Macroinvertebrate Biomonitoring in Intermittent Coastal Plain Streams Impacted by Animal Agriculture

Stephanie Davis, Stephen W. Golladay,* George Vellidis, and Catherine M. Pringle

ABSTRACT

Little attention has been given to the ecology of intermittent coastal plain streams in the southeastern United States, and it is not known whether available macroinvertebrate biomonitoring methods reliably detect degradation in these streams. This study compared differences in biomonitoring metrics between reference and agricultural streams, and between the flow period (January–April) and the intermittent flow period (May–December). Percentages of crustaceans, isopods, and Ephemeroptera–Plecoptera–Trichoptera (EPT) were significantly higher at the reference site than the two most impacted sites during the flow period, probably resulting from the abundance of leaf litter and lower temperatures. During this same period, the agriculturally impacted sites had a significantly higher percentage of dipterans—a group that thrives in the silty, nutrient-rich waters. Four metrics (percent Crustacea, Isopoda, Diptera, and EPT) had no overlap between values for the most impacted and the least impacted sites during the flow period, but no metrics were able to detect more discrete differences among sites. Sites were physically and biologically similar during the intermittent period when natural stresses (i.e., stagnant water, high temperatures, low dissolved oxygen) were high, with many metrics, such as percentages of dominant family, burrowers, chironomids, and dipterans becoming similar at all sites. Our findings indicate that development of a better understanding of invertebrate fauna in reference conditions and of the natural variation in intermittent streams is necessary to develop effective biomonitoring programs for these systems.

Animal-based agriculture is an expanding industry in the southeastern coastal plain of the United States, causing increasing concern regarding animal waste management (Warrick and Stith, 1995; Ball, 1997). If not properly managed, animal production can have widespread, negative impacts on stream environments through nutrient enrichment, sedimentation, and habitat degradation (Cooper, 1993; Burkholder et al., 1997; Carpenter et al., 1998). Monitoring of these animal operations can aid in the development of appropriate guidelines for management.

Biological monitoring is one tool that can be used to evaluate stream health. The use of biomonitoring is growing because it can detect cumulative physical, chemical, and biological impacts of stream-degrading activities (Karr and Chu, 1999). Macroinvertebrates are commonly used in biomonitoring because they are widespread, provide a spectrum of responses to disturbances, and can act as continuous monitors of stream water quality (Rosenberg and Resh, 1993). However, there are some complicating factors, including seasonal variation and the fact that variables other than water quality can affect distribution and abundance of organisms (Rosenberg and Resh, 1993). Commonly used biomonitoring methods examine either an average tolerance of an invertebrate community or a total biotic index score based on a suite of individual metrics (see Hilsenhoff, 1988; Barbour et al., 1996).

An important consideration for biomonitoring is the variation in aquatic fauna among ecoregions resulting from differences in climate and geology (Hughes and Larsen, 1988). Given the faunal variation across ecoregions, component metrics of biotic indices must be field-tested before they are accepted for use in a given area. The application of existing biotic indices to intermittent coastal plain streams is problematic because of unique habitat and stream flow characteristics, and the difficulty of finding reference streams in an agriculturally dominated landscape. Compared with streams in the piedmont and mountain regions of the southeastern USA, coastal plain streams have lower dissolved oxygen concentrations, higher temperatures, and less stable substrate—conditions that are exacerbated during the summer and fall when many smaller streams either stop flowing or dry completely (Felley, 1992; Smock and Gilinsky, 1992). Invertebrate response to these natural stresses may translate into low biotic metric evaluations because most biotic indices and metrics were designed for perennial higher-gradient streams with high total taxa and EPT richness. Both EPT and total taxonomic richness are predicted to be lower in intermittent than perennial streams (Feminella, 1996), and lower in coastal plain streams than in piedmont and mountain streams (Lenat, 1988).

Another complication in evaluating intermittent coastal plain streams is extreme seasonal flow variability, which could translate into seasonally fluctuating biological assessment evaluations. Studies have shown that stream drying is accompanied by seasonal shifts in stream community structure (Williams and Hynes, 1977; Boulton and Lake, 1990; Boulton and Lake, 1992; Miller and Golladay, 1996). As streams dry, biotic metric values would be expected to decline, due to decreases in sensitive species and increases in tolerant taxa. Although some indices have been adapted for perennial coastal plain streams (Lenat, 1993; Barbour et al., 1996; Maxted et al., 2000), we are not aware of any for intermittent streams.

As water withdrawals and pumping increase across

S. Davis and S.W. Golladay, J.W. Jones Ecological Research Center, Route 2, Box 2324, Newton, GA 31770. G. Vellidis, Dep. of Biological and Agricultural Engineering, Univ. of Georgia, Tifton, GA 31793-0748. C.M. Pringle and S. Davis, Institute of Ecology, Univ. of Georgia, Athens, GA 30602-2602. Received 18 Feb. 2002. *Corresponding author (sgollada@jonesctr.org).

Published in J. Environ. Qual. 32:1036–1043 (2003).

Abbreviations: BMP, best management practice; EPT, Ephemeroptera–Plecoptera–Trichoptera.

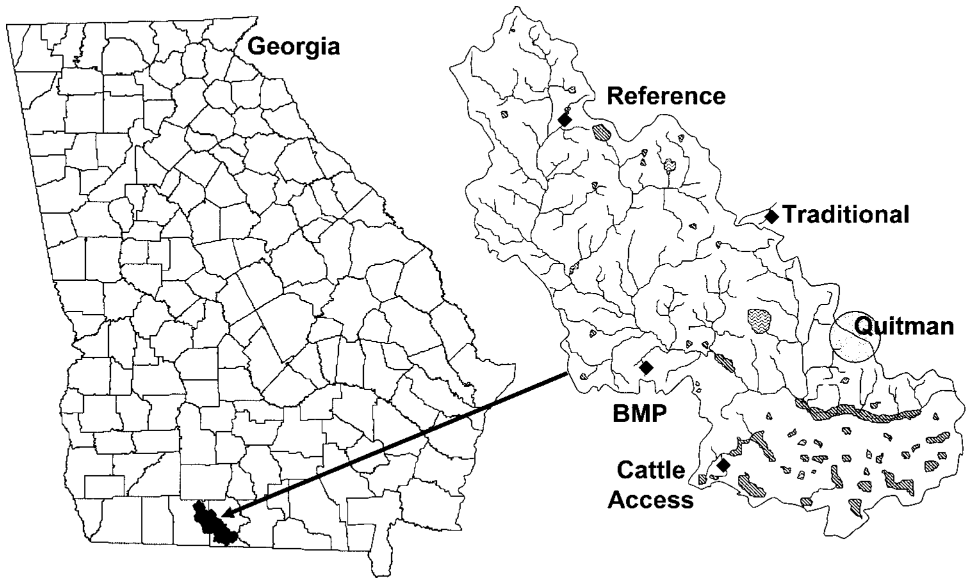

Fig. 1. Map of Piscola Creek watershed, with study sites.

the southeastern USA, more perennial streams will become intermittent and appropriate assessment methods will be needed. This study was designed to evaluate the utility of current biomonitoring metrics in intermittent coastal plain streams by collecting chemical, physical, and biological data from a watershed affected by animal and irrigated row crop agriculture. The objective of this study was to determine whether habitat and/or water quality degradation from agricultural activity in intermittent coastal plain streams could reliably be detected using biomonitoring methods.

MATERIALS AND METHODS

Study Site

Piscola Creek watershed is located in the Gulf Coastal Plain region of the Suwannee River basin in Georgia (Fig. 1). Within this 390-km^2 watershed, tributaries up to third order are intermittent, experiencing long periods of no flow each year, usually during the summer and fall. These blackwater streams flow alternately through shallow swampy areas and defined stream channels. Piscola Creek watershed has been designated as impaired according to the Georgia Department of Natural Resources citing regulations in the Clean Water Act Section 303(d) and is the site of a USDA Natural Resources Conservation Service water quality improvement project (Georgia Department of Natural Resources, Environmental Protection Division, 1998). The primary environmental concerns for Piscola Creek are elevated nutrients, sediment, and fecal bacteria, which are attributed mainly to row crop agriculture and hog (*Sus scrofa*) and cattle (*Bos taurus*) operations in the watershed. The work reported here is part of a larger effort to quantify the water quality impacts of agricultural best management practice (BMP) implementation in the Piscola Creek watershed (Vellidis et al., 1999). Best management practices for agriculture range from activities such as maintaining riparian buffers to control erosion and nutrient inputs to streams, to installing manure lagoons to treat animal waste.

Four sampling sites in the Piscola Creek watershed were selected for chemical, physical, and biological assessment based on landowner permission and land use type. The sites were: reference, BMP, traditional, and cattle access. All of the sites had at least an 8-m forested buffer except the cattle access site, where only a few overstory trees remained. Our reference stream had the most intact riparian forest buffer (Table 1) and had a much higher percentage of forested drainage area than the other four sites (Table 2).

Animal production at the BMP site included approximately 2800 hogs. Best management practices included roofed hog confinement facilities (2200 finishing hogs), liquefied manure lagoons, land application of the liquefied manure with an irrigation system up-watershed from the BMP site, and the rotation of 600 breeding sows to avoid denuding the pastures (Table 1). Approximately 50% of the drainage area is either under cultivation or in pasture (Table 2).

At the traditional agriculture site, most of the 300 hogs were penned near the stream, but were restricted from the water by fencing and a narrow band of dense riparian vegetation (Table 1). Runoff from denuded areas reached the stream during storm events. On the other side of the stream was a row-crop agricultural field, which was separated from the stream by about 8 m of riparian forest. Almost 75% of the traditional site's drainage area is either under cultivation or in pasture (Table 2).

At the cattle access site, approximately 30 cows and 50 goats had free access to the stream. Waste from about 400 hogs drained into the stream during storm events and when the soils were saturated (Table 1). The level of disturbance at the cattle access site was visibly more extensive than at the

Table 1. Stream order, land use impacts, and extent of riparian vegetation at study sites.

Site	Stream order	Land use	Riparian vegetation
Reference	3	no animal agriculture	20 m forested
Best management practice	2	confinement with lagoons; manure land-applied; swine rotated on pasture	10 m forested
Traditional	2	runoff from swine; no animal access to stream	8 m forested
Cattle access	3	runoff from swine; cattle and goat access to stream	scattered trees

Table 2. Drainage area and land use for each study site watershed.

Site	Drainage area	Forested	Cultivated	Pasture	Other
	m^2	%			
Reference	3 571 200	56	29	4	11
Best management practice	892 800	41	41	6	12
Traditional	450 000	12	69	5	14
Cattle access	1 089 900	35	37	11	17

other three sites as evidenced by actively eroding banks and feces in the stream. Pasture and cultivated land make up almost 50% of this drainage area (Table 2).

Methods

Physical, chemical, and biological monitoring was conducted monthly from March 1998 to May 1999, but data were not collected when streams were dry. Stream flow velocity was measured with an electronic current meter at 10-cm intervals at three cross-stream transects at each site. Percent cover of different substrates was visually estimated across each transect, and percent canopy cover was determined with a spherical densiometer. The percentages of sand and silt were combined into the variable percent sand + silt. Flow proportional composite water samples were collected weekly at all sites with automatic composite water samplers controlled by electronic data loggers. Further details on chemical sampling methodology and analyses are provided in Vellidis et al. (1999).

One day per month for every month when water was present, macroinvertebrate samples were collected at three locations at each site with a D-frame net. A 2-m stretch of stream was swept all the way across for 2 min, sampling all habitats in the area. Invertebrates were preserved in ethanol and washed from organic matter in the laboratory. Using a dissecting scope, macroinvertebrates were identified to lowest practical taxonomic level, usually genus, with the exception of certain taxa (primarily Chironomidae and Oligochaeta) that were identified to higher levels.

For the purposes of analysis, sampling dates were divided into two periods—flow (January–April) and intermittent flow (May–December). These seasons are based on 68 yr of monthly mean discharge data for the Withlacoochee River near Quitman, GA, the basin in which the Piscola Creek watershed is located (Stokes and McFarlane, 1997). The underlying assumption is that intermittent streams typically dry during the river's low-flow periods. Our sites closely followed this pattern of flow.

We tested metrics previously shown to be valuable in biomonitoring (Kerans and Karr, 1994; Barbour et al., 1996; Fore et al., 1996), and developed additional metrics to examine seasonal trends and differences among sites (Table 3). Certain metrics were not used because of insufficient taxonomic resolution (e.g., EPT/Chironomidae, taxa richness). The metrics percent burrowers and percent open respiratory (percent of invertebrates with open respiratory systems) were developed to examine seasonal and site differences in mechanisms that macroinvertebrates employed to live in silty, low dissolved oxygen conditions. When calculating percent open respiratory system, Chironomidae and Oligochaeta were excluded due to insufficient taxonomic resolution. With the exception of percent Isopoda, expected responses for many of the metrics are the same for increasing degradation and decreasing flow (Table 3). Isopod numbers have been found to increase in some polluted settings and to decrease in others, but isopods in intermittent streams are always expected to decrease as flow decreases because they are adapted to burrow into the sediments to escape desiccation.

Table 3. Expected responses of metrics to increasing degradation and decreasing flow based on other studies (Williams and Hynes, 1977; Boulton and Lake, 1992; Kerans and Karr, 1994; Barbour et al., 1996; Fore et al., 1996). Percent burrowers and open respiratory were designed for this study.

Metric	Increasing degradation	Decreasing flow
Percent dominant family	increase	increase
Percent Diptera	increase	increase
Percent Chironomidae	increase	increase
Percent Ephemeroptera	decrease	decrease
Percent EPT†	decrease	decrease
Percent Pelecypoda	decrease	decrease
Percent Gastropoda	decrease	decrease
Percent Odonata	increase	increase
Percent Oligochaeta	increase	increase
Percent Amphipoda	decrease	decrease
Percent Isopoda	increase or decrease	decrease
Percent Crustacea	decrease	decrease
Percent burrowers	increase	increase
Percent open respiratory	increase	increase

† Ephemeroptera–Plecoptera–Trichoptera.

For the flow season, metrics were compared using a Kruskal–Wallis one-way analysis of variance (ANOVA) on ranks. Only dates where all streams were flowing were included in the analysis. If significant differences were detected ($p < 0.05$), the Student–Newman–Keuls multiple comparison procedure was used to detect differences between sites ($p < 0.05$). Box plots were constructed for tested metrics with significant site differences.

RESULTS AND DISCUSSION

Agricultural Impacts

All agriculturally influenced sites in this study had elevated nutrient levels, turbidity, solids, and percentage of sand + silt substrates (Vellidis et al., 1999) relative to the reference site, which had higher percentages of wood + roots, leaf, and pebble habitat (Table 4). Our results are similar to those of other studies that found degraded conditions at pasture sites due to the presence of animals in stream channel and riparian areas (Quinn et al., 1992b; Osbourne and Kovacic, 1993; Stevens and Cummins, 1999; Strand and Merritt, 1999). The cattle access site in this study was clearly the most impaired, as shown by its nutrient enrichment, habitat degradation, and riparian disturbance (Vellidis et al., 1999; Table 4). All three agriculturally influenced sites had elevated nutrient concentrations, but the BMP and traditional sites had higher-quality in-stream habitat (higher percent leaves and wood + roots and lower percent sand + silt) than at the cattle access site (Table 4). These results support other studies that have shown that even minimal riparian buffers provide benefits to streams (Lowrance et al., 1985; Belsky et al., 1999; Stevens and Cummins, 1999; Strand and Merritt, 1999).

Chironomidae was the most common taxon found at all of the sites throughout both flow periods, but the

Table 4. Physical measurements for the study sites, February 1998 to May 1999.

	Reference	Best management practice	Traditional	Cattle access
Canopy opening, %	6 (0–29)†	5 (1–17)	5 (0–29)	13 (4–41)
Temperature, °C	18 (7–25)	20 (15–25)	19 (10–25)	22 (12–30)
Velocity, m s^{-1}	0.05 (0–0.1)	0.08 (0–0.7)	0.02 (0–0.5)	0.04 (0–0.1)
Sand + silt, %	49 (22–100)	61 (14–100)	66 (30–100)	85 (38–100)
Leaves, %	20 (0–60)	22 (0–50)	10 (0–70)	3 (0–23)
Wood + roots, %	18 (0–44)	12 (0–67)	20 (0–64)	4 (0–27)
Pebbles, %	10 (0–30)	2 (0–18)	3 (0–28)	1 (0–19)

† Values are means, with minimum and maximum values in parentheses.

remaining taxa varied among sites (Table 5). The main difference in community structure among the sites was the higher percentage of crustaceans at the reference and BMP sites and the large percentage of dipterans at the traditional and cattle access sites during the flow period (Fig. 2). Isopods, amphipods, and copepods were the next most common taxa after chironomids at the reference and BMP sites, while the remaining taxa at the traditional site were dominated by oligochaetes and copepods and the cattle access site was dominated by other dipteran taxa (Table 5).

Only a small subset of the metrics tested in this study actually captured the differences among sites, and then, only during the flow period. Consistent with other studies (Kerans and Karr, 1994; Robinson and Minshall, 1995; Fore et al., 1996), we found that percent dominant family and percent Diptera were reliable metrics. Although percent burrowers, percent Chironomidae, percent Crustacea, and percent Isopoda have not been reliable indicators in some studies (e.g., Kerans and Karr, 1994; Barbour et al., 1996), we found them to be useful indicators of stream condition during the flow period. Broader regional studies are needed to determine whether these metrics become variable at a larger range of sites and land use impacts.

Figure 2 provides a qualitative presentation of differences in metrics and flow seasons. For the flow period only, percent dominant family, percent burrowers, percent Chironomidae, and percent Diptera were much lower at reference and BMP sites than at traditional and cattle access sites (Fig. 2). Percentages of EPT, Crustacea, and Isopoda were much higher at the reference site compared with the three other sites during the flow period (Fig. 2). There was little difference among the sites for percent of macroinvertebrates with open respiratory systems during the flow period (Fig. 2).

Although large differences were found between the reference site and the traditional and cattle access sites for seven of the metrics during the flow period, only percent Crustacea, percent Diptera, percent Isopoda, and percent EPT showed no overlap between the least impacted site (reference) and the most impacted site (cattle access) for all sampling dates during the flow period according to box plots (Fig. 3). The metrics percent Isopoda and percent Crustacea were significantly lower at the cattle access and traditional sites (Fig. 3), probably due to the limited availability of leaf detritus habitat and food. Percent Diptera was significantly higher at the two most impacted sites (Fig. 3), probably due to excessive sedimentation and nutrient enrichment.

The traditional and cattle access sites had much higher percentages of chironomids, dipterans, dominant family, and burrowers than reference and BMP sites during the flow period. It has been documented that an abundance of dominants and burrowers in sediment-smothered streams is largely due to the replacement of sensitive taxa that require silt-free substrate with large numbers of sediment-tolerant invertebrates, such as chironomids (Quinn et al., 1992a; Kerans et al., 1995; Strand and Merritt, 1999). Blood-red chironomids and other dipterans (e.g., Psychodidae and *Eristalis*) that are considered indicators of severely polluted sites were found at these sites. As found in other regions, these taxa appear to be useful as indicators in coastal plain streams (Hilsenhoff, 1988; Resh et al., 1996).

Although percent EPT was significantly higher at the reference site than the three agricultural sites during the flow period (Fig. 3), we are cautious about recommending its use as a metric for intermittent coastal plain streams because so few EPT were found in this study (usually 0 to 1 individuals m^{-2}). Gregory (1996) also found extremely low numbers of EPT in his study of intermittent coastal plain streams, usually collecting fewer than 5 individuals m^{-2}. In streams such as these where EPT abundance is naturally low, the EPT metric may not be appropriate because EPT cannot be reliably collected in large enough quantities for comparison (Lenat and Barbour, 1994; Wallace et al., 1996).

Another concern is that the range of tolerance within the EPT could result in conflicting assessments because some EPT taxa increase with organic enrichment. Because most of the EPT in this study were early instars,

Table 5. Five most common taxa for each study site by flow period, starting with most common.

Site	Flow period	Intermittent period
Reference	Chironomidae (Diptera), *Lirceus* (Isopoda), *Caecidotea* (Isopoda), *Crangonyx* (Amphipoda), Copepoda	Chironomidae (Diptera), *Lirceus* (Isopoda), Oligochaeta, *Neoporus* (Coleoptera), *Caecidotea* (Isopoda)
Best management practice	Chironomidae (Diptera), Copepoda, Oligochaeta, *Crangonyx* (Amphipoda), *Pisidium* (Pelecypoda)	Chironomidae (Diptera), *Pisidium* (Pelecypoda), *Caecidotea* (Isopoda), Oligochaeta, *Crangonyx* (Amphipoda)
Traditional	Chironomidae (Diptera), Oligochaeta, Copepoda, *Pisidium* (Pelecypoda), *Crangonyx* (Amphipoda)	Chironomidae (Diptera), Oligochaeta, Copepoda, *Pisidium* (Pelecypoda), *Aedes* (Diptera)
Cattle access	Chironomidae (Diptera) Ceratopogonidae (Diptera), *Simulium* (Diptera), *Physella* (Gastropoda), Copepoda	Chironomidae (Diptera), *Psychoda* (Diptera) Ceratopogonidae, Oligochaeta, Ephydridae (Diptera)

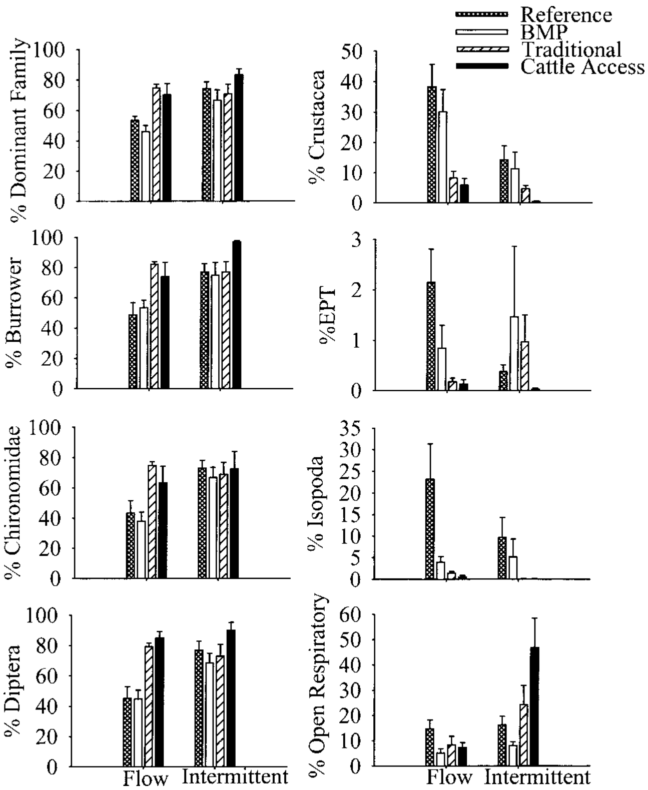

Fig. 2. Means (+1 SE) of metrics that had large differences between the reference site and one or more of the impaired sites during the flow and intermittent flow periods.

identification of individuals below the family level was difficult, and thus, it is unclear whether they were indicators of good or poor water quality. For example, certain *Baetis*, *Stenacron*, and *Caenis* (all Ephemeroptera) have higher tolerances for nutrient enrichment at the generic level than at the family level, but we do not know whether the EPT in this study had a high or low tolerance because in many cases we could not identify them below family and the family level uses an average value for tolerance (Hilsenhoff, 1988; Lenat, 1993). We considered using a "PT" index but given that only 8% of the collected EPT were Plecoptera or Trichoptera and that densities for the "PT" were well below 1 individual m^{-2}, a "PT" index would have very small numbers to use. Our results suggest caution in the use of EPT metrics in intermittent coastal plain streams due to low numbers and because effects of anthropogenic and natural stress may not be resolvable at higher taxonomic levels.

Flow Effects

Flow conditions followed the same cycle at all sites, drying in late spring and early summer. During July 1998, two large storms delivered almost 229 mm (9 in) of rain, causing flow to resume in all streams except the BMP site. The sites also received heavy precipitation from two hurricanes during September 1998, which is normally a dry time of year. All four streams were flowing after the hurricanes. Flow velocity decreased to zero at all sites on at least one sampling date during the study, but there were differences in how long each site had water (Fig. 4). The traditional site never went dry, but was characterized by nonflowing pools over half of the study. The cattle access site was dry for two months, whereas the reference site was dry for three months. Both streams were reduced to isolated, nonflowing pools most of the fall and late spring. The BMP site was dry eight months of the study.

Due to anthropogenic impacts, streams draining the traditional and cattle access sites probably flowed for longer durations than they would naturally. At the traditional site, subsurface drainage from the irrigated field that adjoined the riparian zone probably was a source of additional water, and at the cattle access site, little vegetation was present, thus there was decreased transpiration. This provided an extended period for macroinvertebrate colonization and more time for the completion of life cycles for some taxa. Conversely, extended inundation may cause reduction of other taxa by altering environmental cues necessary for completing life cycles or by eliminating summer refugia (Golladay et al., 1997). Some differences in macroinvertebrates among sites could be attributable to variation in water availability for colonization and life cycle completion, not solely to agricultural impacts. Future studies should consider these effects.

Multiple studies have shown that stream biomonitoring that did not differentiate among samples taken during different seasons indicated better water quality in winter versus summer (Lenat, 1993; Linke et al., 1999). Seasonal variation in the physicochemical environment is especially pronounced in intermittent streams, and large interseasonal differences in macroinvertebrate abundance, taxonomic richness, and community composition and structure have been observed in other intermittent stream studies (Smith and Pearson, 1987; Boulton and Lake, 1990, 1992). This study also found extreme seasonal shifts in abundance and taxonomic richness at all sites, but documented a dramatic shift in community composition only at the two least impacted streams (reference and BMP).

The reference site had significantly higher percentages of EPT, crustaceans, and isopods and a significantly lower percentage of dipterans during the flow period compared with the most impaired sites (traditional and cattle access) (Fig. 3). These differences were much less apparent during the intermittent period when all sites were subjected to naturally harsh conditions (Fig. 2). There was comparatively little seasonal change in the percent composition of orders at the two most impaired sites—both had high percentages of dipterans year-round. Dampened seasonal changes in percent composition of taxa at disturbed sites may be the result of year-round stresses imposed by nutrient and sediment pollution, while less impacted streams experienced stresses only during low-flow periods. Some of the changes seen at the BMP site may have also been related to its extended duration of low or no flow.

In this study, one of the most obvious changes in the invertebrate assemblage as stream flow decreased was the increasing abundance of individuals with open respi-

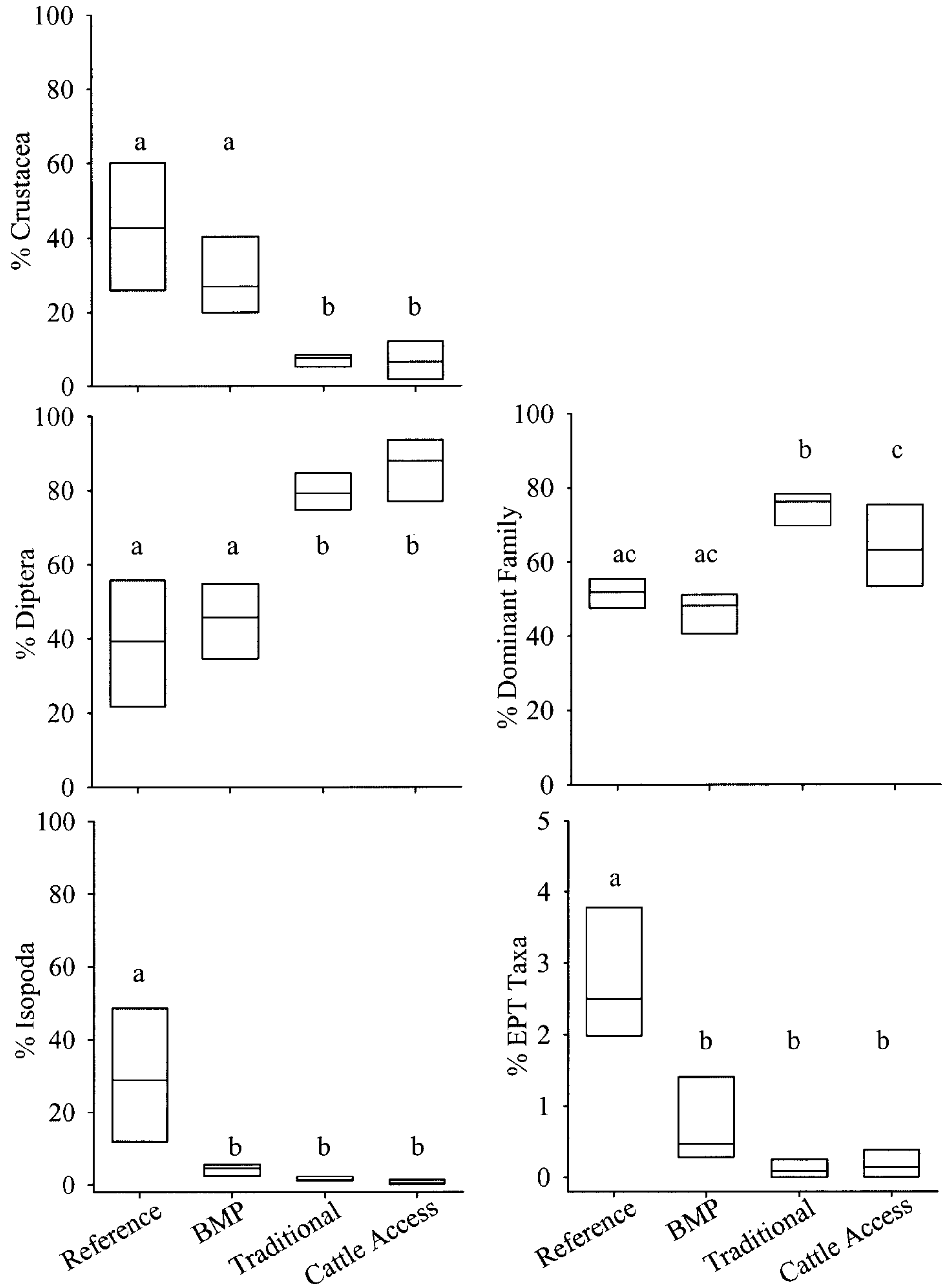

Fig. 3. Box plots of metrics that showed significant differences among most and least impacted sites during the flow period. Metrics were analyzed using a Kruskal–Wallis one-way analysis of variance (ANOVA) on ranks followed by multiple comparison procedure. For a given metric, boxes with different letters are significantly different ($p < 0.05$).

ratory systems and respiratory pigment, and decreasing abundance of sensitive taxa that required high dissolved oxygen levels (Fig. 2, Table 5). Most of the taxa with open respiratory systems were dipterans, although some coleopterans and hemipterans also had open systems. The mechanisms used included hemoglobin, atmospheric breathing, and air stores. If chironomids and oligochaetes had been included in the calculation of percent with open respiratory systems (they were excluded due to insufficient taxonomic resolution), the percentages would probably have been even higher.

All sites except the traditional site had higher percentages of dominant family, burrowers, dipterans, and chironomids during the intermittent period versus the flow period, and the percentage of crustaceans decreased at all sites during the intermittent period (Fig. 2). Other studies have documented a similar increase in tolerant taxa and decrease in sensitive taxa with decreasing flow due to changing physicochemical conditions of intermittent streams, mainly higher temperatures and lower dissolved oxygen concentrations (Boulton and Lake, 1992; Williams, 1996).

Coastal plain streams commonly show an increase in stress-tolerant taxa in the summer due to natural stresses

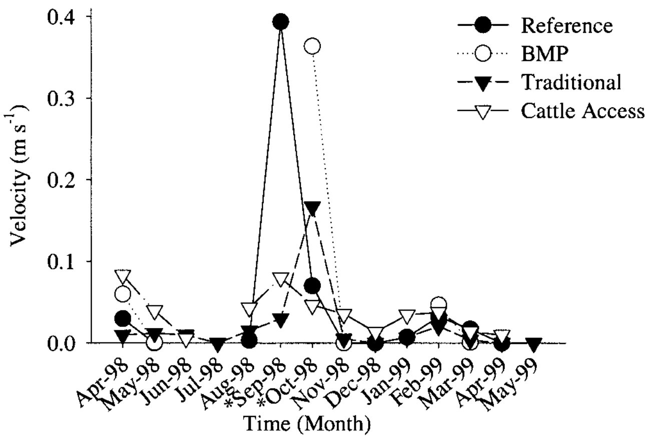

Fig. 4. Velocity measurements at each study site. A star indicates a tropical storm or hurricane.

(Lenat, 1993), which is what was seen in the Piscola Creek watershed. In perennial streams, silty, low-oxygen conditions are commonly an indication of water quality impairment, and the resulting benthic community usually is dominated by dipterans capable of burrowing and respiring in waters with low oxygen (Strand and Merritt, 1999). Based on this information, most biomonitoring methods consider high percentages of dominant family and dipterans and low percentages of EPT to be indicators of impaired streams (Kerans and Karr, 1994; Fore et al., 1996). If sites in this study had been rated according to those standards, all of them would be ranked as impaired during the intermittent period.

CONCLUSIONS

No differences could be detected among sites using many of the metrics tested in this study. The four metrics with the most promise were percent Crustacea, percent Isopoda, percent Diptera, and percent EPT, but even these metrics only detected differences in the most extreme cases, and then, only during the flow period (January–April). Distinctions were especially difficult to discern during the intermittent flow period (May–December), when natural stresses overwhelmed human stresses at all sites. Convergence of metric values at all sites during the intermittent period was attributable primarily to changes in the relative abundance of taxa, mainly increased abundance of stress-tolerant invertebrates. Currently, no biomonitoring methods appear to be adequate for intermittent coastal plain streams; however, the North Carolina Biotic Index (NCBI) is currently being modified for swamp streams (David Lenat, North Carolina Division of Water Quality, personal communication, 2002). This modified NCBI may be applicable to the intermittent streams in this study. Until such methods are available, our results indicate that a better understanding of natural variation and of reference condition fauna in intermittent coastal plain streams is needed to develop a useful biomonitoring program for these streams.

ACKNOWLEDGMENTS

We thank Jan Battle, Kevin Hiers, Frankie Hudson, Maggie Kizer, and Julie Varnadoe for assistance with field and lab work. Special thanks are extended to Bruce Wallace, Broughton Caldwell, and David Lenat for advice on invertebrate identification. Financial support provided by the J.W. Jones Ecological Research Center, R.W. Woodruff Foundation, and USEPA 319(h) funds.

REFERENCES

Ball, J. 1997. Hog farms draw heat with plans. Wall Street Journal. 12 November, Section S1.

Barbour, M.T., J. Gerritsen, G.E. Griffith, R. Frydenborg, E. McCarron, J.S. White, and M.L. Bastian. 1996. A framework for biological criteria for Florida streams using benthic macro-invertebrates. J. North Am. Benthol. Soc. 15:185–211.

Belsky, A.J., A. Matzke, and S. Uselman. 1999. Survey of livestock influences on stream and riparian ecosystems in the western United States. J. Soil Water Conserv. 54:419–431.

Boulton, A.J., and P.S. Lake. 1990. The ecology of two intermittent streams in Victoria, Australia. I. Multivariate analyses of physicochemical features. Freshwater Biol. 4:123–141.

Boulton, A.J., and P.S. Lake. 1992. The ecology of two intermittent streams in Victoria, Australia. III. Temporal changes in faunal composition. Freshwater Biol. 27:123–138.

Burkholder, J.M., M.A. Mallin, H.B. Glasgow, Jr., L.M. Larsen, M.R. McIver, G.C. Shank, N. Deamer-Melia, D.S. Briley, J. Springer, B.W. Touchette, and E.K. Hannon. 1997. Impacts to a coastal river and estuary from rupture of a large swine waste holding lagoon. J. Environ. Qual. 26:1451–1466.

Carpenter, S.R., N.F. Caraco, D.L. Correl, R.W. Howarth, A.N. Sharpley, and V.H. Smith. 1998. Nonpoint pollution of surface waters with phosphorus and nitrogen. Ecol. Appl. 8:559–568.

Cooper, C.M. 1993. Biological effects of agriculturally derived surface water pollutants on aquatic systems—A review. J. Environ. Qual. 22:402–408.

Felley, J.D. 1992. Medium-low gradient streams of the Gulf Coastal Plain. p. 233–269. *In* C.T. Hackney, S.M. Adams, and W.H. Martin (ed.) Biodiversity of the southeastern United States: Aquatic communities. John Wiley & Sons, New York.

Feminella, J.W. 1996. Comparison of benthic macroinvertebrate assemblages in small streams along a gradient of flow permanence. J. North Am. Benthol. Soc. 15:651–669.

Fore, L.S., J.R. Karr, and R.W. Wisseman. 1996. Assessing invertebrate responses to human activities: Evaluating alternative approaches. J. North Am. Benthol. Soc. 15:212–231.

Georgia Department of Natural Resources, Environmental Protection Division. 1998. Georgia 1998 list of waters as required by the Section 303(d) of the federal Clean Water Act. Georgia DNR, Atlanta.

Golladay, S.W., B.W. Taylor, and B.J. Palik. 1997. Invertebrate communities of forested limesink wetlands in southwest Georgia, USA: Habitat use and influence of extended inundation. Wetlands 17: 383–393.

Gregory, M.B. 1996. The effects of riparian zone management on water quality and macroinvertebrate community structure on the southeastern Coastal Plain. Masters thesis. Univ. of Georgia, Athens.

Hilsenhoff, W.L. 1988. Rapid field assessment of organic pollution with a family-level biotic index. J. North Am. Benthol. Soc. 7:65–68.

Hughes, R.M., and D.P. Larsen. 1988. Ecoregions: An approach to surface water protection. J. Water Pollut. Control Fed. 60:486–493.

Karr, J.R., and E.W. Chu. 1999. Restoring life in running waters: Better biological monitoring. Island Press, Washington, DC.

Kerans, B.L., S.A. Ahlstedt, T.A. McDonough, F.J. Sagona, and C.F. Saylor. 1995. Stream bioassessment and contrasting land uses in the Tennessee Valley. p. 135–144. *In* K. Steele (ed.) Animal waste and the land–water interface. Lewis Publ., Boca Raton, FL.

Kerans, B.L., and J.R. Karr. 1994. A benthic index of biotic integrity (B-IBI) for rivers of the Tennessee Valley. Ecol. Appl. 4:768–785.

Lenat, D.R. 1988. Water quality assessment of streams using a qualitative collection method for benthic macroinvertebrates. J. North Am. Benthol. Soc. 7:222–233.

Lenat, D.R. 1993. A biotic index for the southeastern United States: Derivation and list of tolerance values, with criteria for assigning water-quality ratings. J. North Am. Benthol. Soc. 12:279–290.

Lenat, D.R., and M.T. Barbour. 1994. Using benthic macroinvertebrate community structure for rapid, cost-effective, water quality monitoring: Rapid bioassessment. p. 187–215. *In* S.L. Loeb and A. Spacie (ed.) Biological monitoring of aquatic systems. Lewis Publ., Boca Raton, FL.

Linke, S., R.C. Bailey, and J. Schwindt. 1999. Temporal variability of stream bioassessments using benthic macroinvertebrates. Freshwater Biol. 42:575–584.

Lowrance, R., R. Leonard, and J. Sheridan. 1985. Managing riparian ecosystems to control nonpoint pollution. J. Soil Water Conserv. 40:87–91.

Maxted, J.R., M.T. Barbour, J. Gerritsen, V. Poretti, N. Primrose, A. Silvia, D. Penrose, and R. Renfrow. 2000. Assessment framework for mid-Atlantic coastal plain streams using benthic macroinvertebrates. J. North Am. Benthol. Soc. 19:128–144.

Miller, A.M., and S.W. Golladay. 1996. Effects of spates and drying on macroinvertebrate assemblages of an intermittent and a perennial prairie stream. J. North Am. Benthol. Soc. 15:670–689.

Osbourne, L.L., and D.A. Kovacic. 1993. Riparian vegetated buffer strips in water-quality restoration and stream management. Freshwater Biol. 29:243–258.

Quinn, J.M., R.J. Davies-Colley, C.W. Hickey, M.L. Vickers, and P.A. Ryan. 1992a. Effects of clay discharges on streams, 2. Benthic invertebrates. Hydrobiologia 248:235–247.

Quinn, J.M., R.B. Williamson, R.K. Smith, and M.L. Vickers. 1992b. Effects of riparian grazing and channelisation on streams in Southland, New Zealand. 2. Benthic invertebrates. N. Z. J. Mar. Freshwater Res. 26:259–273.

Resh, V.H., M.J. Myers, and M.J. Hannaford. 1996. Macroinvertebrates as biotic indicators of environmental quality. p. 647–667. *In* F.R. Hauer and G.A. Lamberti (ed.) Methods in stream ecology. Academic Press, San Diego, CA.

Robinson, C.T., and G.W. Minshall. 1995. Effects of open-range livestock grazing on stream communities. p. 145–154. *In* K. Steele (ed.) Animal waste and the land–water interface. Lewis Publ., Boca Raton, FL.

Rosenberg, D.M., and V.H. Resh. 1993. Introduction to freshwater biomonitoring and benthic macroinvertebrates. p. 1–9. *In* D.M. Rosenberg and V.H. Resh (ed.) Freshwater biomonitoring and benthic macroinvertebrates. Chapman & Hall, New York.

Smith, R.E.W., and R.G. Pearson. 1987. The macroinvertebrate communities of temporary pools in an intermittent stream in tropical Queensland. Hydrobiologia 150:45–61.

Smock, L.A., and E. Gilinsky. 1992. Coastal Plain blackwater streams. p. 271–311. *In* C.T. Hackney, S.M. Adams, and W.H. Martin (ed.) Biodiversity of the southeastern United States: Aquatic communities. John Wiley & Sons, New York.

Stevens, M.H.H., and K.W. Cummins. 1999. Effects of long-term disturbance on riparian vegetation and in-stream characteristics. J. Freshwater Ecol. 14:1–17.

Stokes, W.R., III, and R.D. McFarlane. 1997. Water resources data Georgia water year 1997. Volume 2: Gulf of Mexico and Tennessee River basin regions. Water Data Rep. GA-97-2. U.S. Geol. Survey, Reston, VA.

Strand, M., and R.W. Merritt. 1999. Impacts of livestock grazing activities on stream insect communities and the riverine environment. Am. Entomol. 45:13–29.

Vellidis, G., R. Lowrance, P. Gay, J. Sheridan, and D. Bosch. 1999. Water quality of Piscola Creek watershed. Am. Soc. of Agric. Eng. Tech. Paper 99-2131. ASAE, St. Joseph, MI.

Wallace, J.B., J.W. Grubaugh, and M.R. Whiles. 1996. Biotic indices and stream ecosystem processes: Results from an experimental study. Ecol. Appl. 6:140–151.

Warrick, J., and P. Stith. 1995. Boss Hog: North Carolina's pork revolution. The News & Observer. 19–26 February, Section A1.

Williams, D.D. 1996. Environmental constraints in temporary fresh waters and their consequences for the insect fauna. J. North Am. Benthol. Soc. 15:634–650.

Williams, D.D., and H.B.N. Hynes. 1977. The ecology of temporary streams II. General remarks on temporary streams. Int. Rev. Gesamten Hydrobiol. 62:53–61.