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Diversity and Longitudinal Patterns of Stoneflies (Plecoptera) in a Southwestern Missouri Ozark Stream

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Abstract: *Plecoptera species are documented from 6 longitudinal sites over a 10-year period 2002 - 2012 in a southwestern Missouri Ozark stream, including a Missouri Department of Natural Resources reference reach. Benthos, light trapping, net, and hand collections were used to capture Plecoptera every month of the year with highest sampling Nov - Jun. We collected 5,645 individuals representing 7 families, 17 genera, and 29 species including 4 confirmed species of Capniidae (38% of total), 3 Leuctridae (29%), 2 Taeniopterygidae (1.2%), 1 Nemouridae (0.81%), 3 Chloroperlidae (0.95%), 12 Perlidae (27%), and 5 Perlodidae (3.1%). Allocapnia rickeri, followed by Zealeuctra claasseni, Agnetina capitata, Acroneuria frisoni, and Perlesta decipiens were the most commonly collected species. An expected longitudinal downstream gradient of increasing Plecoptera richness was apparent, ranging from 9 species collected in stream headwaters to 21 species at the most downstream site.*

Identifiable richness throughout the watershed was highest between January and May (19 species present in April). Plecoptera richness in this stream compares favorably to collections in two high-quality streams in the western Ozarks in northeastern Oklahoma and streams in the Ouachita Mountains of central Arkansas.

Key words: *richness*, *benthic macroinvertebrates*, *Ozarks*, *Interior Highlands*

Introduction

Stonefly (Plecoptera) richness is in decline in the Midwest (DeWalt et al., 2005; DeWalt et al., 2012) and around the globe (Zwick, 1992; Bojkova et al., 2013). Given the reported 29% loss and 50% vulnerable status of stoneflies in neighboring Illinois, macroinvertebrate surveys (DeWalt et al., 2005), especially of sensitive taxa such as Plecoptera, are critical. Such studies in Illinois were possible only because historical distributions were known and taxonomy was well resolved. Macroinvertebrate declines have been attributed to anthropogenic sources including modified flow regimes, altered channel morphology, loss of riparian cover, and increased nutrient and sediment loads from agriculture (DeWalt et al., 2005). Land use and land cover have changed in the Jones Creek watershed from a forest and native grassland mixture to primarily animal agriculture (Schroeder, 1982). Plecoptera are one of the most pollution intolerant aquatic insect orders (Hynes, 1976; Merritt et al., 2008) with well resolved taxonomy (Poulton and Stewart, 1991) making this group well suited to measure degradation in stream condition.

Longitudinal macroinvertebrate surveys are critical to understanding stream ecosystem dynamics and water quality assessment. Stream ecosystem invertebrate communities vary on a longitudinal gradient as predicted by food resources (Vannote et al., 1980), temperature (Nebeker, 1971), flow (Lake, 2003), riparian vegetation (Hawkins et al., 1982), stream morphology (Stanford et al., 2005), and land use (Allan, 2004). Smaller scale studies are important to understand effects of local events, floods, drought, and pollution (Ryck, 1973). Local events have the ability to drastically decrease macroinvertebrate community density and diversity (Wallace, 1990). Longitudinal surveys provide a watershed-level benchmark for assessing disturbance severity and recovery.

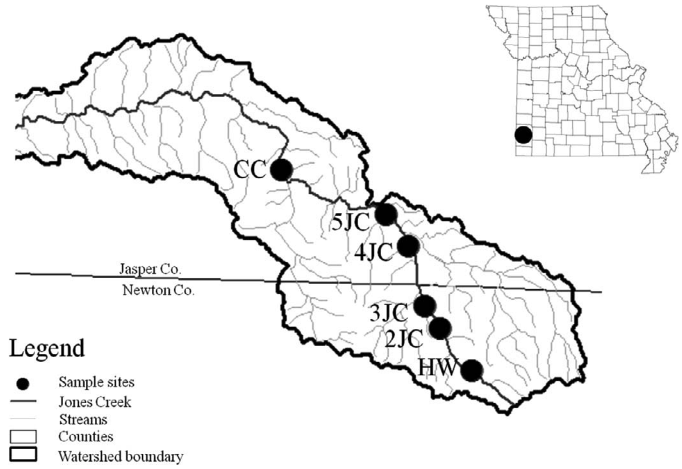
Jones Creek is one of 62 state reference streams and one of only 3 reference streams in southwestern Missouri (Sarver et al., 2002). These reference streams were selected based on three criteria, low anthropogenic influence, an unaltered flow regime, and an intact and healthy biota (Sarver et al., 2002). Such reference streams are a vital component in restoration efforts and biological monitoring (Stoddard et al., 2006). Despite the reference status of Jones Creek, no studies have investigated any recent biotic changes with a specific focus on pollution sensitive taxa (Hilsenhoff, 1987). The only published macroinvertebrate survey from Jones Creek was conducted 1964 - 1965 with 9 Plecoptera taxa reported in upper Spring River tributaries including Jones and Center Creeks (Ryck, 1973). In this study our objectives were to longitudinally survey the Plecoptera taxa from a regional reference stream and compare the stonefly assemblage to other well-documented high quality regional watersheds.

Methods

Jones Creek and Center Creek (Fig. 1) are tributaries of the Spring River system flowing through Jasper and Newton Counties in southwestern Missouri. These watersheds are geologically part of the Springfield Plateau which forms the north and northwest portion of the Interior Highlands which includes the Ozark and Ouachita Mountains of Arkansas, Oklahoma, and Missouri. Streams in this region typically have a riffle and pool pattern (Brown and Brussock, 1991) with Springfield Plateau sediments composed of limestone and chert cobble and pebble. Because of the porous karst nature of the Plateau, headwaters and downstream reaches can be intermittent. If unaffected by agriculture, riparian zones in southwestern Missouri are typically narrow gallery forests in uplands expanding into valley wide forests downstream (Schroeder, 1982). Red elm, sycamore, and river birch are the dominant streamside vegetation in the Jones Creek watershed. Land use (USGS, 2006) in the Jones Creek watershed is primarily pasture (64%) for both cattle grazing and hay, followed by deciduous forest (28%) and some row crop agriculture (2%). Animal agriculture is primarily beef cattle and pasturage along with four poultry confined animal feeding operations (CAFOs).

Study sites (Fig. 1) were selected based on longitudinal arrangement from the headwaters to downstream locations. The headwater site (HW, 36.991N 94.214W) is located downstream of several convergent intermittent channels with permanent flow maintained by several springs at and upstream of the site. There is no public access or cattle grazing at this location. The Beech Road site (2JC, 37.023N 94.247W) is in the midst of an intermittent reach that is typically dry in summer through early winter. Cattle are present upstream of the crossing. Pasture enlargement has led to bank collapse downstream. Quail Road (3JC, 37.039N 94.260W), with nearby large springs, was used for a number of earlier Plecoptera collections, but was abandoned for later studies because of bridge work and gravel removal. Quail Road is the upstream Missouri DNR reference site on Jones Creek. Bobwhite Road (4JC, 37.079N 94.263W), the downstream Missouri DNR reference site, has permanent flow with cattle present upstream but not downstream of the road crossing. Public has access at this site for fishing and swimming. Jones Creek at County Road 130 ford (5JC, 37.100N 94.294W) is a major recreational site but has no cattle present. Several upstream pastures adjacent to the stream have recently been converted to winter wheat and corn. The farthest downstream site lies on Center Creek (CC, 37.129N 94.383W). No cattle are present in this reach, but the channel has been modified for recreational usage. Upstream of this site on Grove Creek explosives were manufactured from 1901 until 2001 (MDNR, 2005) which led to releases of waste chemicals, especially ammonia, into the watershed. One of Ryck's 1964 - 1965 sampling sites was located below the confluence of Grove Creek, and he noted the comparative paucity in Plecoptera and Ephemeroptera taxa (Ryck, 1973).

Figure 1. Jones Creek Watershed, Missouri. HW=headwaters, 2JC = 2nd site downstream of HW, 3JC = 3rd site downstream, 4JC = 4th site downstream, 5JC = 5th site downstream, CC = Center Creek (6th site downstream).



Physical measures from the most recent longitudinal study, March 2013 (Table 1), included distance downstream from beginning of most intermittent stream channel as indicated on a USGS 7.5 minute map, water temperature, conductivity (primarily calcium and bicarbonate ions), dissolved oxygen, channel width, wetted perimeter, average depth, and velocity across riffle used for discharge estimates. Substrate size was estimated by the average minimum dimensions of the 20 largest particles in a 0.09 m^2 macroinvertebrate box sampler (5 replicates). Visual estimates were made of canopy cover, leaf pack cover, and eroded (collapsed) bank. Riparian habitat was assessed with EPA rapid assessment scores (low 0 to high of 20, Metcalf-Smith, 2009) and average total width above and below collection site estimated from winter satellite photos. Hach kits were used to estimate nitrate and phosphate (3 replicates). Total coliforms,

Table 1. Physical measures of Jones Creek, Missouri, 2013. Values collected on the afternoon of 13 March 2013. *3JC site was not used in 2013 study when environmental measures were collected. **EPA rapid bioassessment scores range between 0 and 20. ***3M corporation petrifilm using an average of three films.

Variable	HW	2JC	3JC*	4JC	5JC	CC
Elevation (m)	354	320	329	302	295	284
Distance downstream (km)	4.73	10.71	13.72	20.00	24.48	31.60
Water Temperature (°C)	8	9		12	12	12
Conductivity (µS cm^{-1})	181	260		305	320	366
DO (mg O_2 L^{-1})	10.2	10.9		12.1	12	12.6
Channel width (m)	6	13		17	22	47
Wetted perimeter (m)	5	6		11.3	20.5	22
Riffle depth (m)	0.045	0.053		0.098	0.079	0.368
Riffle velocity (m s^{-1})	0.61	0.10		0.60	1.20	0.63
Discharge (m^3 s^{-1})	0.2	0.0		0.7	0.9	4.2
Substrate (m)	1.39	0.15		0.15	0.16	0.2
Canopy cover at noon (%)	30	70		20	10	0
Leafpack cover (%)	2	18		2	8	2
Erroded bank (%)	20	60		8	0	100
Riparian zone width (score)**	14	8		18	20	5
Riparian zone total width (m)	23/27	14/64	101/54	1150/74	179/142	156/24
Nitrate (mg $NO_3{}^{-1}L^{-1}$)	4.8	3.9		7.8	3.8	5
Phosphate (mg $PO_4{}^{-3}$ L^{-1})	0.76	0.47		2.75	0.40	2.30
Total coliforms (col mL^{-1})***	16	20		32	26	50

colonies mL^{-1}, (3 replicates) were estimated with Petrifilm (3M Corporation, Microbiology Products 3M Health Care Ltd. Leicestershire, England).

Plecoptera specimens included nymphs (n), exuvia (ex), and adult males (m) and females (f) representing collections taken 2001 - 2012 along 6 sites on the Jones and Center Creek continuum. Collections included a focused winter and spring study in 2009 and quantitative longitudinal, urban-rural, and leaf pack decomposition studies by aquatic ecology Missouri Southern State University students. Benthic samples for nymphs were taken with box and D-net samplers (Merritt et al., 2008). Both natural leaf packs and quantitative mesh bag leaf packs were hand-picked in the field or processed in the laboratory. Adult sampling depended on Plecoptera families. Winter Plecoptera Capniidae, Leuctridae, and Taeniopterygidae were captured on exposed stones in riffles as well as underneath leaves and stones near the shoreline. Perlodidae were sampled with vegetation net sweeps and black lights. Chloroperlidae adults were primarily netted in flight over water or picked from exposed stones. We did not observe any adult Nemouridae. Perlidae were sampled primarily with black lights and net sweeps. Identifications were made using regional keys (Poulton and Stewart, 1991). Voucher specimens were deposited in the Missouri Southern State University aquatic collection. Relationship between stream site and Plecoptera richness was determined using a linear regression with distance downstream as the predictive variable ($P = 0.05$).

Results

Plecoptera of the Jones Creek watershed were based on 5,645 identifications and included 7 families, 17 genera, and 29 species (Table 2). Families included Capniidae (4 species), Leuctridae (3), Taeniopterygidae (2), Chlorperlidae (3), Nemouridae (1), Perlidae (12), and Perlodidae (5). Most commonly collected taxa were *Allocapnia rickeri,* followed by *Zealeuctra claasseni, Agneteina capitata, Acroneuria frisoni, Agnetina flavescens, Isoperla namata,* and *Perlesta decipiens*. Six endemic taxa included *Zealeuctra warreni, Alloperla ouachita, Perlesta fusca, Neoperla falayah, N. harpi,* and *N. osage*. All endemics except *Perlesta fusca* were collected from the downstream sample sites (4JC, 5JC, and CC). *Perlesta fusca* was the most abundant endemic present from upstream sample sites (85 specimens), especially 2JC (70 of 85 specimens).

Environmental measures tended to increase in the downstream direction reflecting both an increase in stream size and an increase in agricultural influence (Table 1). Stream size had predictable increases in wetted perimeter, channel width, riffle depth, and discharge. Both temperature and

Table 2. Longitudinal composition of Plecoptera in Jones Creek watershed from headwaters (HW) to Center Creek (CC) in southwestern Missouri. n = nymphs, ex = exuvia, m = males, f = females.

Taxa	Stage	HW	2JC	3JC	4JC	5JC	CC	Total
Allocapnia (in diapause)	n	68	2	6	271	105	154	606
	n	11					1	12
	ex			7	1	8	2	18
Allocapnia granulata	m		4		11	36	38	89
	f		5		17	17	24	63
Allocapnia mystica	m		10	3	21	50	11	95
	f		5	6	14	33	4	62
Allocapnia rickeri	m	11	19	160	186	161	176	713
	f	2	17	96	85	94	74	368
Paracapnia angulata	n				13			13
Leuctra tenuis	n				33	7		40
	ex				5	6		11
	m				15	2		17
	f				9	4		13
Zealeuctra	n	7	284	13	747	7	3	1061
	ex		2					2
Zealeuctra claasseni	m		249	1	1	1		252
	f		197	5				202
Zealeuctra warreni	m				1			1
	f				1			1
Taeniopteryx	ex						3	3
Taeniopteryx burksi	n						19	19
	m				1	1	13	15
	f						8	8
Strophopteryx fasciata	n		1				15	16
	m				1	1	1	3
Amphinemura delosa	n	1			10		34	45
Alloperla caudata	n		4				8	12
	m				2	9		11
	f				7	10		17
Alloperla ouachita	m					2		2
	f					1		1
Haploperla brevis	n	3	2		9			14
	ex				4			4
Acroneuria frisoni	n	3	2	5	116	12	15	153
	ex			11	23	4	6	44
	m				3			3
	f				8	11	3	22
Agnetina	n			1	43	1	13	58
Agnetina capitata	n			13	156	1	7	177
	ex			5	35			40
	m				9			9
	f				1			1
Agnetina flavescens	n			1	93		34	128
	m			1				1
Neoperla	n				13	15	42	70
Neoperla catharae	n						3	3

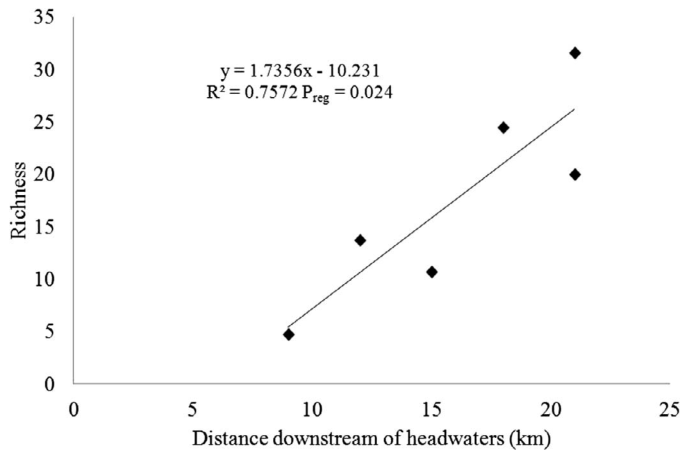
Table 2. Continued.

Taxa	Stage	HW	2JC	3JC	4JC	5JC	CC	Total
Neoperla falayah	n						7	7
	ex					1	16	17
	m					1	22	23
	f					8	21	29
Neoperla harpi	n			1	1	1	5	8
	ex					1	6	7
	m						1	1
	f						1	1
Neoperla osage	n					7	4	11
	ex					3	15	18
	f					8		8
Perlesta	n	46	26		296	51	23	442
Perlesta cinctipes	ex		1					1
	m		2					2
Perlesta decipiens	n	3	3	1	48	5	7	67
	ex		2		1	1		4
	m		1		2	7	3	13
	f		1		9	51		61
Perlesta fusca	n	7	70	5	3			85
Perlinella drymo	n	1			4		10	15
	m				3			3
	f				1	1	4	6
Perlinella ephyre	f						13	13
Clioperla clio	n	2	5				2	9
	m	1						1
	f	3	2					5
Helopicus nalatus	n						2	2
Hydroperla crosbyi	n						4	4
Isoperla	n				2	1		3
Isoperla namata	n		3	1	84	1	3	92
Isoperla mohri	n		33	1		1		35
	ex		3	1				4
	m		8					8
	f		8					8
								5531

dissolved oxygen increased slightly downstream of 2JC. Three variables were highest in the mid sample sites (4JC) including riparian zone width, total nitrate, and total phosphate. Total conductivity, eroded bank, and total coliforms were also higher downstream. No change was detected in substrate composition. Riparian zone width varied considerably with highest quality and width at 4JC and 5JC.

Plecoptera richness increased significantly downstream (Fig. 2, Table 2) with 9 species at HW and 21 species at the most downstream site, CC. Four of those 21 taxa were only collected at the CC site, *Neoperla catharae, Perlinella ephyre, Helopicus nalatus,* and *Hydroperla crosbyi*. *Allocapnia rickeri, Acroneurea frisoni,* and *Perlesta decipiens* were found at all six sites. The same linear increase in Plecoptera species persisted when species richness was partitioned monthly (Fig. 3) where the gradual increase was clearest Jan - Dec and in June. Plecoptera adult richness (emergence) had both longitudinal and seasonal predictability (Fig. 4). At the HW site only one to 2 species of Plecoptera were collected within a single month. However, downstream at CC as many as 5 Plecoptera species were collected. Plecoptera emergence richness peaked twice annually in February and in June. Emergence patterns across all sites were similar to those presented in Poulton and Stewart (1991). Except for some delayed emergence at the intermittent site, 2JC, no longitudinal temporal shifts in emergence within species were observed.

Figure 2. Plecoptera predicted total richness by longitudinal position. Richness for each sampled site was measured collectively across all sample years (2002-2012).



Capniidae

Four species of Capniidae (2,053 total specimens, 1,397 adults) were confirmed from adults or in one case, exuvia, within the watershed. *Allocapnia* nymphs (606) that cannot yet be identified to species were common in leaf packs and benthic samples including 12 in nymphal diapause. *Allocapnia rickeri* (738 m, 368 f), found at all six sites, was the most common Capniidae. Emergence periods were more prolonged downstream of 2JC (Table 3). *Allocapnia granulata* (89 m, 63 f) were found at all sites except HW and 3JC with longest adult emergence period at 4JC. *Allocapnia mystica* (95 m, 62 f) were collected at all sites except HW with the longest emergence at 2JC and CC. Although adults of *Paracapnia angulata* were not found from any of these 6 sites, 13 small nymphs were collected from leaf packs at 3JC.

Leuctridae

Three species of Leuctridae were collected. Leuctridae nymphs were collected at every site Jan – Aug. *Leuctra tenuis* (40 nymphs, 11 exuvia, 17 m, 13 f) were present at 4JC and 5JC with adults emerging in September. *Zealeuctra* nymphs (1,061) cannot be identified to species. *Zealeuctra claasseni* adults (261 m, 202 f) were abundant at 2JC and present at 3JC, 4JC, and 5JC, emerging Dec – Apr. *Zealeuctra warreni* (1 m, 1 f) were only found at 4JC Nov – Dec.

Taeniopterygidae

Two genera of Taeniopterygidae were collected. *Taeniopteryx burksi* (19 n, 3 ex, 15 m, 8 f) were present at 4JC, 5JC, and CC with emergence Jan - Apr. Nymphs, only collected at CC, were found Dec – Jan. Adults and nymphs were primarily collected from leaf packs. More widespread *Strophopteryx fasciata* (16 n, 3 m) occurred at 2JC, 4JC, 5JC, and CC with nymphs and adults present Dec – Feb.

Nemouridae

Only *Amphinemura delosa* was represented in Jones Creek. No adults were collected, but nymphs (45) were present at HW, 4JC, and CC Feb - Apr. Seventeen of the nymphs were collected from an intermittent spring run at CC.

Chloroperlidae

Three species were collected from this family. Adults of *Alloperla caudata* (12 n, 11 m, 17 f) were found May - Jun at 4JC and 5JC. Nymphs were collected April (2JC) and June (CC) before emergence May - Jun. *Alloperla ouachita* (2 m, 1 f) were collected May – Jun at 5JC. *Haploperla brevis* nymphs (14) were present at HW, 2JC, and 4JC. No adults were captured, but exuvia were found at 4JC Jun – Jul.

Perlidae

Perlidae was the most taxonomically diverse family represented by 5 genera and 13 species. Several species in this family were never caught as adults but were identifiable as

Figure 3. Longitudinal Plecoptera richness patterns in Jones Creek. Values represent nymph and adult species. HW = headwaters, 2JC = 2nd site downstream of headwaters, 3JC = 3rd site downstream, 4JC = 4th site downstream, 5JC = 5th site downstream, CC = Center Creek, 6th site downstream.

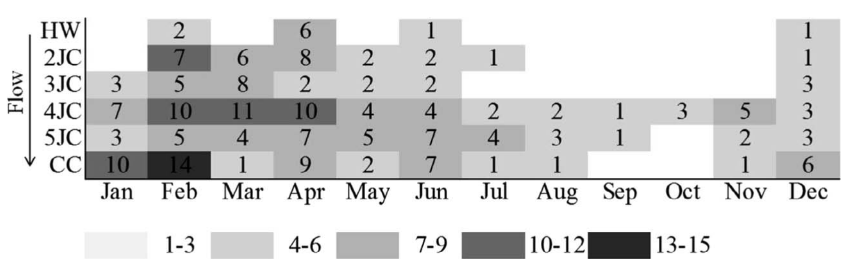
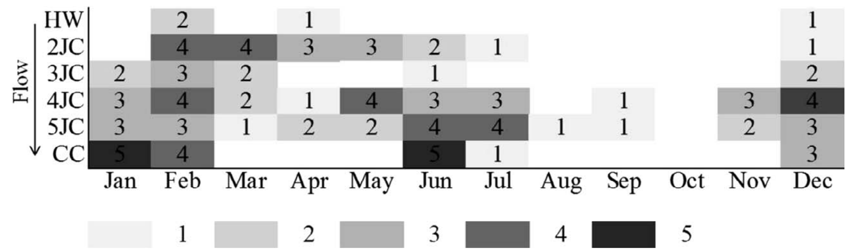


Figure 4. Plecoptera adult richness longitudinally from Jones Creek. Values represent species. HW = headwaters, 2JC = 2nd site downstream of HW, 3JC = 3rd site downstream of HW, 4JC = 4th site downstream of HW, 5JC = 5th site downstream of HW, CC = Center Creek, 6th site downstream.



nymphs. *Acroneuria frisoni* (153 n, 51 ex, 3 m, 22 f) were present as nymphs at all sites Jan – Dec. Emergence at 4JC, 5JC, and CC occurred between late February (1 ex, CC) and July with peak emergence late May – Jun. *Agnetina* were absent at HW and 2JC. *Agnetina flavescens* (128 n) and *A. capitata* (177 n) were common at downstream sites Dec – Apr. Emergence for *A. flavescens* was evidenced by a single male captured at a light trap at 3JC in June. *Agnetina capitata* emergence (40 ex, 9 m, 1 f) occurred late Mar – Apr (ex, 3JC). *Neoperla* was represented by 4 species. Small *Neoperla* nymphs were collected at 3JC, 4JC, 5JC, and CC Jan - Aug. *Neoperla catharae* was represented by 3 nymphs captured late February at CC. Identifiable *N. falayah* (7 n) were collected April and June at CC. *N. falayah* emerged (17 ex, 23 m, 29 f) at 5JC and CC Jun – Jul. *Neoperla harpi* (8 n) had a wider distribution collected at 3JC, 4JC, 5JC, and CC. *Neoperla harpi* emergence (7 ex, 1 m, 1 f) was evidenced at 5JC and CC Jul – Aug. *Neoperla osage* nymphs (11) were present at 5JC and CC Feb – Jul. *Neoperla osage* emerged at 5JC and CC (18 ex, 8 f). *Perlesta* was represented by three species. Small *Perlesta* (442 n) were present at all sites excluding 3JC Jan – Apr. *P. cinctipes* emerged May – Jun based on one exuvia and 2 males at 2JC. Recognizable *P. decipiens* (67 n) were present Jan – Apr at all sites. *Perlesta decipiens* emerged (13 ex, 13 m, 61 f) Jun – Jul at 2JC, 4JC, 5JC, and CC. *Perlesta fusca* (85 n), collected Mar – May at 4JC and upstream, were especially common at the 2JC intermittent site (70 n). Both species of *Perlinella* were collected. *Perlinella drymo* (15 n) were collected January and April at HW, 4JC, and CC. Emergence was evidenced by three males and six females collected at 4JC and 5JC Apr – Jun. *Perlinella ephyre* adults (13 f) were only collected in June at CC.

Perlodidae

Five species of Perlodidae were identified. *Clioperla clio* (9 n) were present at HW, 2JC, and CC Jan – Apr. *Clioperla clio* adults (1 m, 5 f) were collected only at HW and 2JC Mar – Apr. *Helopicus nalatus* (2 n) and *Hydroperla crosbyi* (4 n) were found at CC in January. *Isoperla mohri* (35 n) were found Mar – Apr at 2JC, 3JC, and 5JC with adults (4 ex, 8 m, 8 f) emerging Mar – Apr at 2JC and 3JC. *Isoperla namata* (92 n) were collected Feb – Apr at 2JC, 3JC, 4JC, 5JC, and CC.

This study, along with Battle Branch (Ernst and Stewart, 1985) and Spring Creek (Heth, unpublished data), represent the 3 well-surveyed Plecoptera studies of relatively undisturbed watersheds in the Springfield Plateau (Table 4). Forty-one Plecoptera species were identified in the 3 watersheds. Jaccard similarities were Jones - Battle Branch (64%), Jones - Spring Creek (51%), and Battle Branch - Spring Creek (39%). Fourteen species were common to these 3 watersheds, *Allocapnia rickeri, Paracapnia angulata, Leuctra tenuis, Zealeuctra claasseni, Z. warreni, Strophopteryx fasciata, Amphinemura delosa, Alloperla caudata, Haploperla brevis, Acroneuria frisoni, Agnetina capitata, Neoperla osage, Clioperla clio,* and *Isoperla namata*.

Discussion

Ryck (1973) is our only source of stonefly data from Jones Creek. Included in his 1964 – 1965 study are 3 headwater streams of the Spring River which are at or above our CC site. Ryck reports 9 common taxa including *Allocapnia sp.*, *Strophopteryx fasciata, Acroneuria arida* (=*A. evoluta, now A. frisoni,* Stark and Brown, 1991), *Agentina capitata, Neoperla clymene, Perlesta placida, Helopicus nalatus, Isoperla duplicata,* and *I. mohri*. Because *Perlesta placida,* and *Neoperla clymene* are now known to be species complexes (Stark and Baumann, 1978; Stark and Lentz, 1988; Stark, 1989) we do not know which species Ryck intended. All of Ryck's taxa with the exception of *I. duplicata* were found in this study. *Isoperla duplicata* taxonomy remains unresolved with none of our *Isoperla* specimens similar to illustrations of *I. duplicata* in Frison (1935). Ryck only presents general taxonomic trends, with emphasis on effects of disturbance, but

Table 3. Plecoptera from Jones Creek. Values represent individuals collected. n = nymphs, m = males, f = females.

		Month												
Taxa	Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Allocapnia granulata	m	13	25	1								9	41	89
	f	12	19	1								14	17	63
Allocapnia mystica	m	9	15									10	61	95
	f	5	6									11	40	62
Allocapnia rickeri	m	213	206	101									193	713
	f	85	124	74									85	368
Paracapnia angulata	n			13										
Leuctra tenuis	n			1	1		12	16	3	2	2	3		40
	m									17				17
	f									13				13
Zealeuctra warreni	m											1		1
	f												1	1
Zealeuctra claasseni	m		76	148	37									261
	f		56	93	53									202
Taeniopteryx burksi	n	15	3										1	19
	m	2	11	1	1									15
	f	4	4											8
Strophopteryx fasciata	n	10	6											16
	m	1	2											3
Amphinemura delosa	n		1	1	43									45
Haploperla brevis	n			4	10									14
Alloperla caudata	n				4		8							12
	m					10	1							11
	f					12	5							17
Alloperla ouachita	m					1	1							2
	f						1							1
Agnetina flavescens	n	28	26	11	61								2	128
	m						1							1
Agnetina capitata	n	10	20	21	67	17	21	7	5		9	4		177
	m					4	5							9
Acroneuria frisoni	n	11	58	29	34	12	1	2	2		2	1	2	153
	m					2	1							3
	f					1	13	18						22
Neoperla catharae	n		3											3
Neoperla falayah	n				1		6							7
	m						22	1						23
	f						26	3						29
Neoperla osage	n		2	2	3	1	1	2						11
	f							7	1					8
Neoperla harpi	n			1	2		3	1	1					8
	m							1						1
	f							1						1
Perlesta cinctipes	m						2							2
Perlinella drymo	n	6	8		1									15
	m				3									3
	f				2		4							6
Perlinella ephyre	f						13							13
Isoperla namata	n	1	17	18	56									92

Table 3. Continued.

Taxa	Stage	Month												Total
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Isoperla mohri	n		13	19	3									35
	m			3	5									8
	f			2	6									8
Clioperla clio	n	2		4	3									9
	m				1									1
	f		2		3									5
Hydroperla crosbyi	n	4												4
Helopicus nalatus	n	2												2

site specific details, the locations, taxa lists, and abundances, are absent. The present deposition of Ryck's specimens is unknown. Such specifics are critical for subsequent biologists attempting to detect taxonomic changes over time.

All Interior Highland families except one and all genera except 5 are present in the Jones Creek watershed (Poulton and Stewart, 1991). Habitat requirements or regional rarity are likely the reason certain Plecoptera species were not collected from the current study, especially the intermittent 2JC site which probably excludes long-lived taxa and those that are not adapted to drying. Pteronarcyidae are limited to large cold rivers or rivers with major spring inputs. *Nemocapnia* is rare with only a single record in the Highlands (Poulton and Stewart, 1991). Of the Nemouridae, *Amphinemura* was only found in low densities. *Prostoia,* common in other Springfield Plateau streams (Ernst and Stewart, 1986), was absent, both perhaps because fine detrital sediments, typical habitat for Nemouridae, are scarce in this watershed. The other regional nemourid, *Shipsa,* is very rare in the Interior Highlands. Of the Perlidae, *Attaneuria* is uncommonly collected from large rivers. *Paragnetina kansensis* is uncommonly collected from large warm rivers, and *P. media,* collected from large rivers with spring flow, is on the southwestern limit of its continental distribution (Poulton and Stewart, 1991).

A strong downstream longitudinal increase in Plecoptera species richness is present in this study, perhaps reflecting habitat complexity and colonization abilities. As streams become progressively larger, the variety of habitats, deep pools, macrophyte beds, substrate, and large woody debris becomes more complex providing additional habitat niches for Plecoptera (Rice et al., 2001). Plecoptera have difficulty colonizing from neighboring aquatic habitats primarily because of low adult vagility, especially in females (Griffith et al., 1998; Petersen et al., 2004), high dissolved oxygen needs, and requisite temperature cues (Hynes, 1976). Headwaters of neighboring watersheds in this study are beyond the measured flight paths of some Plecoptera (Briers et al., 2004). Nearby lentic habitat, the common farm ponds, do not meet stonefly oxygen needs. Spring pools, typical of the karst geology, lack the necessary temperature cues required in stonefly development (Hynes, 1976; Glazier, 1991). Colonization is then directionally limited to the stream channel through downstream drift and the upstream flight of ovipositing females (Müller, 1982). Habitat complexity and limited colonization then support an expected downstream increase in Plecoptera richness. *Hydroperla crosbyi* and *Helopicus nalatus,* large-bodied univoltine species, are only found at the lowermost site. Taxa missing at upstream sites include two species of *Allocapnia, Agnetina, Neoperla,* and *Isoperla,* all of which may be attributed to harsher drying patterns in some upstream sites, especially the losing stream reach at 2JC. However intermittent 2JC was notable for the abundance of *Zealeuctra* and *Perlesta,* both of which are known to have diapausing eggs and rapid development (Snellen and Stewart, 1979a; Snellen and Stewart, 1979b). Intermittent reaches like 2JC are often dominated by drying adapted stonefly taxa, many of which are regional endemics (Heth, 2006; Sheldon and Warren, 2009).

Plecoptera communities in the watershed are a result of the regional species pool. This regional pool determines an upper species limit for the watershed with local assemblages along the longitudinal gradient determined by colonization ability and local habitat structure. Recolonization following an extinction event is dependent on the distance from refugia, usually downstream. Local extinction depends on the nature and frequency of disturbance and the size of the habitat (Thienemann, 1954; MacArthur and Wilson, 1963; Connell, 1978). Constraints (sieves, filters, templates) unique to Plecoptera taxa such as temperature cues, dissolved oxygen, adequate hyporheos, riparian vegetation, and drying regimes limit successful colonization (Gleason, 1926; Sheldon and Warren, 2009). Natural disturbances, flooding and especially drought, limit some Plecoptera taxa, especially semivoltine

Table 4. Presence-absence comparisons among five high-quality streams in the Interior Highlands, Jones Creek, Missouri. Battle Branch, Oklahoma (Ernst and Stewart, 1985), Spring Creek, Oklahoma (Heth, unpublished), Little Glazypeau Creek (LCPC) and upper Alum Fork, Arkansas (Heth, 2006; Sheldon and Warren, 2009).

	Springfield Plateau			Ouachitas	
	Jones	Battle	Spring	LGPC	upper Alum
Allocapnia granulata	1		1		1
Allocapnia jeannae			1	1	1
Allocapnia mohri			1	1	1
Allocapnia mystica	1			1	
Allocapnia ozarkana					1
Allocapnia peltoides					
Allocapnia rickeri	1	1	1	1	1
Allocapnia sandersoni			1		
Paracapnia angulata	1	1	1	1	
Leuctra tenuis	1	1	1	1	
Zealeuctra cherokee					1
Zealeuctra claasseni	1	1	1	1	1
Zealeuctra narfi				1	1
Zealeuctra warreni	1	1	1	1	1
Taeniopteryx burksi	1			1	1
Taeniopteryx metaqui					1
Strophopteryx arkansae					1
Strophopteryx cucullata			1	1	1
Strophopteryx fasciata	1	1	1		
Amphinemura delosa	1	1	1	1	1
Prostoia completa		1	1		1
Alloperla sp.			1		
Alloperla caudata	1	1	1	1	
Alloperla hamata				1	
Alloperla ouachita	1			1	
Haploperla brevis	1	1	1	1	1
*Acroneuria frisoni**	1	1	1	1	1
Acroneurea perplexa				1	1
Agnetina flavescens	1		1		
Agnetina capitata	1	1	1		
Neoperla sp. A		1			
Neoperla catharae	1	1		1	1
Neoperla choctaw				1	1
Neoperla falayah	1		1		1
Neoperla harpi	1	1			1
Neoperla osage	1	1	1	1	
Perlesta baumanni				1	1
Perlesta browni				1	1
Perlesta cinctipes	1		1		1
Perlesta decipiens	1		1	1	1
Perlesta fusca	1		1	1	1
Perlesta placida		1			
Perlinella drymo	1	1			
Perlinella ephyre	1	1			
Clioperla clio	1	1	1	1	1
Helopicus nalatus	1	1		1	
Hydroperla crosbyi	1			1	1
Isoperla bilineata			1		
Isoperla burksi			1		1
Isoperla mohri	1		1		
Isoperla namata	1	1	1	1	
Isoperla ouachita			1	1	1
Isoperla signata		1			
Total	30	23	30	30	31

species. Anthropogenic disturbances, especially those that affect constraints unique to Plecoptera, may be more severe.

Diversity in the Jones Creek watershed compares favorably to several well-studied streams in the Interior Highlands. Poulton and Stewart (1991) documented 88 stonefly taxa in the Interior Highlands including 43 stonefly taxa in the Springfield Plateau. Ernst and Stewart (1985) intensively sampled Battle Branch, a small second order stream of the Springfield Plateau in Delaware County of northeastern Oklahoma, and found 23 stonefly taxa. Heth (unpublished data) in a longitudinal macroinvertebrate study of nearby Spring Creek, Cherokee, Mayes, and Delaware counties, Oklahoma, found 28 taxa at 8 sampling sites along this larger watershed. Two other studies in the Ouachita Mountains (Heth, 2006; Sheldon and Warren, 2009) sampled the Little Glazypeau and upper Alum Fork watersheds. The uppermost Alum Fork sites are located in a relatively undisturbed watershed, some with no logging or agriculture in historic times. Headwater streams in upstream Alum Fork tributaries are all intermittent. Little Glazypeau, located in a clear-cut pine management area but still with an intact 10 m riparian zone, has a more favorable flow regime and more developed hyporheos (Heth, 2006). Sheldon and Warren (2009) intensively sampled Plecoptera at 38 sites in these two watersheds and found 30 and 31 taxa in Little Glazypeau and upper Alum Fork, respectively. A core of 14 taxa common to all 3 of the studied Springfield Plateau streams, 7 of those taxa were also common to the Ouachita streams. This common species core might represent those best adapted for recolonization and drought. Six of the 9 taxa in the upper sites of this study are also part of that core. Both drying and a 4 km losing stream reach likely serve as survival and recolonization filters at these upper sites.

Jones Creek is in better condition than many southwestern Missouri streams. Human density is low, and the watershed is missing the effects of past lead and zinc mining typical of southwestern Missouri (Wildhaber, 2000; Angelo et al., 2007; Allert, et al., 2012). Nearby well-surveyed streams include rural Carver Branch with headwaters protected in a national monument (19 species, R. L. S. Heth, NPS report to George Washington Carver National Monument), upper Turkey Creek, a largely suburban stream (8 species), and urban Joplin Creek (none, R. K. Heth, unpublished data). However, the Jones Creek watershed still suffers from the effects of agriculture and human modifications. Pasture expansion, logging, and cattle grazing degrade riparian zones. Subsequent bank collapse leads to wider, warmer streams as well as higher sediment load. Cattle also contribute nutrients and coliforms directly into the stream (Sunohara et al., 2012). CAFO manure applications to pastures in the watershed add excess nutrients into the stream (Leet et al., 2012). Recreational use and channel modification also contribute to bank erosion and substrate disturbance.

Plecoptera are especially vulnerable to disturbance (DeWalt et al., 2005) and may be viewed as a first sentinel in watershed management of small streams. Species specific and quantitative data are therefore needed, especially in this reference watershed, for future comparisons and assessment of water quality and protection of this most interesting stream insect order. Effective protective measures (Stewart and Stark, 2002), especially riparian fencing (Arnaiz et al., 2011) and off-stream watering, should be encouraged through stakeholder cooperative efforts and targeted funding of state and federal resources to protect this healthy Plecoptera community.

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