition of field and collection ditches

A total of 261 individual sediment cores were collected, yielding 138 macroinvertebrate taxa, spanning 6 phyla, with a total of 40,570 individuals (Supplementary Material). Most taxa (96) were within the class Insecta, among which 54 taxa were in the order Diptera, and of those, 36 were genera of the family Chironomidae. There were 42 non-insect taxa collected, which comprised 72.2% of the total abundance of macroinvertebrates collected. The majority of the assemblage (90%) was dominated by the 13 most abundant taxa (Table 1). ANOVA showed that taxon richness and macroinvertebrate abundance did not differ between field and collection ditches (Fig. 3). There was a significant effect of season on taxon richness (Wald-$\chi^2 = 15.48$, df $= 3$, $P = 0.001$) but not abundance. Taxon richness was significantly higher in winter than other months with a mean of 20 taxa (range 12–29) compared to 15 taxa (range 3–29) in other seasons (Fig. 3B). The overall mean abundance per ditch was 5821 ind./m^2 (range 336–29,490 ind./m^2; Fig. 3A).
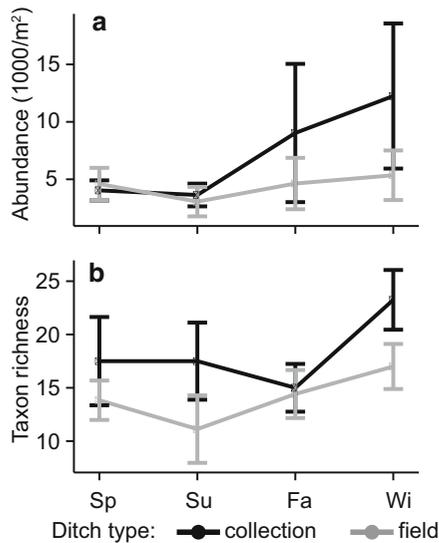
Fig. 2 Summary of environmental variables measured over seasons for field and collection ditches. Means are calculated from 12 observations (4 site means × 3 months within each season); total observations for field ditches were 10 in spring and 5 in summer due to dry periods. *Error bars* represent ±1 SEM. *Sp* spring (Mar–May), *Su* summer (Jun–Aug), *Fa* fall (Sep–Nov), *Wi* winter (Dec–Feb)
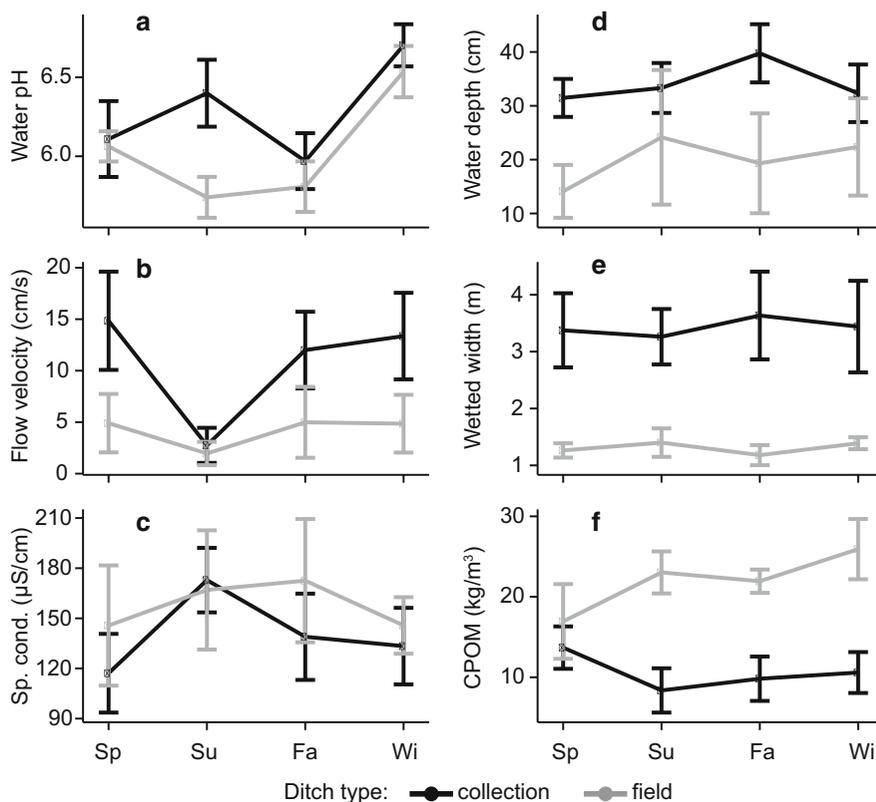
Table 1 Top 13 most abundant macroinvertebrate taxa, which comprise 90% of the entire ditch benthic assemblage. Abundance measures are the mean density of individuals of that taxon collected across all samples from each type of ditch

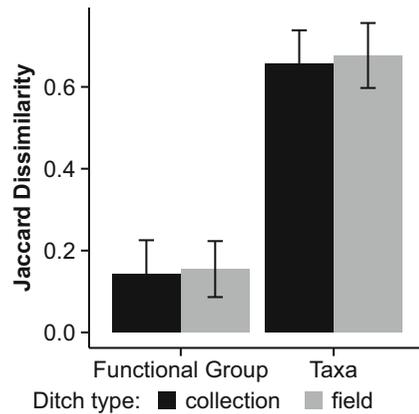| Taxon	Abundance (indv./m²)	
	Collection	Field
Order Diptera		
Chironomus	2156.7*	29.9
Cricotopus	72	91.7
Order Amphipoda		
Crangonyx	9.3	240.8*
Gammarus	100.4*	10.4
Order Isopoda		
Caecidotea	105.9	1303.5*
Order Veneroida		
Pisidium	167.6	429.6*
Musculium	292.8*	7.7
Class Oligochaeta		
Limnodrilus hoffmeisteri Claparède	2061.8	1497.3
Ilyodrilus templetoni Southern	1274.2*	31.2
Spirosperma nikolskyi Lastockin & Sokolskaya	1.9	456.1*
Dero digitata Müller	97.4	40.6
Isochaetides curvisetosus Brinkhurst & Cook	65.2	61.1
Eclipidrilus fontanus Wassel	17.7	61.1

* Represents significant association of taxon with ditch type (α = 0.05) based on indicator species analysis
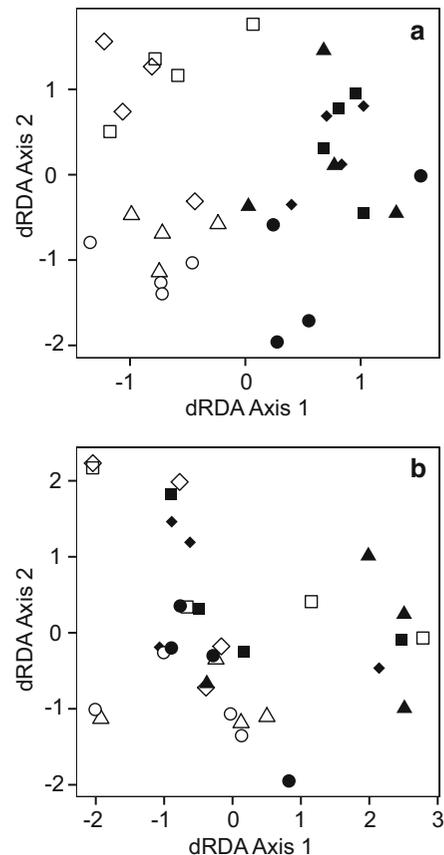
Fig. 3 Summary of **A** abundance and **B** richness measured across seasons for field and collection ditches. Means are calculated from 12 observations (4 site means × 3 months within each season); total observations for field ditches were 10 in spring and 5 in summer due to dry periods. *Error bars* represent ±1 SEM. *Sp* spring (Mar–May), *Su* summer (Jun–Aug), *Fa* fall (Sep–Nov), *Wi* winter (Dec–Feb)

Fig. 4 Turnover in taxa and functional groups in field and collection ditches following dry periods. *Error bars* represent ±1 SEM

Collection ditches retained water throughout the year, allowing continuous sampling. All field ditches were dry for at least 1 month during the summer: two were dry during sampling dates in May through July, one was dry from June through July, and one was only dry for the July sample date. All field ditches held water for the August sample date following heavy precipitation from a hurricane that passed through the area. A paired *t* test shows that dissimilarity of taxonomic composition of sites between April and August does not differ between field and collection ditches ($t = 0.63$, df $= 3$, $P = 0.57$) (Fig. 4). Turnover in functional groups between this time period was also not affected by drying ($t = 0.2$, df $= 3$, $P = 0.85$).

Multivariate ordination of the burrowing invertebrate assemblage shows that field and collection ditches tend to separate from one another along the first constrained axis (Fig. 5A). Monte Carlo permutation showed a significant difference in macroinvertebrate assemblage composition between field and collection ditches ($F = 4.45$, df $= 1, 24$, $P = 0.01$), but no significant effect of season on assemblage composition ($F = 0.95$, df $= 3, 24$, $P = 0.55$). Ditch type correlated with the first constrained axis, which accounted for 14.4% of the total variance in the

Fig. 5 dRDA biplot of **A** ditch sites by taxa and **B** sites by functional groups with ditch type and season as explanatory variables. Points represent site scores for field (*closed*) and collection (*open*) ditches across seasons (*circle* spring, *triangle* summer, *square* fall, *diamond* winter)

assemblage dissimilarity matrix. Results of the IndVal analysis showed 21 taxa are significantly associated with collection ditches, and 15 taxa associated with field ditches (Supplementary Material). Table 1 shows associations of the top 13 most abundant taxa with the two classes of ditches. Of the top 13 most abundant taxa, four taxa are significantly associated with collection ditches, while five taxa are significantly associated with field ditches. The remaining four taxa were equally associated with both classes of ditch, including the most abundant species (*L. hoffmeisteri*).

After assigning all taxa from the assemblage dataset to functional groups, the site-by-taxa table of 138 taxa was distilled to nine functional groups for feeding and burrowing. The ditch benthic assemblage was dominated by taxa in the collector–gatherer functional feeding group (83.6%), followed by collector–filterers (7.9%), predators (3.8%), shredders (3.2%), and scrapers (1.5%). Nearly all (97.1%) of the benthic assemblage had burrowing habits, which were divided into conveyors (49.5%), gallery diffusors (29.6%), and biodiffusors (18.0%). Multivariate ordination of functional groups does not reveal discrete grouping based on ditch type or season (Fig. 5B). Monte Carlo permutations found no significant effect of ditch type ($F = 1.67$; df = 1, 24; $P = 0.22$) or season ($F = 1.23$; df = 3, 24; $P = 0.16$) on functional group composition.

Discussion

Drainage ditches are an important part of farming infrastructure for managing soil moisture, yet also serve as a habitat for aquatic organisms and as a tool for regulating transport of agrochemicals to regional watersheds (Herzon & Helenius, 2008). The objective of this study was to determine the taxonomic and functional group composition of benthic invertebrates in ditches, and to determine differences in the assemblage between ditch types and seasons to determine potential roles that invertebrates play in transport and transformation of chemicals in ditches. We found that benthic macroinvertebrate assemblages in drainage ditches are dominated by generalist collector–gatherers, which have the potential to affect decomposition of fine-particulate organic matter (FPOM) and carbon availability within the sediment (Wallace & Webster, 1996). Most of the macroinvertebrate assemblage in ditches is capable of bioturbation, or the physical

disruption of aquatic sediments, which can alter the exchange of materials between the sediment and surface water (Meysman et al., 2006). Although field and collection ditches support different taxonomic assemblages, the functional group compositions are similar between ditch types. This suggests that the macroinvertebrate assemblage has the potential to affect ecosystem functions of ditches through bioturbation of ditch sediment and decomposition of FPOM. Bioturbation by benthic macroinvertebrates in ditches may play an important role in regulating transformation and delivery of nutrients and carbon from ditches to receiving waters.

Field and collection ditches differed in only a subset of environmental variables measured during this study: flow velocity, wetted width, CPOM, and whether or not the ditches were dry over the summer. Field and collection ditches did differ in how pH changed over seasons, but this may be due to the limited pH measurements in field ditches over summer months (5 in field ditches, 12 in collection ditches). Therefore, differences between benthic assemblages of field and collection ditches may be due to difference in hydroperiod, size of habitat area, or CPOM availability. Field ditches that are subject to dry periods did not display more turnovers in taxa or functional groups relative to collection ditches that remained constantly filled with water. For taxa to persist in field ditches over dry periods, they must be adapted to either survive desiccation or quickly recolonize the ditch following rewetting (Delucchi & Peckarsky, 1989). The differences in assemblage composition between field and collection ditches could therefore reflect differences in traits associated with survival of dry conditions. Of the top 13 most abundant taxa, 5 were significantly associated with field ditches (*Crangonyx sp., Pisidium sp., Spirosperma nikolskyi* Lastockin & Sokolskaya, *Caecidotea* sp., *Eclipidrilus fontanus* Wassell). *Crangonyx* and *Caecidotea* are both genera of aquatic crustaceans (orders Amphipoda and Isopoda, respectively). There are species of both genera capable of living in shallow aquifers, but the species collected from this study did not show characteristics of subterranean lifestyle. Instead, these two genera are fairly mobile within surface waters, and possibly colonize field ditches as they rewet from adjacent permanent bodies of water. For this study, all field ditches had a hydrologic connection with a collection ditch that retained water

throughout the year, and could have served as a source of colonists. *Pisidium* is a genus of aquatic clam that is capable of surviving brief periods of desiccation by retaining its offspring internally within a marsupium (Smith, 2001). Little information is available on the biology and ecology of the aquatic worms *S. nikolskyi* and *E. fontanus*. These species likely survive periods of desiccation by retreating deeper within the hyporheic zone to find moist refuges (Fend & Lenat, 2012).

Differences in water permanence in ditches may also result in differences in the physical structure of the benthic habitat and may change the suitability of the ditch as habitat for different species. Vaughan et al. (2008) described differences in the sediment profiles of field and collection ditches from Maryland's Eastern Shore and documented the development of pedogenic structure in field ditches as a result of wet and dry cycles, while larger collection ditches tended to have structureless single-grained sediment. The sediment structure of field ditches may produce larger interstices that can be utilized by benthic invertebrates searching for refuges. The presence of rooted vegetation may also play a role in determining the composition of benthic invertebrates in ditches (Shupryt & Stelzer, 2009). Field ditches sampled in this study all supported rooted vegetation in the channel during dry periods, while collection ditches typically only supported rooted vegetation along the banks. Vegetation growing within the channel may contribute to higher CPOM levels in field ditches. The presence of plant roots in field ditches may provide different physical habitat as well as a food resource to burrowing invertebrates that is not available in collection ditches. Although there were no consistent differences in flow velocities between field and collection ditches, differences in flow characteristics may further shape the sediment habitat. Two of the field ditches measured during this study never had measurable flow, while all of the collection ditches had measurable flow velocities during most of the year. Higher average flow velocities may increase the transport of fine-sediment particles, leaving coarse-textured sediment at the surface, while ditches with little or intermittent flow may have increased deposition of fine-sediment particles (Allan & Castillo, 2007). Future studies would be needed to separate the effects of differences in mineral particle size distribution and the development of higher-level sediment structure on the benthic assemblage composition of drainage ditches.

Even with differences in taxonomic composition between the two types of ditches, there were no significant differences in abundance or functional group composition between ditch type or across seasons. Taxon richness increases during winter months in ditches, but aquatic macroinvertebrate richness is expected to increase in late winter and early spring in temperate, coastal plains streams as insect larvae develop and prepare to emerge in the spring and summer (Stranko et al., 2014). Therefore, although there may be differences in assemblage composition between individual ditches, the same functional groups tend to be represented across ditches and throughout the year. Ditches receive different inputs at different times of the year in accordance with farming practices (Alberts et al., 1978). In spring, manure and fertilizers are applied to fields and may enter ditches as well. In summer, as crops are growing in adjacent fields the water table becomes drawn down and many ditches experience dry or stagnant conditions. In fall, there may be inputs of organic matter from harvested crop residues or from mowing ditch banks. In winter, most agricultural practices are halted until the following spring. Throughout these variable seasonal conditions, the abundance and functional group composition of the macroinvertebrate community in ditches remains constant.

The ditches in this study support benthic macroinvertebrate assemblages dominated by collector–gatherer taxa. Collector–gatherers are expected to be the most abundant functional feeding group in low-gradient sandy and fine-sediment habitats such as ditches (Wallace & Webster, 1996). The functional role of these invertebrates is not well understood, but they may increase rates of decomposition of fine-particulate organic matter (FPOM) (Wallace & Webster, 1996; Pringle et al., 1999). This may alter the availability of energy in the form of organic carbon to microbes in the sediment, which could affect rates of biogeochemical transformations. More functional feeding group diversity may exist within other areas of the ditch not sampled in this study (e.g., clinging to emergent vegetation). These invertebrates are not in close contact with the sediment and therefore feeding activities by these groups may be less likely to directly impact processes occurring across the sediment–water interface. Ditches are also often managed through mowing and dredging to reduce vegetation, leaving the sediment surface as the dominant available habitat for

aquatic macroinvertebrates. Therefore, functions provided by the sediment-dwelling assemblage likely dominate the functions provided by the total aquatic macroinvertebrate community within drainage ditches.

We found that ditches support a high diversity of functional bioturbation groups, and bioturbation by benthic macroinvertebrates may be an important function of the invertebrate community. Bioturbation can alter physical and chemical properties of sediment and redistribute materials between the sediment and overlying water, and these changes may have important consequences for drainage ditches (Webb & Eyre, 2004; Lewandowski et al., 2007; Montserrat et al., 2008; Chaffin & Kane, 2010). Interactions between different feeding and burrowing behaviors can lead to increased ecosystem function, as physical, chemical, and biological heterogeneity of the sediment are increased (Lohrer et al., 2004).

Maximizing biogeochemical and physical processes to reduce the delivery of agricultural pollution to receiving waters has become an active area of research for drainage ditches (Needelman et al., 2007a). Through manipulations of ditch morphology and regulation of drainage rates, drainage ditches have become a valuable tool for reducing the transport of sediment and nutrients to streams and rivers. Some studies have documented the effects of emergent plant communities (Cooper et al., 2004) and microbial communities (Shigaki et al., 2008) on water quality, but to date there have been no studies that take into account the role of the benthic invertebrate assemblage. Macroinvertebrate communities within drainage ditches may alter the rates of nutrient transformations and transport, and sediment deposition within ditches through bioturbation. In areas with flat topography and high water tables, drainage ditches may be the initial site where nutrients and pesticides enter the watershed from agricultural fields. Predicting specific effects of burrowers on ecosystem functions is difficult, and may depend upon the habitat context in which the bioturbation is taking place (Mermillod-Blondin & Rosenberg, 2006; Mermillod-Blondin, 2011). We found differences in the taxonomic composition of the burrowing assemblage between field and collection ditches, but not a difference in functional group composition. A more detailed approach using individual functional traits to characterize the burrowing assemblage of ditches rather than functional groups may be more sensitive to differences between these habitat types. Detailed knowledge of these traits may inform future studies of the function of macroinvertebrates in drainage ditches by better predicting the effects of different bioturbation functional traits on nutrient cycling and other biogeochemical processes occurring across the sediment–water interface.

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