Aquatic Invasions (2010) Volume 5, Issue 1: 97-102
This is an Open Access article; doi: 10.3391/ai.2010.5.1.11

Proceedings of the 16th International Conference on Aquatic Invasive Species (19-23 April 2009, Montreal, Canada)

Research article

Experimental evaluation of the impacts of the invasive catfish *Hoplosternum littorale* (Hancock, 1828) on aquatic macroinvertebrates

Craig Duxbury[1*], Jeff Holland[2] and Marianne Pluchino[3]

[1]*Walt Disney Imagineering, Research and Development, 1365 Ave. of The Stars, Lake Buena Vista, Florida, USA*
[2]*Reedy Creek Improvement District, 2191 South Service Ln., Lake Buena Vista, Florida, USA*
[3]*Seminole County, Surface Water Quality, 1101 East First St., Sanford, FL, 32711, USA*
E-mail: craig.v.duxbury@disney.com (CD), jholland@rcid.fl.us (JH), mpluchino@seminolecountyfl.gov (MP)
[*]*Corresponding author*

Received: 28 August 2009 / Accepted: 16 February 2010 / Published online: 22 February 2010

Abstract

The hoplo catfish [*Hoplosternum littorale* (Hancock, 1828)] is a callichthyid catfish native to South America. It was first recorded in Florida in 1995. It has now dispersed throughout much of Florida. It is thought that this fish has had little or no impacts to native fish. However, it is unknown if the introduction of this fish can cause other ecological impacts, such as alteration of aquatic invertebrates assemblages. We conducted a cage experiment to evaluate the effects of the hoplo catfish on macroinvertebrates. Results showed that macroinvertebrate abundance and taxa on artificial substrates (MAS) were reduced by 31 and 50% in the fish treatments, respectively. The entire macroinvertebrate assemblage structure was significantly different between fish and no-fish treatments. This difference was driven primarily by reductions in amphipods, and chironomids. Macroinvertebrates were also identified from fish stomachs and these were compared to assemblages on the MAS. We found a smaller subset of taxa in the stomachs, as compared to the MAS. These results suggest that this fish could alter the macroinvertebrate assemblage structure. This could have implications for environmental monitoring programs that use macroinvertebrates to assess water quality.

Key words: aquatic invasive species, cage experiments, biomonitoring, Florida

Introduction

Invasive species are considered to be a significant threat to biodiversity (Levine 2008). Non-native, invasive fish have also contributed to the worldwide loss of biodiversity (Clavero and Garcia-Berthou 2005). Introduced and invasive fishes are now present in all states and all major aquatic ecosystems in the United States. A moderate climate, extensive water-bodies, and a large human population means that Florida has 127 nonindigenous fish species (Fuller et al. 1999). In 1995, the hoplo catfish [*Hoplosternum littorale* (Hancock, 1828)], a callichthyid catfish native to South America, was reported in Florida (Nico et al. 1996), and has rapidly spread throughout the state (Fuller et al. 1999; Pearlstine et al. 2007; Gestring et al. 2009; Emerson 2007). This fish exhibits a number of characteristics typical of successful invaders, including tolerance to a wide range in temperature and dissolved oxygen (Brauner et al. 1995), a wide dietary breadth (Mol 1995), and high fecundity (Hostache and Mol 1998; Nico and Muench 2004).

Many experimental and observational studies have shown that fish can have significant top-down and bottom-up impacts on primary and secondary production (Matsuzaki et al. 2008). Furthermore, introductions of fish can lead to ecological cascades (Kaufman 1992) and alteration of nutrient cycles (Schindler et al. 2001), and changes in aquatic (Power 1990) and terrestrial food webs (Baxter et al. 2004). Fish predation has been found to be a strong influence on the structure of macroinvertebrate assemblages (Williams and Taylor 2003; Cheever and Simon 2008; Flecker 1992a; Allan 1982; Dudgeon 1991; Miller and Crowl 2005). In addition, introduced fish can also impact macroinvertebrate assemblages (Flecker and Townsend 1994; Knapp et al. 2001); however, this result is not always certain (Harig and Bain 1998; Englund and Polhemus 2001).

Macroinvertebrates are a diverse group of organisms, that are important component of freshwater ecosystems (Wallace and Webster 1996). Because of their high abundance and a wide range in environmental tolerances, these organisms are frequently used in biomonitoring programs to assess water quality (Rosenberg and Resh 1993). In these programs, changes in macroinvertebrate assemblages are assumed to be due to changes in water quality. However, biotic interactions are not often assessed, especially for a novel invader. Thus, our objective was to assess the effects of this fish on the macroinvertebrate assemblage of central Florida.

Materials and methods

The study site was located on Reedy Creek, a blackwater stream (Meyer 1990) in the Kissimmee River watershed. The stream is characterized by relatively low nutrients, low ionic strength, and high concentrations of organic acids (Hampson 1993). This low-gradient stream flows through extensive, mixed hardwood swamps, dominated by cypress [*Taxodium distichum* (L.) L.C. Rich.].

We used enclosure cages (n = 10) to test the effects of fish on macroinvertebrates. The experimental design included two treatments: fish and a control with no fish, with five replicates per treatment. Cages were 1m (H)×0.82m (L)×0.65m (W) composed of polyvinyl pipes forming the frame and then completely covered with 14 mm mesh size aquaculture screen. Cages were secured to the stream bottom with metal stakes. Cages were placed in pairs, the two located next to each other in areas of similar depth and velocity; one cage with fish, and the control treatment. Water depth in cages ranged from 0.52 to 0.88 m. Water velocity averaged 0.4 and 0.2m sec^{-1} outside and inside the cages, respectively. Debris was cleared from the front of the cages once per week.

Prior to the start of the experiment (October 2005), we caught the hoplo catfish from the study stream using a cast net. We then placed two catfish into each fish-treatment cage. We chose two fish per cage for several reasons. The first is that there are no published reports of typical brown hoplo densities. Second, it appears that these fish exhibit schooling behavior based on our observations (unpublished data) and synchronized breathing behavior has been reported (Sloman et al. 2009). The ten fish averaged 205 mm (range: 176 to 246 mm) in total length, and 159 g in average weight (range: 113 to 227 g).

Macroinvertebrate analyses

Stream invertebrates were quantified using a modification of the 14 plate artificial substrates (APHA et al. 1989), hereafter referred to as macroinvertebrate artificial substrates (MAS). We modified the MAS by reducing the number of hardboard plates from 14 to five per artificial substrate. Three MAS were placed in each treatment cage, attached with monofilament line in the center of the cage. After 28 days, the MAS and fish were removed from the cages. At the laboratory, the MAS were disassembled, and the macroinvertebrates were carefully dislodged using soft brushes. Macroinvertebrates were sorted alive. The macroinvertebrates were then identified to the family or order. The total number of individuals and total number of taxa were calculated separately for each MAS. Since cages were the experimental units, we averaged the numbers of individuals and taxa from the three MAS for each cage to obtain a mean number per cage.

Stomach analyses

At the end of the experiment, fish were sacrificed, weight and length were measured, and stomachs were removed. The macroinvertebrate data were pooled from the two fish in each cage. Invertebrates in the stomachs were identified and enumerated to the lowest practicable level, as noted above.

Water quality

At the beginning and end of the experiment temperature, conductivity, dissolved oxygen, and pH was measured with a Hydrolab Quanta meter. Measurements were made mid-depth, approximately 0.25 m.

Analyses

Differences in macroinvertebrates (total individuals and taxa) between fish and no-fish treatments were compared with t-tests after checking for homogeneity of variances. Since we found no evidence of heterokedasticity, we used the untransformed data. The relationship between fish length and number of organisms found in the stomachs were assessed using simple linear regression. Univariate statistics were calculated with Statistica Ver. 7.1 (StatSoft 2006).

We also conducted several multivariate analyses to examine the impacts of fish on macroinvertebrates. First, we used nonmetric multidimensional scaling (MDS) to visualize patterns in the entire macroinvertebrate assemblage structure between fish and no-fish MAS (Clarke 1993; Clarke and Ainsworth 1993). This nonparametric technique was based on the Bray-Curtis similarity matrix of the fourth-root transformed macroinvertebrate assemblage data. Organisms were averaged from the three MAS per cage for this analyses. A 4^{th} root transformation was applied to downweight the strong dominance from several taxa. An analyses of similarity (ANOSIM) was then used to test for significant differences between the treatments. ANOSIM is a nonparametric permutation procedure applied to the rank similarity matrix underlying the MDS ordination that compares the degree of differences among treatment groups, and calculates an R statistic. The significance level of the R statistic is calculated by comparing to a permutation distribution (Clarke 1999). We used 9,999 permutations on the Bray-Curtis distance of the 4th root transformed data. SIMPER was used to calculate the contributions of each taxon to differences. The multivariate analyses were conducted using the PRIMER-E software package 6.1.11 (Clarke and Warwick 2001).

Results

Water quality

Temperature and dissolved oxygen decreased from the beginning to the end of the experiment (Table 1). Conductivity and pH did not change between the time periods.

Macroinvertebrates

A total of 1,998 macroinvertebrates were identified from the MAS. On average, there were about 30% fewer organisms found on the MAS in the fish treatments (p = 0.08, 2 sided t-test) (Figure 1A). There were a total of 11 taxa, and a 50% reduction in taxa richness on the fish treatment MAS (Figure 1B) (p=0.05). Chironomids and oligochaetes dominated, accounting for greater than 90% of the total number of organisms. Chironomids comprised 46 and 63%, and Oligochaeta comprised about 50 and 31%, of the organisms on the MAS in the fish and no-fish treatments, respectively.

Table 1. Physiochemical water quality data in stream at start and end of experiment, measured with a hand-held meter.

Parameter	Value at Beginning of Experiment	Value at End of Experiment
Temperature (ºC)	25.1	18.5
Dissolved Oxygen (mg/L)	3.9	0.96
Conductivity (µS/cm)	139	139
pH	6.2	6.2

Table 2. A comparison of the relative abundance (within treatments) of taxa (Family or Order level) found on the artificial substrates (MAS) in fish and no-fish treatments (n=10, each), and in the stomach contents of caged fish (n=10).

Family or Order	Fish MAS	No Fish MAS	Caged Fish Stomach
Chironomidae	46.3	63.2	87.9
Oligochaeta	50.3	30.6	0.0
Gastropoda	2.30	4.00	1.7
Amphipoda	0.13	0.80	5.5
Odonata	0.63	0.50	0.0
Ephemeroptera	0.00	0.10	0.0
Clitellata	0.00	0.10	0.0
Collembola	0.38	0.08	0.0
Coleoptera	0.00	0.10	0.0
Acarifomres	0.00	0.00	1.7
Bivalva	0.00	0.20	1.0
Decapoda	0.00	0.00	0.3
Ceratopogonidae	0.13	0.33	1.7

Table 3. Results from SIMPER analyses indicating the five dominant taxa that contributed the greatest influence in differences in macroinvertebrate assemblage structure between fish and no-fish MAS. Average abundance based on 4th root transformed data.

Taxa	Average Abundance Fish Treatment	Average Abundance No-Fish Treatment	Contribution (%)
Amphipoda	0.15	0.73	17.1
Odonata	0.50	0.40	13.3
Chironomidae	2.20	2.64	12.3
Ceratopogonidae	0.15	0.48	11.8
Oligochaeta	2.24	2.14	9.7

Stomach analyses

A total of 290 organisms were identified from the fish stomachs collected from the caged fish. There were nine to 65 organisms per stomach There was no relationship between length of fish and the number of organisms found in the stomachs (p>0.05). Seven taxa were found in the stomachs of the caged fish (Table 2). Chironomids were the most abundant taxa, accounting for almost 90% of the total number of organisms found in the stomachs of the caged fish. Amphipods were the second most abundant taxon, accounting for almost 6% of the total number of organisms.

Multivariate analyses

The MDS plot shows a clear separation in macroinvertebrate assemblages between fish and no-fish treatments (Figure 2). The relatively low stress (0.14) indicates that these data can be effectively described in two-dimensional space (Clarke and Warwick 2001). The ANOSIM test showed that there were significant (R=0.424, P = 0.032) differences in macroinvertebrate assemblages between treatments. The SIMPER analyses indicated that the difference in assemblage structure was influenced by five taxa which accounted for a cumulative contribution of 64% (Table 3). The difference in assemblage structure was primarily influenced by larger numbers of dragonflies (Odonata) and fewer numbers of amphipods, chironomids, and the biting chironomids (Ceratopogonidae) on the fish treatment MAS.

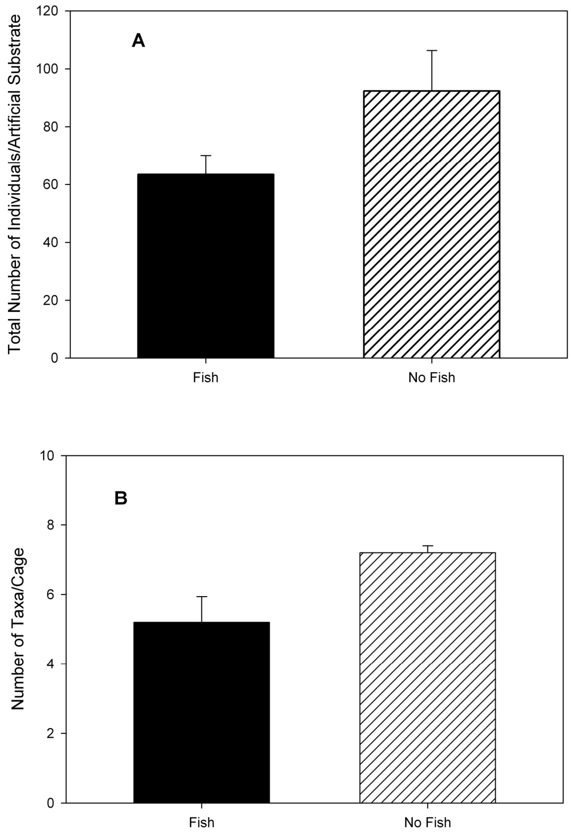

Figure 1. (A) Mean (+/-1 SE) number of organisms collected from the modified artificial substrates (p =0.08). (B) Mean (+/-1 SE) number of taxa from the MAS (p =0.05). Dark bars represent fish treatment and hatched bars represent no-fish treatments.

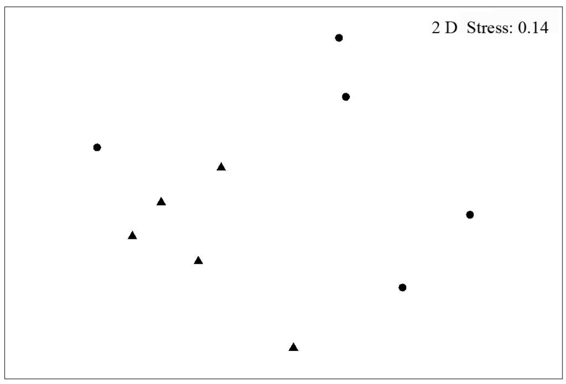

Figure 2. Nonmetric multidimensional scaling plot (MDS) showing macroinvertebrate assemblages (MAS) collected from artificial substrates in cages with fish (▲) and no-fish (●). Each symbol represents the average of three MAS.

Discussion

Our results suggest that hoplo catfish impact aquatic macroinvertebrate assemblages on artificial substrates. We found that macro-invertebrate abundances and taxa richness on MAS in cages with fish were significantly reduced by about 30 and 50%, respectively (Figures 1A, B). While there are many examples in the literature documenting strong impacts of fish on macroinvertebrates in freshwater systems (Flecker 1992b; Dudgeon 1991; Williams and Taylor 2003; Englund and Polhemus 2001; Gido 2003; Ruetz et al. 2006; Baxter et al. 2004; Miller and Crowl 2005) the results are sometimes equivocal (Allan 1982; Flecker and Allan 1984; Culp 2009; Reice 1991; Englund and Polhemus 2001).

We think that direct predation could be one explanation for the macroinvertebrate reductions on the fish treatment substrates. We base this conclusion on the fact that many of the macroinvertebrates found in fish stomachs were similar to macroinvertebrates found on MAS. Further, chironomids were the most abundant organism found in the stomachs, and these insects are a common food item for these fish (Mol 1995; Gestring et al. 2009). However, indirect influences could also explain the reduction in invertebrates. For example, we observed greater numbers of predatory dragonflies on the fish MAS. This may have been because the catfish may not eat these insects. A larger number of dragonflies, could have decreased the overall number of invertebrates. Another indirect influence may have been related to behavioral impacts. The cage mesh size did not preclude macroinvertebrates from leaving the cages. Therefore, fish may have caused macroinvertebrates to flee from predation, or may have simply been dislodged from the MAS. The presence of fish can result in a strong drift response from aquatic insects (Flecker 1992a).

Regardless of the mechanism, our results suggest that these catfish can alter the macroinvertebrate assemblage structure (Figure 2). Other investigators have found that introduced fish result in changes in macroinvertebrate assemblages (Englund and Polhemus 2001; Miller and Crowl 2005). Alterations of the macroinvertebrate assemblage and changes in relative abundances, similar to what we observed can have important implications for water quality monitoring programs. Many water quality monitoring programs incorporate biomonitoring as part of an environmental assessment. Macroinvertebrates are considered to integrate water quality, and changes in macroinvertebrate assemblages are largely assumed to be in direct response to changes in water chemistry. Thus, a novel, invasive predator such as the hoplo catfish could alter the macroinvertebrate assemblage, leading to incorrect conclusions about water quality.

While our results suggest that this invasive catfish could impact macroinvertebrates, clearly there are uncertainties. For example, a mechanistic explanation would help clarify these impacts. Also, environmentally realistic fish densities, especially, as compared to native fish, should be estimated. To our knowledge, there are no published data on the densities of these fish. Finally, the impacts of the hoplo must be compared to native fish. This knowledge would lead to a better understanding of the ecological impacts of this invasive fish.

Acknowledgements

We would like to thank the field biologists who participated in this study. Specifically, Tom Troffer, and Iwona Staniswoski helped with gathering these data. This work was supported by WDI Research and Development, as well as RCID Environmental Services. We thank them for their support. Two anonymous reviewers provided helpful comments on this paper.

References

Allan JD (1982) The effects of reduction in trout density on the invertebrate community of a mountain stream. *Ecology* 63: 1444-1455, doi:10.2307/1938871

APHA, AWWA, WPCF (1989) Standard methods for the examination of water and wastewater. Washington, DC. 1624 pp

Baxter CV, Fausch KD, Murakami M, Chapman PL (2004) Fish invasion restructures stream and forest food webs by interrupting reciprocal prey subsidies. *Ecology* 85: 2656-2663, doi:10.1890/04-138

Brauner CJ, Ballantyne CL, Randall DJ (1995) Air breathing in the armoured catfish (*Hoplosternum littorale*) as an adaptation to hypoxic, acidic, and hydrogen sulphide rich waters. *Canadian Journal of Zoology* 73: 739-743, doi:10.1139/z95-086

Cheever BM, Simon KS (2008) Seasonal influence of brook trout and mottled sculpin on lower trophic levels in an Appalachian stream. *Freshwater Biology* 54: 524-535, doi:10.1111/j.1365-2427.2008.02128.x

Clarke KR (1993) Non-parametric multivariate analyses of changes in community structure. *Australian Journal of Ecology* 18: 117-143, doi:10.1111/j.1442-9993.1993.tb00438.x

Clarke KR (1999) Nonmetric multivariate analysis in community-level ecotoxicology. *Environmental Toxicology and Chemistry* 18: 118-127, doi:10.1897/1551-5028(1999)018<0118:NMAICL>2.3.CO;2

Clarke KR, Ainsworth M (1993) A method of linking multivariate community structure to environmental variables. *Marine Ecology Progress Series* 92: 205-219, doi:10.3354/meps092205

Clarke KR, Warwick RM (2001) Change in marine communities: An approach to statistical analysis and interpretation. Second Edition. Plymouth, UK, PRIMER-E: Plymouth Marine Laboratory, 160 pp

Clavero M, Garcia-Berthou E (2005) Invasive species area leading cause of animal extinctions. *Trends in Ecology & Evolution* 20: 110, doi:10.1016/j.tree.2005.01.003

Culp JM (2009) Experimental evidence that stream macroinvertebrate community structure is unaffected by different densities of coho salmon fry. *Journal of the North American Benthological Society* 5: 140-149, doi:10.2307/1467868

Dudgeon D (1991) An experimental study of the effects of predatory fish on macroinvertebrates in a Hong Kong stream. *Freshwater Biology* 25: 321-330, doi:10.1111/j.1365-2427.1991.tb00494.x

Emerson EE (2007) Reproduction of the introduced catfish *Hoplosternum littorale* (Callichthyidae) in the St. Johns River Water Management District upper basin. Thesis. Florida Institute of Technology, Melbourne, Florida, 75 pp

Englund RA, Polhemus DA (2001) Evaluating the effects of introduced rainbow trout (*Oncorhynchus mykiss*) on native stream insects on Kauai Island, Hawaii. *Journal of Insect Conservation* 5: 265-281, doi:10.1023/A:1013331525088

Flecker AS (1992a) Fish predation and the evolution of invertebrate drift periodicity: evidence from neotropical streams. *Ecology* 73: 438-448, doi:10.2307/1940751

Flecker AS (1992b) Fish trophic guilds and the structure of a tropical stream: weak direct vs. strong indirect effects. *Ecology* 73: 927-940, doi:10.2307/1940169

Flecker AS, Allan JD (1984) The importance of predation, substrate, and spatial refugia in determining lotic insect distributions. *Oecologia* 64: 306-313, doi:10.1007/BF00379126

Flecker AS, Townsend CR (1994) Community-wide consequences of trout introduction in New Zealand streams. *Ecological Applications* 4: 798-807, doi:10.2307/1942009

Fuller PL, Nico LG, Williams JD (1999) Nonindigenous fishes introduced into the inland waters of the United States. American Fisheries Society, Bethesda, Maryland, 613 pp

Gestring KB, Shafland PL, Stanford MS, Eisenhauer RL (2009) Status and selected life history attributes of the illegally introduced brown hoplo (*Hoplosternum littorale*) in Florida. *Florida Scientist* 72: 37-47

Gido KB (2003) Effects of gizzard shad on benthic communities in reservoirs. *Journal of Fish Biology* 62: 1392-1404, doi:10.1046/j.1095-8649.2003.00124.x

Hampson PS (1993) Hydrology and water quality of Reedy Creek in the Reedy Creek Improvement District, Central Florida. USGS Water-Resources Investigations Report, Tallahassee, Florida, 57 pp

Harig AL, Bain MB (1998) Defining and restoring biological intergrity in wilderness lakes. *Ecological Applications* 8: 71-87

Hostache G, Mol JH (1998) Reproductive biology of the neotropical armoured catfish *Hoplosternum littorale* (Siluriformes-Callichthyidae): a synthesis stressing the role of the floating bubble nest. *Aquatic Living Resources* 11: 173-185, doi:10.1016/S0990-7440(98)80114-9

Kaufman L (1992) Catastrophic change in species-rich freshwater ecosystems. The lessons of Lake Victoria. *BioScience* 42: 846-858, doi:10.2307/1312084

Knapp RA, Matthews KR, Sarnelle O (2001) Resistance and resilience of alpine lake fauna to fish introductions. *Ecological Monographs* 71: 401-421, doi:10.1890/0012-9615(2001)071[0401:RAROAL]2.0.CO;2

Levine JM (2008) Biological invasions. *Current Biology* 18: 57-60, doi:10.1016/j.cub.2007.11.030

Matsuzaki SS, Usio N, Takamura N, Washitani I (2008) Contrasting impacts of invasive engineers on freshwater ecosystems: an experiment and meta-analysis. *Oecologia* 158: 673-686, doi:10.1007/s00442-008-1180-1

Meyer JL (1990) A blackwater perspective on riverine ecosystems. *BioScience* 40: 643-651, doi:10.2307/1311431

Miller SA, Crowl TA (2005) Effects of common carp (*Cyprinus carpio*) on macrophytes and invertebrate communities in a shallow lake. *Freshwater Biology* 51: 85-94, doi:10.1111/j.1365-2427.2005.01477.x

Mol JH (1995) Ontongenetic diet shifts and diet overlap among three closely related neotropical amoured catfishes. *Journal of Fish Biology* 47: 788-807, doi:10.1111/j.1095-8649.1995.tb06003.x

Nico LG, Muench AM (2004) Nest and nest habitats of the invasive catfish *Hoplosternum littorale* in Lake Tohopekaliga, Florida: A novel association with non-native *Hydrilla verticillata*. *Southeastern Naturalist* 3: 451-466, doi:10.1656/1528-7092(2004)003[0451:NANHOT]2.0.CO;2

Nico LG, Walsh SJ, Robins RH (1996) An introduced population of the South American Callichthyid catfish *Hoplosternum littorale* in the Indian River Lagoon System, Florida. *Florida Scientist* 59: 189-200

Pearlstine E, Bear WM, Mazzotti FJ, Rice KG (2007) Checklist of fish in rice and sugarcane fields of the Everglades Agricultural Area. *Florida Scientist* 70: 113-119

Power ME (1990) Effects of fish in river food webs. *Science* 250: 811-814, doi:10.1126/science.250.4982.811

Reice SR (1991) Effects of detritus loading and fish predation on leafpack breakdwon and benthic macroinvertebrates in a woodland stream. *Journal of the North American Benthological Society* 10: 42-56, doi:10.2307/1467763

Rosenberg DM, Resh VH (eds) (1993) Freshwater biomonitoring and benthic macroinvertebrates. Chapman and Hall, New York, 488 pp

Ruetz CRI, Breen MJ, Vanhaitsma DL (2006) Habitat structure and fish predation: effects on invertebrate colonisation and breakdwon of stream leaf packs. *Freshwater Biology* 51: 797-806, doi:10.1111/j.1365-2427.2006.01525.x

Schindler DE, Knapp RA, Leavitt PR (2001) Alteration of nutrient cycles and algal production resulting from fish introductions into mountain lakes. *Ecosystems* 4: 308-321, doi:10.1007/s10021-001-0013-4

Sloman KA, Sloman RD, De Boeck G, Scott GR, Iftikar FI, Wood CM, Almeida-Val VMF, Val AL (2009) The role of size in syncrhonous air breathing of *Hoplosternum littorale*. *Physiological and Biochemical Zoology* 82: 625-634, doi:10.1086/605936

StatSoft, I. (2006) Statistica. StatSoft. Tulsa, Oklahoma

Wallace JB, Webster JR (1996) The role of macro-invertebrates in stream ecosystem function. *Annual Review Entomology* 41: 115-139, doi:10.1146/annurev.en.41.010196.000555

Williams LR, Taylor CM (2003) Influence of fish predation on assemblage structure of macroinvertebrates in an intermittent stream. *Transactions of the American Fisheries Society* 132: 120-130, doi:10.1577/1548-8659(2003)132<0120:IOFPOA>2.0.CO;2