MIDGE (DIPTERA: CHIRONOMIDAE AND CERATOPOGONIDAE) COMMUNITY RESPONSE TO CANAL DISCHARGE INTO EVERGLADES NATIONAL PARK, FLORIDA

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With 3 figures and 2 tables

ABSTRACT: Quantitative samples of chironomid and ceratopogonid midge pupal exuviae were collected along 4 nutrient gradients in Everglades National Park (ENP in order to determine midge community response to nutrient enrichment and identify possible indicators of water quality. Community abundance, species richness, and Shannon-Wiener diversity showed no consistent relationship with nutrient gradients. Eight species were significantly sensitive to sources of enrichment; 7 of these species were also sensitive to nutrient enrichment in Water Conservation Area 2A (WCA-2A) studied in 2001. Seven species were significantly tolerant to, and more abundant with enrichment, but none of these species were significantly tolerant to enrichment in WCA-2A. This discrepancy in tolerant species probably reflects differences in species responses to low gradients in ENP versus the much steeper gradient in WCA-2A.

RESUMO: Com o objectivo de determinar a resposta das comunidades de mosquitos ao enriquecimento de nutrientes e identificar eventuais indicadores de qualidade da água, foram colhidas amostras quantitativas de exúvias de pupas de quironomídeos e ceratopogonídeos ao longo de 4 gradientes de nutrientes provenientes de efluentes de canais, no Parque Nacional de Everglades (PNE). A abundância da comunidade, riqueza específica e o índice de diversidade de Shannon-Wiener, não revelaram uma relação consistente com a proximidade relativa aos efluentes dos canais. Oito espécies demonstraram ser significativamente mais sensíveis aos efluentes dos canais; Destas, 7 foram igualmente sensíveis ao enriquecimento de nutrientes na Área de Conservação da Água 2A (ACA-2A) estudada em 2001. Sete espécies revelaram ser significativamente tolerantes e mais abundantes perto dos efluentes dos canais; no entanto nenhuma destas demonstrou ser significativamente tolerante ao enriquecimento na ACA-2A. Esta discrepância na tolerância reflecte provavelmente diferenças na resposta das

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Bol. Mus. Mun. Funchal, Sup. N.º 13: 39-50, 2008 ISSN 0870-3876

espécies a gradientes reduzidos no PNE em contraposição aos gradientes muito mais acentuados observados na ACA-2.

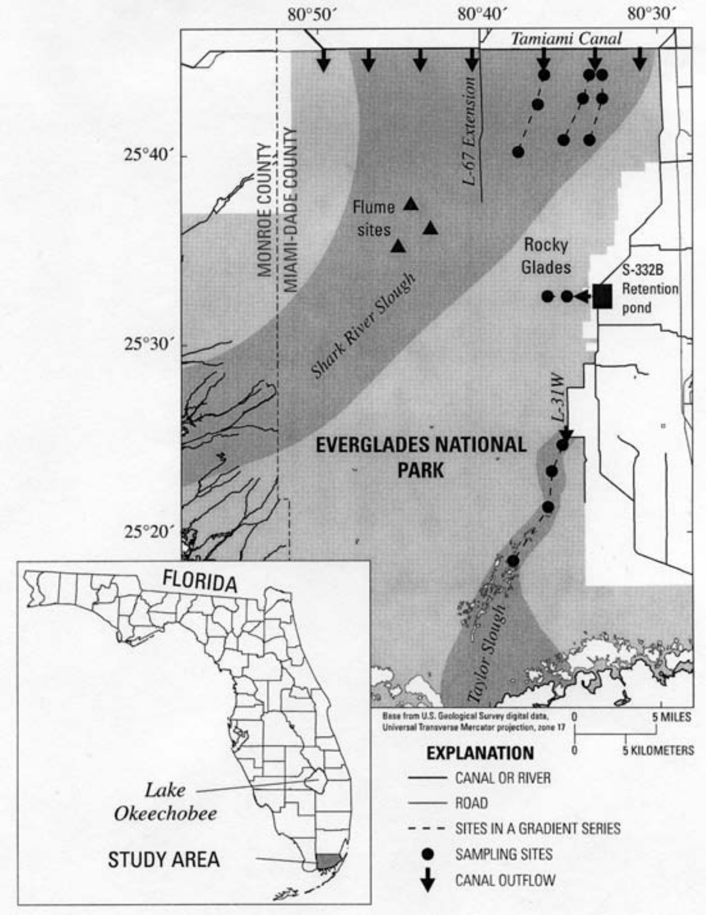
INTRODUCTION

The Everglades is a phosphorus-limited oligotrophic marsh system that is highly sensitive to phosphorus enrichment (NOE *et al.* 2001). Despite its nutrient limitation, the Everglades supports unusually high standing stocks of periphyton, a keystone feature of the system (TURNER *et al.*, 1999). Marsh communities can undergo profound structural and functional changes to nutrient loads as low as 5 ppb above ambient levels (GAISER *et al.* 2005). However, the assimilation capacities of Everglades marshes for total phosphorus (TP) loading are so high that marsh waters near sources of enrichment often show no elevation in water TP. Agricultural and urban inputs of P currently threaten the biotic integrity of the Everglades ecosystem, particularly the northern Everglades where enriched canal water from agricultural areas causes eutrophication characterized by dense stands of *Typha*. Proposed modifications planned for the Central and South Florida Project as part of the Comprehensive Everglades Restoration Plan (CERP) will alter water flow into Everglades National Park (ENP). Effective biomonitoring methods need to be developed and implemented to ensure these modifications do not degrade ENP marsh systems.

Chironomid communities have been used for assessing water quality in the northern Everglades (KING, 2001; KING & RICHARDSON, 2002). KING (2001) listed 19 chironomid species that were indicative of specific nutrient conditions in Water Conservation Area 2A (WCA-2A). However, his collections were conducted along a much greater nutrient gradient than those currently found within Everglades National Park (ENP). Many of the indicators that he found may be either absent or unresponsive to biological changes along nutrient gradients in ENP. Since ENP managers are interested in implementing midge pupal exuviae sampling as a efficient biomonitoring method for detecting nutrient enrichment, this study presents results of midge species and community responses along 4 nutrient gradients created by canal inflows into ENP and attempts to identify community metrics and species that may serve as indicators of either water quality or nutrient enrichment in ENP marshes.

MATERIAL AND METHODS

Midge communities were sampled along transects from 4 inflows into ENP: L-31W canal discharge into Taylor Slough, 332B retention pond discharge into the Rocky Glades, and from 2 Tamiami Canal culverts discharging into Northeast Shark River Slough (NESRS) (Fig. 1). Two habitat types, defined by their dominant plant species, were sampled at 2 to 4 sample sites along each transect, *Eleocharis* and *Cladium* habitats were sampled at 4 sites (50 m, 1.5 km, 4 km, and 8 km) downstream of discharge into Taylor Slough and at 3 sites along three transects in Shark Slough (100 m, 1.0 km, 3.0 km). At the S-332B retention pond, *Cladium* and *Muhlenbergia* habitats were sampled 50 m and 1000 m west of the pond outflow. Quantitative samples of floating midge pupal exuviae were collected by skimming the water surface within four 0.25 m^2 bottomless plastic corrals placed side-by-side within each habitat type, giving a 1.0 m^2 total sample surface area. The density of emergent vegetation, periphyton, and floating algae in Everglades marshes greatly inhibits exuvial drift; thus quantitative measures of exuvial species richness at the water surface were assumed to represent the density of emerging species per unit area of underlying marsh habitat. For each sample, we recorded water depth, the number of stems of each plant species present, and visual estimates of the percentage of water surface covered by floating algae (metaphyton) and stems covered by calcareous epiphyton. Chironomid pupal exuviae were identified to species or morphospecies using JACOBSEN (2008). Plant tissue, whole water, and soil samples were collected from each sampling site for nutrient analyses at the University of Florida Tropical Research and Educational Center, Homestead, FL. Total P of soil samples was determined by extraction using HCl.



Base from U.S. Geological Survey digital data, Universal Transverse Mercator projection, zone 17

Figure 1. Everglades National Park showing location of sampling transects downstream of canal discharges into the Park.

Indicator species analysis (INSPAN, DUFRÊNE & LEGENDRE, 1997) was used to identify midge taxa with significant affinities for marshes near or far away from canal outflow. INSPAN was conducted using PC-ORD 4.08 (MjM Software, Gleneden Beach, Oregon, USA). Separate INSPAN analyses were performed on samples from *Eleocharis* habitats, *Cladium* habits, and all habitats combined to increase the overall power of significance tests.

RESULTS

The nutrient gradients represented by these discharges were small (Fig. 2). Only water and *Eleocharis* plant tissue samples, showed increases in mean-P levels near inflow points (paired t-test: t=3.319, *P*=0.004; t=6.143, *P*=0.004 respectively). Water total-P levels were higher near inflows at both transects sampled in NESRS and near retention pond 332B, but showed no change in Taylor slough near the L-31W canal. *Eleocharis* tissue percent total-P concentrations were higher near canal ouflow into upper Taylor Slough and NESRS. No significant changes were observed in *Cladium* tissue levels or soil levels of total-P with distance from inflows.

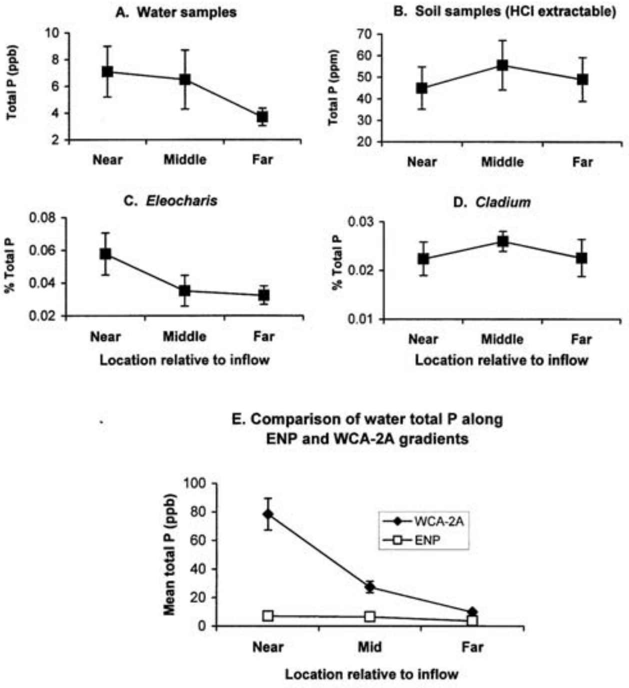
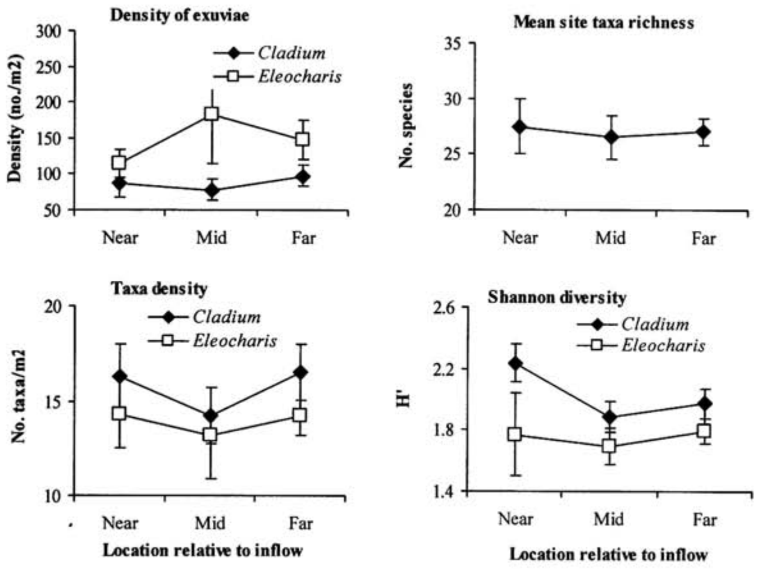


Figure 2. Mean total-P (+SE) concentrations in water, soil, and plant tissue samples collected along inflow gradients sampled in Everglades National Park, Autumn, 2001. A. Water samples. B. Soil samples (HCl extraction). C. *Eleocharis* tissue. D. *Cladium* tissue. E. Comparison of water total-P gradients in ENP (this study) with those reported for WCA-2A by KING (2001).

A. Northest Shark River Slough and Taylor Slough



B. Rocky Glades marshes near retention pond 332B

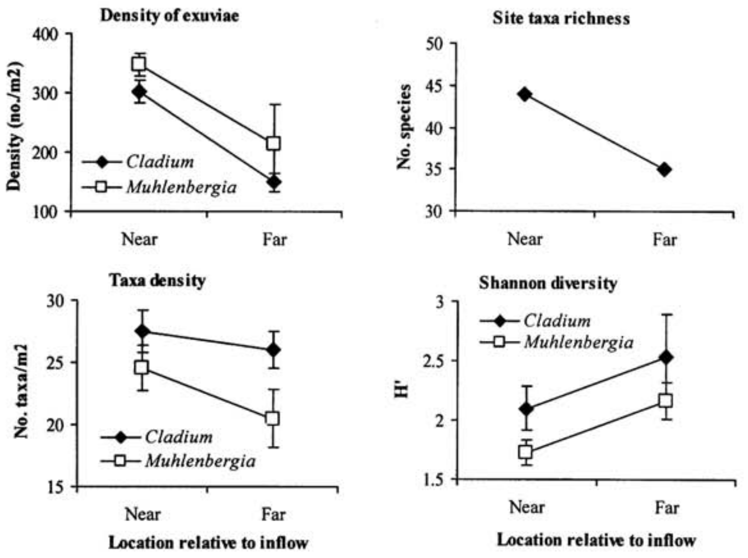


Figure 3. Mean (+SE) abundance, taxa density, site species richness, and diversity of midge pupal exuviae collected in Autumn 2001 samples along 4 canal inflow gradients in eastern Everglades National Park. A. Results from *Cladium* and *Eleocharis* habitats in northeast Shark River Slough and Taylor Slough along 3 canal inflow gradients. B. Results from *Cladium* and *Muhlenbergia* habitats in the Rocky Glades near inflows from retention pond 332B.

Total exuviae density did not change with proximity to inflows in either Taylor Slough or NESRS, but increased near retention pond 332B (Fig. 3). Higher numbers of exuviae were collected in *Eleocharis* and *Muhlenbergia* habitats compared to *Cladium* habitats. *Eleocharis* habitats also had more periphyton growth (52±10% for *Eleocharis* versus 3±3% for *Cladium*, *P* (paired t-test) < 0.001) than *Cladium* habitats in sloughs.

Species richness and diversity metrics showed no clear or consistent response relative to inflow proximity. *Cladium* samples tended to have higher mean species density than *Eleocharis* samples in sloughs and *Muhlenbergia* habitat near 332B. However, *Cladium* and *Eleocharis* habitat mean species densities did not consistently increase with proximity to canal discharges. Mean species density and site species richness increased near the L-31W canal in Taylor Slough and near the 332B retention pond. *Cladium* and *Muhlenbergia* habitats 50m west of retention pond 332B yielded a total of 44 taxa, including several species (e.g., *Chironomus stigmaterus* Say*, Cladopelma forcipis* (Rempel), *Dicrotendipes modestus* (Say)) considered to be indicators of enrichment (ADAMUS & BRANDT, 1990). However, communities in NESRS showed no increase in species richness near inflows. Shannon Wiener diversity increased significantly in *Cladium* slough habitats near canal inflows, but not in *Eleocharis* slough habitat and dropped near 332B outflow in the Rocky Glades.

A total of 70 midge taxa were collected in samples from ENP (58 Chironomidae and 12 Ceratopogonidae; Table 1). Rocky Glades marshes near retention pond 332B had the largest number of species unique to its region (12 species, versus 3 species unique to Taylor Slough, and 7 species unique to NESRS), many of which are considered to be indicators of enrichment.

Eight species were significantly associated with marshes far away from canal discharges and were considered to be sensitive to nutrient enrichment (Table 2). Seven of these species were also sensitive to phosphorus enrichment in WCA-2A (KING, 2001). *Pseudochironomus articaudus* Sæther is rare or absent in WCA-2A (JACOBSEN, 2008). Seven species, including the ceratopogonid, *Bezzia* cf. *nobilis*, were significantly associated with marshes near inflows and are considered to be potential indicators of enrichment for ENP.

TABLE 1. INSPAN analyses results for midge species collected along nutrient gradients in Everglades National Park. Near = near inflows (tolerant to enrichment), Far = far from inflows (sensitive to enrichment); N = number of exuviae collected at near and far sites combined; IV = Indicator value (product of prevalence and percent abundance at preferred location). Significantly associated species (*P* < 0.05) are indicated in bold lettering.

	Preferred location	**Relative abundance in group (%)**	**N**	**IV**	**P**
Chironomidae					
Tanypodinae					
Ablabesmyia sp. A	**Far**	**80**	**56**	**48.8**	**0.0029**
Ablabesmyia sp. B	**Far**	**79**	**29**	**31.2**	**0.0478**
Ablabesmyia sp. C	Near	100	3	10.7	0.2374
Clinotanypus sp.	Near	100	1	3.6	1
Fittkauimyia serta (Roback)	Far	100	1	3.6	1
Labrundinia beckae Roback	Near	100	1	3.6	1
Labrundinia maculata Roback	Near	89	9	15.9	0.1353
Labrundinia neopilosella Beck & Beck	Near	56	314	53.7	0.3548
Labrundinia sp. B Epler	Near	100	1	3.6	1
Labrundinia sp. 6/10 Roback	Near	100	2	3.6	1
Larsia decolorata (Malloch)	Far	55	193	35.6	0.2481
Paramerina sp.	Far	50	72	30.4	0.9179
Orthocladiinae					
Corynoneura sp. B	Near	100	1	3.6	1
Limnophyes sp.	Far	100	2	7.1	0.5021
Parakiefferiella coronata (Edwards)	**Far**	**67**	**189**	**47.6**	**0.0439**
Pseudosmittia sp.	Far	77	13	16.5	0.2108
Pseudochironomini					
Pseudochironomus articaudus Sæther	**Far**	**92**	**203**	**59.2**	**0.0003**
Chironomini					
Apedilum sp.	Near	77	31	24.9	0.1123
Beardius breviculus Reiss & Sublette	Far	54	267	29.1	0.2219
Beardius truncatus Reiss & Sublette	Far	100	1	3.6	1
Chironomus stigmaterus Say	Near	100	1	3.6	1
Chironomus sp. B	Near	93	29	20.0	0.1180
Chironomus (Lobochironomus) sp.	**Near**	**97**	**31**	**20.7**	**0.0225**
Cladopelma forcipis (Rempel)	Near	100	3	10.7	0.2395
Cladopelma sp. A	Near	58	31	18.7	0.4470
Cryptochironomus sp. B	Near	73	15	13.1	0.4585
Dicrotendipes modestus (Say)	Near	100	2	7.1	0.4930
Dicrotendipes simpsoni Epler	Far	100	1	3.6	1

TABLE I (Cont.)	**Preferred location**	**Relative abundance in group (%)**	**N**	**IV**	**P**
Endochironomus nigricans (Johannsen)	Far	67	3	4.8	1
Goeldichironomus cf. *fluctuans* Reiss	Near	84	55	14.9	0.4631
Nilothauma sp.	**Far**	**96**	**69**	**58.1**	**0.0001**
Parachironomus alatus (Beck)	Far	100	2	7.1	0.4929
Parachironomus carinatus (Townes)	Far	71	7	10.2	0.5034
Parachironomus sp. A	Near	67	27	19	0.4806
Polypedilum beckae (Sublette)	**Near**	**93**	**98**	**29.8**	**0.0351**
Polypedilum cf. *falciforme* Maschwitz	**Near**	**100**	**13**	**21.4**	**0.0241**
Polypedilum simulans Townes	**Far**	**84**	**455**	**56.7**	**0.0161**
Polypedilum trigonus Townes	Near	52	118	34.5	0.8344
Polypedilum tritum (Walker)	**Near**	**93**	**41**	**29.8**	**0.0073**
Polypedilum sp. K	Near	50	2	1.8	1
Polypedilum sp. L	Near	100	20	14.3	0.1083
Xenochironomus xenolabis (Kieffer)	Far	100	5	10.7	0.2415
Zavreliella marmorata (Wulp)	Near	72	163	28.2	0.6857
Tanytarsini					
Cladotanytarsus acornutus Jacobsen & Bilyj	**Far**	**95**	**65**	**40.9**	**0.0010**
Cladotanytarsus sp. B	Far	100	4	14.3	0.1141
Cladotanytarsus sp. C	**Far**	**82**	**656**	**70.3**	**0.0216**
Tanytarsus limneticus Sublette	Near	81	355	43.2	0.1524
Tanytarsus sp. ND	**Near**	**100**	**17**	**32.1**	**0.0023**
Paratanytarsus sp. B	Near	100	1	3.6	1
Tanytarsus sp. A	Near	76	38	16.4	0.4538
Tanytarsus sp. B	**Near**	**100**	**7**	**17.9**	**0.0488**
Tanytarsus sp. C	Near	100	5	14.3	0.1126
Tanytarsus sp. D (= sp. R Epler)	Near	69	1293	61.7	0.2416
Tanytarsus sp. E (= sp. J Epler)	Near	100	2	7.1	0.4865
Tanytarsus sp. F	Near	88	42	25.2	0.0540
Tanytarsus sp. G	Near	56	524	49.8	0.4771
Tanytarsus sp. H	Near	100	7	10.7	0.2326
Tanytarsus sp. I	Near	50	6	3.6	1
Ceratopogonidae					
sp. A (=*Dasyhelea* cf. *atlantis* Wirth & Williams)	Near	55	49	19.7	0.7314
sp. B (=*Dasyhelea* cf. *major* [Malloch])	Far	57	1852	57.2	0.3916
sp. C (=*Bezzia* cf. *nobilis* [Winnertz])	**Near**	**90**	**208**	**80.7**	**0.0001**
sp. E (=*Stilobezzia* sp.)	Far	100	1	3.6	1
sp. G	Far	76	42	29.9	0.0590
sp. H	Near	100	1	3.6	1
sp. I	Far	86	7	9.2	0.4869
sp. O	Far	71	7	10.2	0.5170
sp. Q (=*Alluaudomyia* sp.)	Far	100	3	10.7	0.2336

TABLE 2. Lists of midge taxa significantly associated with low-nutrient marshes and nutrient-enriched marshes in Everglades national Park (this study) and Water Conservation Area 2A (KING, 2001).

Indicators of low nutrient conditions

ENP "nutrient-sensitive"	WCA-2A "nutrient-sensitive"
Ablabesmyia sp. A	*Ablabesmyia* sp. A
Ablabesmyia sp. B	*Ablabesmyia* sp. B
Parakiefferiella coronata	*Parakiefferiella coronata*
Nilothauma sp.	*Nilothauma* sp.
Polypedilum simulans	*Polypedilum simulans*
Cladotanytarsus acornutus	*Cladotanytarsus acornutus*
Cladotanytarsus sp. C	*Cladotanytarsus* sp. C
Pseudochironomus articaudus	*Parachironomus alatus*
	Corynoneura sp. B
	Nanocladius alternantherae
	Beardius breviculus
	Paratanytarsus sp. B
	Tanytarsus sp. D

Indicators of nutrient enrichment

ENP "nutrient-tolerant"	WCA-2A "nutrient-tolerant"
Chironomus (*Loboch*.) sp.	*Pseudochironomus richardsoni*
Polypedilum beckae	*Chironomus stigmaterus*
Polypedilum cf. *falciforme*	*Dicrotendipes modestus*
Polypedilum tritum	*Dicrotendipes simpsoni*
Tanytarsus sp. B	*Goeldichironomus holoprasinus*
Tanytarsus sp. ND	*Goeldichironomus* cf. *natans*
Bezzia cf. *nobilis*	*Kiefferulus* sp.
	Polypedilum trigonum
	Tanytarsus sp. F Epler
	Tanytarsus sp. J Epler

DISCUSSION

The unusual chemical and biotic features of the Florida Everglades (nutrient-limited, oligotrophic system, yet supporting the highest known standing stocks of periphyton in the world; TURNER *et al.*, 1999) are quite distinct from other studied marsh systems. Increases in mean species density with nutrient enrichment were observed in slough habitats by RADER & RICHARDSON (1994). However, KING (2001) found that species richness tended to show a unimodal, subsidy-stress response to enrichment in WCA-2A, and was unreliable as a measure of water quality. Further, he found that metrics of taxonomic structure and feeding ecology failed to show monotonic relationships with enrichment. McCORMICK *et al.* (2004) also observed dramatic shifts in species composition along the nutrient gradient in WCA-2A but no change in species diversity. These findings show that stream bioassessment metrics are not effective for assessing Everglades marshes (TURNER *et al.,* 1999; KING, 2001; KING & RICHARDSON, 2002), highlighting the need to use specific measures of community structure and indicator species groups for effective bioassessment of these distinct systems. Changes in community composition, particularly amongst species with different sensitivities to nutrient levels, is a more reliable method of assessing change in ENP water quality (KING, 2001).

The large difference in the range of the WCA-2A and ENP nutrient gradients (Fig. 2E) probably accounts for the compositional differences between indicator species groups determined in this study versus KING (2001). Nutrient-sensitive species for ENP possibly represent a subset of WCA-2A nutrient–sensitive species that are particularly responsive to even small increases in nutrient loading (Table 2). *Pseudochironomus articaudus* has not been found in the northern Everglades (KING 2001; JACOBSEN, 2008). Nutrient-sensitive species in WCA-2A such as *Corynoneura* sp. D EPLER (2001), *Nanocladius alternantherae* (Dendy & Sublette), *Parachironomus alatus* (Beck)*,* and *Paratanytarsus* sp. B EPLER (2001) were too rare in this study to generate significant indicator values. *Tanytarsus* sp. D showed only a weak affinity to low-nutrient marshes along the nutrient gradients in ENP.

Likewise, ENP nutrient-tolerant species may be subsidized by the low levels of enrichment, but may become eliminated by conditions associated with the high P levels present in WCA-2A near the Hillsboro canal. None of the species significantly associated with marshes near ENP inflows are indicators of enrichment in WCA-2A by KING (2001). Most species associated with enriched marshes in WCA-2A (Table 2) are well known indicators of enrichment (ADAMUS & BRANDT, 1990) and are present in ENP, but overall water quality in the Park is high enough to ensure that they are rarely collected. Further collecting along nutrient gradients in ENP will be necessary to empirically validate these species as indicators of enriched waters.

Sampling pupae and exuviae enables species-level identification of Ceratopogonidae and their inclusion as water quality indicators. Ceratopogonids comprised from 25-50% of all midge exuviae in samples (LISTON & TREXLER, 2005, and JACOBSEN, unpublished observations). In this study, *Bezzia* cf. *nobilis* was associated with ENP marshes near canal inflows. Other significant indicators of water quality may eventually be found in the species that mine within *Typha* or fibrous algal mats in enriched waters or the abundant calcareous periphyton present in low-nutrient Everglades marshes (LISTON & TREXLER, 2005).

ACKNOWLEDGMENTS

Thanks to Omar Beceiro and Eric Nelson for their assistance with sample collection. Dr. Yuncong Li provided analyses of water, soil, and plant samples. We also thank Brigitte Lods-Crozet and other reviewers for their helpful suggestions to improve this manuscript. Funding for REJ was provided through Cooperative Agreement No. 5280-8-9015 from Everglades National Park, National Park Service, to Kelsey Downum, Chair, Department of Biological Sciences, Florida International University, Miami, Florida, USA. This contribution is part of a larger study of invertebrates in Everglades National Park that was funded by the Critical Ecosystems Science Initiative of the National Park Service.

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