Oceanological and Hydrobiological Studies

ISSN 1730-413X

Vol. XXXIV
No. 3
2005

Institute of Oceanography
University of Gdańsk
Poland

Oceanological and Hydrobiological Studies
Vol. XXXIV, No. 3

Institute of Oceanography (03-17) University of Gdańsk
2005

Research Article

TROPHIC STRUCTURE OF OZARK CAVE STREAMS CONTAINING ENDANGERED SPECIES

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Key words: endangered species, groundwater pollution, Ozark Plateaus, stable isotopes, trophic web.

Abstract

Six subterranean stream habitats in the central USA that contain rare and endangered cave animals were investigated. Water, sediment, and animal tissue were sampled to determine the degree of pollution inputs, and natural abundance stable carbon and nitrogen isotope analyses were employed to determine trophic structure and hypothetical influence of nutrient pollutants. Environmental quality sampling revealed contamination of water, sediments, and animal tissue by nutrients, toxic metals, and coliform bacteria, originating probably from septic systems and land application of animal feedlot wastes. Stable isotope analyses did not detect nutrient pollutants in the food webs of these habitats, but these analyses did elucidate trophic structure. Three trophic levels are evident in these subterranean streams: a detrital food base of clastic sediment, bat guano, and surface inputs; a second trophic level of detritivores, primarily crustaceans and amphibians; and a top level of predators, primarily fishes. Monitoring and management of sediment quality and flux is recommended to protect subterranean stream habitats.

INTRODUCTION

The fractured and dissolved carbonate terrain (karst) of the Ozark Plateaus ecoregion in central United States of America (USA) contains immense groundwater resources as well as an endemic and imperiled fauna. The southern portion of this ecoregion, the Springfield Plateau, has an unconfined aquifer that is highly susceptible to pollution from land application of animal wastes and septic wastes, and is experiencing rapid land use change and deteriorating water quality (MacDonald *et al.* 1976, Steele 1985). Previous research at Cave Springs Cave (Benton County, Arkansas) indicated that organic pollutants may have augmented the cave food web and impacted the community assemblage, which includes the Ozark cavefish (*Amblyopsis rosae*), designated a threatened species under the USA Endangered Species Act of 1973 (Graening and Brown 2003). This current study determined the food web dynamics and environmental quality of five similar caves containing similarly endangered species to determine if the stresses occurring at Cave Springs Cave were impacting other subterranean habitats.

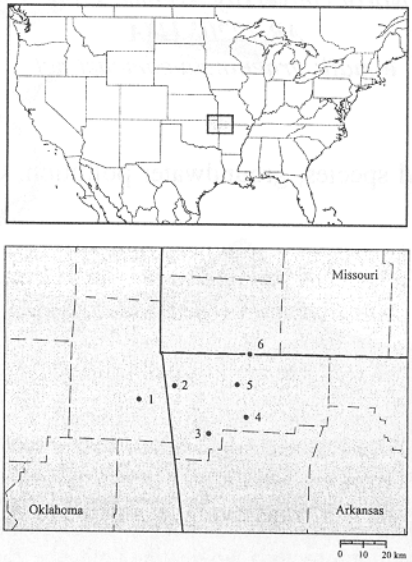

Fig. 1. The lower detail map shows the location of the six study caves (1 = January-Stansbury, 2 = Rootville, 3 = Logan, 4 = Cave Springs, 5 = Civil War, 6 = Bear Hollow) in relation to county boundaries (dashed lines), state boundaries of Arkansas, Oklahoma, and Missouri (solid lines); the upper map shows the location of the detail map (gray box) in relation to the USA state boundaries (solid lines).

Table 1

Rare and endangered species (or higher taxon) found in the six study sites - Bear Hollow Cave (BHC), Cave Springs Cave (CSC), Civil War Cave (CWC), January-Stansbury Cave (JSC), Logan Cave, and Rootville Cave. Data columns show in which site each species occurs, and its rarity ranking - whether or not it is listed under the USA Endangered Species Act, and its National Heritage program global rank (ranging from G1 = imperiled to G5 = common). The total species richness (of macroscopic fauna) of each site is also given.

	Habitats Containing the Species						**Rarity Ranking**	
Species / Taxon	**BHC**	**CSC**	**CWC**	**JSC**	**Logan**	**Root.**	**ESA List**	**Heritage Program**
Amblyopsis rosae		X	X		X	X	yes	G2
Caecidotea spp.		X	X	X	X	X	no	G1 - G4
Cambarus aculabrum	X				X		yes	G1
Diplopoda – cave-adapted				X	X	X	no	---
Myotis grisescens		X	X	X	X		yes	G3
Myotis sodalis		X		X	X		yes	G2
Spelobia tenebrarum				X			no	---
Stygobromus spp.	X	X	X	X	X		no	G1 - G4
Turbellaria – groundwater-adapted			X				no	---
Typhlotriton spelaeus	X	X		X	X	X	no	G4
Total Species Richness	22	40	9	55	34	15		

METHODS

The six subterranean streams studied occur in the same hydrogeological and biological setting: the Springfield Plateau unconfined aquifer in Mississippian-aged, cherty limestone of the Boone Formation. January-Stansbury Cave is located 14 km southeast of the City of Jay, in Delaware County, Oklahoma, and the other five sites are located Benton County, Arkansas, as follows: Cave Springs Cave is in the center of the City of Cave Springs; Bear Hollow Cave is 13 km north of Bentonville; Civil War Cave is 5 km west of Bentonville; Rootville Cave is 9 km northwest of Decatur, and Logan Cave is 13 km east of Siloam Springs (Figure 1). The rare and endangered species found in each cave are listed in Table 1.

Baseflow water samples were taken on 20 February 2000, 5 December 2000, and 19 August 2001. Three storm events were sampled before, during, and after spates (*i.e.*, the ascending and descending limbs of the hydrograph) as follows: storm # 1 on 7 November 2000 with 1 cm rain accumulation; storm # 2 on 13, 14, 15, and 18 February 2001, with 2.5 cm rain accumulation on 12 February, 7.5 cm on 14 February, and 1.3 cm on 15 February; and storm # 3 on 18, 19, and 21 September 2001, with 3.0 cm rain accumulation on September 17 and 1.6 cm on September 18. Grab samples of water were taken at the terminal sump of Bear Hollow Cave, the resurgences of Cave Springs Cave and Logan Cave, and at the first accessible perennial stream pools within Civil War Cave and Rootville Cave. January-Stansberry Cave was not sampled. The Water Quality Laboratory at the University of Arkansas at Fayetteville (UAF) analyzed the following parameters using USA Environmental Protection Agency methods: sulfate, nitrate, chloride, and fluoride in mg l^{-1} (Method 300.0); conductivity in µSiemens cm^{-1} (Method 120.1); ortho-phosphate in mg l^{-1} (Method 365.2); total organic carbon (TOC) in mg l^{-1} C (Method 415.1); turbidity in Nephlometric turbidity units (NTU) (Method 180.1); and total coliform bacteria and *Escherichia coli* densities in colony-forming units (CFU) 100 ml^{-1} (APHA Method 9223,B). Analysis of dissolved metals and metals in sediment and tissues were performed by the UAF Central Analytical Laboratory and reported on a wet basis in parts per million. For statistical analyses, any parameter that was not detected was assigned one-half of the detection limit value for that parameter.

The prominent food web components of all six subterranean streams were sampled for natural abundance stable carbon and nitrogen isotopes. Detailed methodology is described in Graening and Brown (2003). Surface crayfish (*Orconectes punctimanus* and *O. neglectus*) were collected by dip net, placed into clean glass vials, preserved in ice, and brought back to the lab where the abdominal muscles were excised. Where the mean length of crayfish was less than 50 mm, composite samples of abdominal muscle were used. Whole samples of larval salamanders (*Eurycea* sp. and *Typhlotriton spelaeus*) and composite samples of whole cave isopods (*Caecidotea* spp.) were utilized. Although the endangered cavefish and cave crayfishes at these study sites are important members of the food webs, the impact of sacrificing individuals precluded their use in this study. However, the tissue of one Benton cave crayfish (*Cambarus aculabrum*) in Bear Hollow Cave was used because this individual was found recently trampled by a trespasser who breached the cave gate (Graening *et al.* in review). As well, the tissue of one Ozark cavefish (*Amblyopsis rosae*) from Cave Springs Cave was used (Graening and Brown 2003) because this individual was found mortally wounded during a census, perhaps inadvertently trampled. Both individuals were used with permission from the USA Fish and Wildlife Service. Graening and Brown's (2003) isotopic data was used for Cave Springs Cave and Fenolio *et al.*'s (in press) for January-Stansbury cave. Poultry litter (feces, rice hull bedding, feathers, and blood) and beef cattle manure were obtained from the UAF Savoy Experimental Farm. To increase the sample size and accuracy of poultry litter stable isotope ratios, isotope values from this study were combined with similar data from an Ozark stream study by Kwak (1999), who obtained poultry wastes from the same source. Septic system leachate and biosolids were collected from two residential septic systems near Cave Springs Cave. Sewage sludge (press-cake) was collected from the nearby Springdale Sewage Treatment Plant, which has historically (1990 – 1996) applied these biosolids upon the Cave Springs Cave recharge area. Samples of soil, pasture grass (*Festuca arundinacea*) and leaf litter (*Quercus* spp., *Platanus occidentalis*, and *Celtis occidentalis*), were collected from the Cave Springs Cave recharge zone.

All samples were oven-dried or freeze-dried, pulverized, acidified with 1 N HCl to remove inorganic carbon, re-dried, and passed through a Number 30-mesh (590 μm) sieve. Samples were analyzed at the UAF Stable Isotope Laboratory for natural abundance carbon and nitrogen isotope ratio analyses using an isotope ratio mass spectrophotometer. The ratio of heavy and light isotopes in a sample (R_{sa}) were compared to the ratios in a standard (R_{std}), and the difference is calculated on a parts per thousand basis ($^{o}/_{oo}$, or "*per mil*"), in delta (δ) notation (McKinney *et al.* 1950): $\delta\ (^{o}/_{oo}) = (R_{sa} / R_{std} - 1) \times 1000$. The standard deviations of isotope standard runs at this lab were 0.16 $^{o}/_{oo}$ for $\delta^{13}C$ and 0.20 $^{o}/_{oo}$ for $\delta^{15}N$. Carbon isotopic compositions of animals reflect those of their diets within about 1 $^{o}/_{oo}$, with a slight enrichment of ^{13}C occurring overall (Peterson and Fry 1987). Nitrogen isotopic compositions of consumers are enriched by 2 to 5 $^{o}/_{oo}$ compared to their dietary nitrogen, and nitrogen stable isotopes can describe trophic structure and food chain length by the consistent enrichment of the isotope ratio ($^{15}N/^{14}N$) by a mean 3.4 $^{o}/_{oo}$ at each trophic level (DeNiro and Epstein 1981). Discriminant analysis dissimilarity plots were used to discern trophic interactions and a univariate plot of ^{15}N values was used to estimate trophic position.

This study was performed under the following permits: USA Fish and Wildlife Service Recovery Permits #PRT-834518, #TE834518-1, 2, 3 and Special Use Permit 43590-HLB-3-01; Arkansas Natural Heritage Commission Permit #S-NHCC-99-005; and Arkansas Game and Fish Commission Educational Collecting Permits #1082 and #1476. Additionally, permission from private landowners was obtained prior to entering any cave on private land, and no cave was entered when endangered bats were present.

Table 2

Summary statistics (sample size, minimum, mean, and maximum values) of water quality (base flows and storm flows) for the combined habitats of Bear Hollow Cave, Cave Springs Cave, Civil War Cave, Logan Cave, and Rootville Cave from 20 February 2000 to 21 September 2001. Beryllium, chromium, cobalt, molybdenum, and nickel were not detected in any water sample (detection limit = 1 ug l^{-1}).

Parameter	Unit	n	Minimum	Mean	Maximum
Physical					
Temperature	°C	35	11.0	13.6	15.5
Spec. Conduct.	µS cm^{-1}	46	153.0	276.6	480
Turbidity	NTU	46	0	2	10
pH	pH unit	31	5.8	6.3	7.4
Nutrients					
TOC	mg l^{-1} C	48	< 1.0	2.1	6.2
Nitrate-N	mg l^{-1} as N	48	< 0.05	3.12	8.35
Ortho-Phosphate	mg l^{-1} as P	48	0.009	0.023	0.046
Sulfate	mg l^{-1}	48	2.26	4.37	7.90
Dissolved Metals/Ions					
Aluminum	µg l^{-1}	39	< 1	11	70
Antimony	µg l^{-1}	39	< 1	2	10
Arsenic	µg l^{-1}	48	< 1	9	30
Barium	µg l^{-1}	48	20	60	370
Boron	µg l^{-1}	31	< 1	16	170
Cadmium	µg l^{-1}	48	< 1	1	4
Chloride	mg l^{-1}	48	1.90	5.74	9.90
Copper	µg l^{-1}	48	< 1	23	60
Fluoride	µg l^{-1}	48	< 1	47	150
Lead	µg l^{-1}	48	< 1	8	40
Selenium	µg l^{-1}	48	< 1	2	20
Vanadium	µg l^{-1}	48	< 1	2	10
Zinc	µg l^{-1}	48	< 1	36	390
Microbial					
Escherichia coli	CFU 100 ml^{-1}	48	< 10	336	7,380
Total Coliforms	CFU 100 ml^{-1}	46	20	3,906	24,192

RESULTS

Pooled results of base flow and storm flow sampling from February 2000 to September 2001 at Bear Hollow Cave, Cave Springs Cave, Civil War Cave, Logan Cave, and Rootville Cave are summarized in Table 2. All water samples detected some level of coliform bacterial contamination and many storm samples exceeded the Arkansas State Maximum Contaminant Level (MCL) for fecal coliforms; many water samples also exceeded the Arkansas State MCL for selenium, copper, and lead (Arkansas Pollution Control and Ecology

Table 3

Concentrations of metals (arsenic, barium, beryllium, cadmium, cobalt, chromium, copper, lead, selenium, vanadium, and zinc) in mg kg^{-1} (wet basis) of cave stream sediment, *Myotis* bat guano, and tissues of cave-adapted isopods (*Caecidotea* spp.), salamanders (*Eurycea* sp.), and sculpin (*Cottus carolinae*); detection limit was 1 mg kg^{-1}.

	As	Ba	Be	Cd	Co	Cr	Cu	Pb	Se	V	Zn
Bear Hollow Cave											
Sediment # 1	< 1	164	1	2	26	< 1	17	155	< 1	84	436
Sediment # 2	1	166	1	< 1	16	6	20	8	1	78	238
Sediment # 3	1	96	1	< 1	31	< 1	16	38	< 1	99	236
Eurycea sp.	< 1	1	< 1	< 1	< 1	< 1	1	2	< 1	< 1	3
Caecidotea sp.	< 1	159	< 1	1	< 1	< 1	99	< 1	< 1	26	188
Cave Springs Cave											
Sediment	< 1	59	2	1	5	< 1	16	323	< 1	78	144
Civil War Cave											
Sediment # 1	2	46	1	1	2	< 1	14	8	< 1	24	63
Sediment # 2	2	28	< 1	< 1	3	< 1	8	7	< 1	72	62
Caecidotea sp.	2	24	< 1	0.42	< 1	< 1	15	< 1	< 1	1	20
Logan Cave											
Sediment # 1	1	56	1	< 1	9	< 1	2	5	< 1	32	21
Sediment # 2	9	50	1	< 1	41	< 1	14	19	< 1	101	83
Sediment # 3	5	32	< 1	< 1	27	< 1	17	17	< 1	211	68
Bat guano	< 1	13	< 1	< 1	2	< 1	163	15	11	3	64
C. carolinae	< 1	5	< 1	< 1	< 1	1	2	12	4	< 1	15
Orconectes sp. # 1	< 1	8	< 1	< 1	< 1	< 1	30	11	< 1	< 1	33
Orconectes sp. # 2	< 1	13	< 1	< 1	< 1	< 1	40	12	< 1	< 1	58
Rootville Cave											
Sediment	< 1	101	1	< 1	10	< 1	10	14	< 1	58	47

Commission 1998). Analyses of metals in cave stream sediments, and tissues of crustaceans and salamanders are summarized in Table 3. Stable isotope analyses were performed to determine if nutrient pollutants were augmenting the trophic webs of the study streams. Analysis of the trophic components of Bear Hollow Cave stream indicate that cave sediment and surface soil were the trophic base, and may be directly utilized by larval eurycid salamanders (Figure 2). Because of the distance in isotopic signatures, little other interaction between trophic members could be inferred. The trophic web of Cave Springs Cave is more complex (Figure 3), and Graening and Brown (2003) reported that this food web had three distinct trophic levels: a food base of benthic detritus; a guild of invertebrate consumers – isopods, crayfish, and historically, amphipods; and a top predator - Ozark cavefish. Graening and Brown (2003) also concluded that the primary diet of Ozark cavefish was stygobitic isopods, and secondarily, guano. Guano was not likely the main food item of isopods; rather, sewage-derived organic matter was a likely source because of its similar

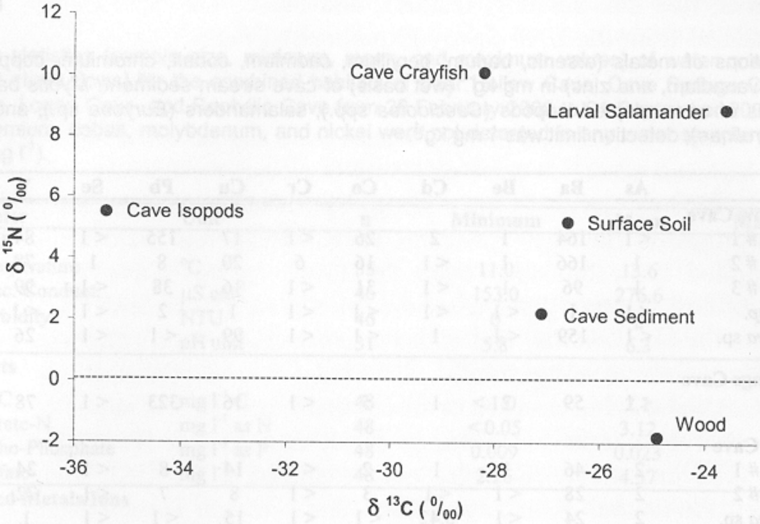

Fig. 2. Crossplot of delta ^{13}C versus delta ^{15}N mean ratios ($^o/_{oo}$) of Bear Hollow Cave food web components: larval salamander (*Eurycea lucifuga*), cave isopods (*Caecidotea ancyla*), cave crayfish (*Cambarus aculabrum*), cave stream sediment, surface soil, and timbers from an historic mining operation inside the cave. These results indicate that cave sediment and surface soil appear to be the trophic base, and that little trophic interaction exists between the fauna sampled.

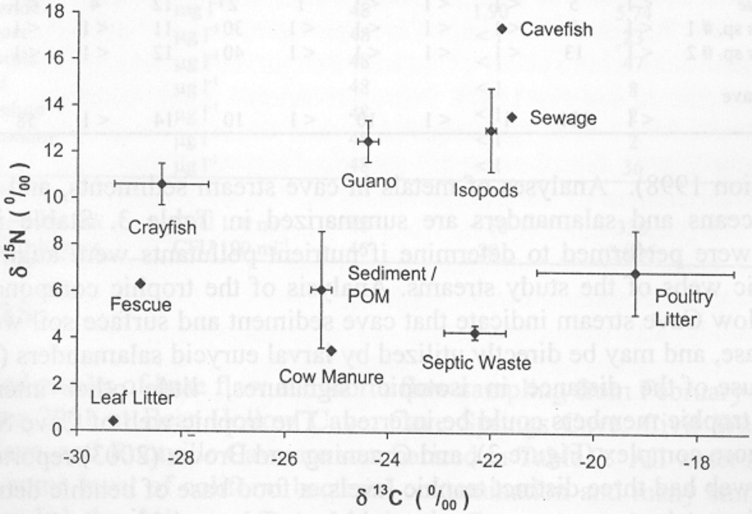

Fig. 3. Crossplot of delta ^{13}C versus delta ^{15}N mean values ($^o/_{oo}$ +/- 1 SE) of Cave Springs Cave food web components (from Graening and Brown 2003): cave isopods (*Caecidotea stiladactyla*, n = 2), Ozark cavefish (*Amblyopsis rosae*), cave stream sediment and POM - particulate organic matter (n = 4), epigean crayfish (*Orconectes punctimanus*) and potential organic matter inputs of septic waste (n = 3), poultry litter (n = 5), swine waste (n = 4), and cow manure.

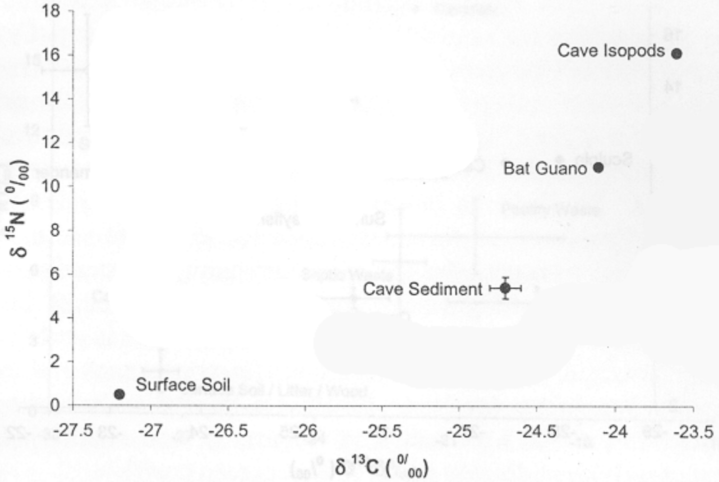

Fig. 4. Crossplot of delta ^{13}C versus delta ^{15}N mean ratios ($^o/_{oo}$ +/- 1 SE) of Civil War Cave food web components: cave isopods (*Caecidotea antricola*), *Myotis* guano, cave stream sediment (n = 2), and surface soil. These results suggest that cave sediment and bat guano are the trophic base, and that bat guano may be consumed directly by cave isopods.

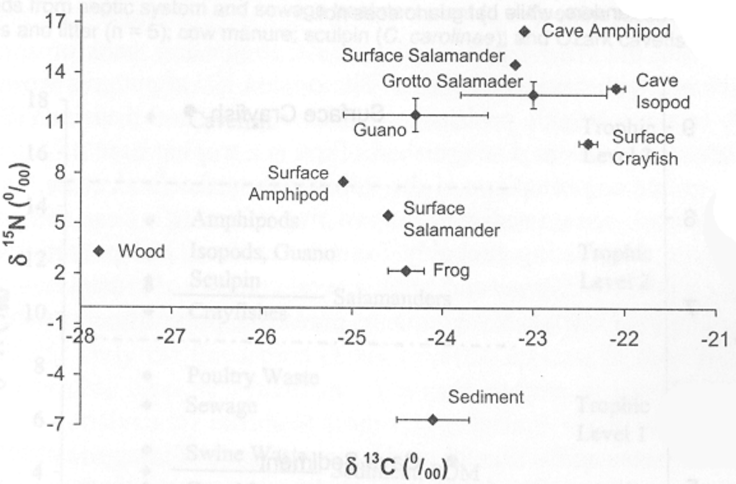

Fig. 5. Crossplot of delta ^{13}C versus delta ^{15}N mean ratios ($^o/_{oo}$) +/- 1 SE of January-Stansbury Cave food web components (from Fenolio *et al.*, in press): cave stream sediment (n = 3), pickerel frogs (*Rana palustris*, n = 3), epigean salamander (*Eurycea* sp., n = 2), epigean crayfish (*Orconectes* sp., n = 3), stygobitic isopods (*Caecidotea* spp., n = 3) and amphipods (*Stygobromus* sp., n = 2), epigean amphipods (*Gammarus* sp.), *Myotis* guano (n = 3), grotto salamander (*Typhlotriton spelaeus*, n = 4), and wood debris from a historic distillation operation inside the cave (n = 2). These results suggest that cave sediment and bat guano are trophic resources for salamanders and crustaceans.

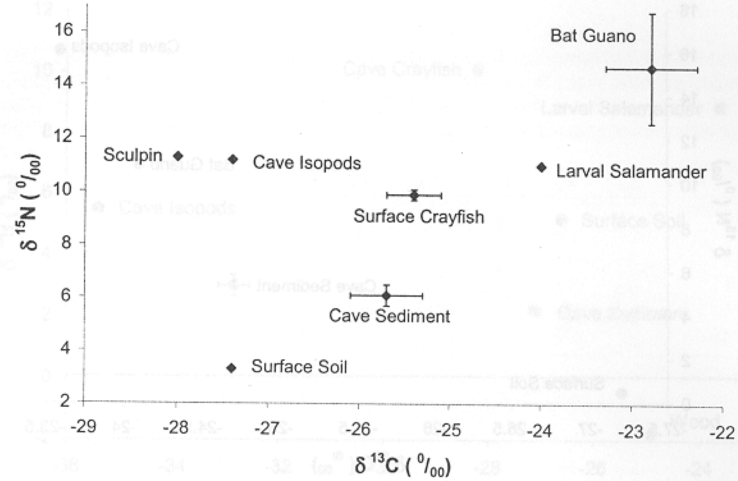

Fig. 6. Crossplot of delta ^{13}C versus delta ^{15}N mean ratios ($^{o}/_{oo}$ +/- 1 SE) of Logan Cave food web components: cave isopods (*Caecidotea antricola*), sculpin (*Cottus carolinae*), surface crayfish (*Orconectes neglectus* and *O. punctimanus*, n = 4), larval grotto salamander (*Typhlotriton spelaeus*), *Myotis* guano (n = 2), cave stream sediment (n = 4), and surface soil. These results indicate that cave sediment is probably derived from surface soil, and provides a trophic base for crustaceans and larval salamanders, while bat guano does not.

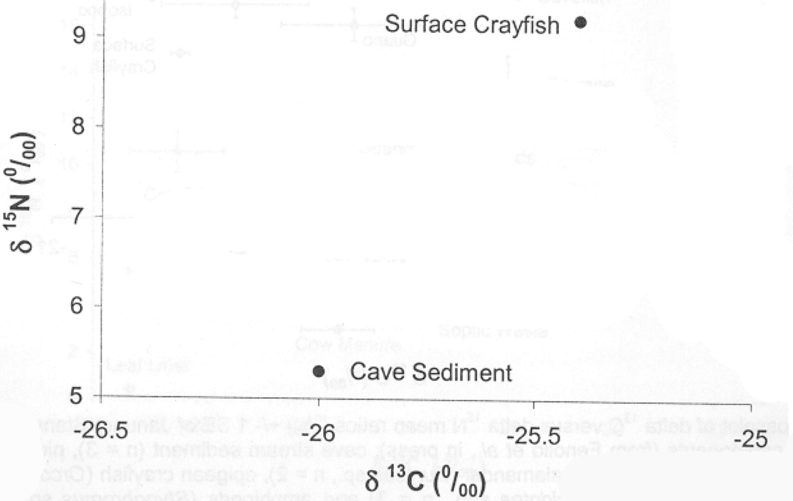

Fig. 7. Crossplot of delta ^{13}C versus delta ^{15}N mean ratios ($^{o}/_{oo}$ +/- 1 SE) of Rootville Cave food web components: surface crayfish (*Orconectes neglectus*) and cave stream sediment. These results indicate that cave sediment provides a trophic resource for crayfish.

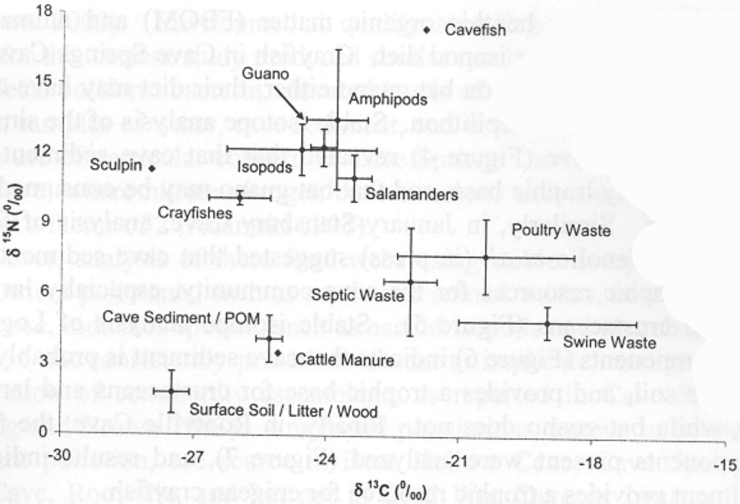

Fig. 8. Crossplot of delta ^{13}C versus delta ^{15}N mean ratios ($^{0}/_{00}$ +/- 1 SE) of pooled data of trophic components from all six study sites: crayfishes (*Orconectes* spp. and *C. aculabrum*, n = 13); *M. grisescens* guano (n = 11); cave stream sediment and particulate organic matter (n = 15); surface soil, leaf litter, fescue, and submerged wood (n = 8); stygobitic isopods (*Caecidotea* spp., n = 8); salamanders (*T. spelaeus* and *Eurycea* spp., n = 8); amphipods (*G. minus* and *Stygobromus* spp., n = 3); biosolids from septic system and sewage treatment plant (n = 4); swine feces and litter (n = 4); poultry feces and litter (n = 5); cow manure; sculpin (*C. carolinae*); and Ozark cavefish (*A. rosae*).

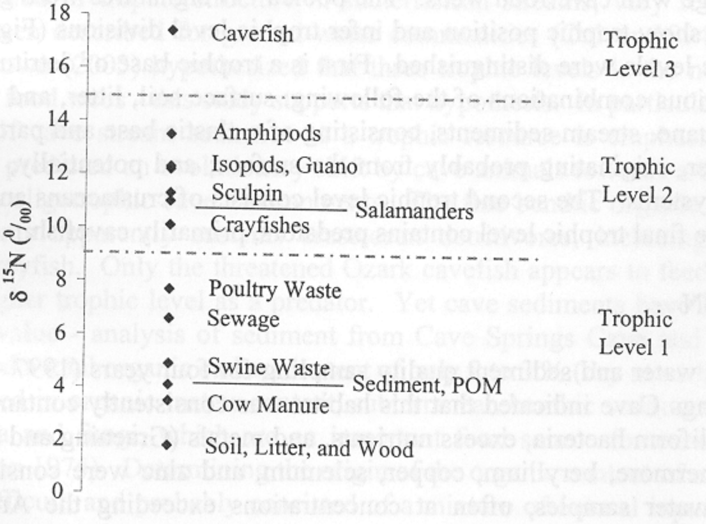

Fig. 9. Univariate plot of ^{15}N ratios of all pooled food web components of the six study caves, showing trophic position and inferred trophic levels (dashed lines).

isotopic signature. Fine benthic organic matter (FBOM) and animal wastes could also contribute to the isopod diet. Crayfish in Cave Springs Cave did not appear to rely exclusively upon bat guano either; their diet may have consisted of a mixture of FBOM and epilithon. Stable isotope analysis of the simple food web in Civil War Cave (Figure 4) revealed that that cave sediment and bat guano are the likely trophic base, and that bat guano may be consumed directly by cave isopods. Similarly, in January-Stansbury Cave, analysis of food web components by Fenolio *et al.* (in press) suggested that cave sediment and bat guano were trophic resources for the cave community, especially larval salamanders and crustaceans (Figure 5). Stable isotope analysis of Logan Cave food web components (Figure 6) indicate that cave sediment is probably derived from surface soil, and provides a trophic base for crustaceans and larval salamanders, while bat guano does not. Finally, in Rootville Cave, the few food web components present were analyzed (Figure 7), and results indicate that cave sediment provides a trophic resource for epigean crayfish.

The data of trophic components from all six study sites were then pooled and graphed (Figure 8) to elucidate general trophic interactions in Ozark cave streams. There was a tight clustering of isotopic signatures of amphipods, isopods, crayfishes, salamanders, and guano, suggesting strong trophic interaction. Confined animal feeding operation wastes and septic wastes were clustered separately from the other trophic components, suggesting weak or non-existent trophic linkage with cave food webs. The pooled ^{15}N signatures were graphed separately to show trophic position and infer trophic level divisions (Figure 9). Three trophic levels were distinguished. First is a trophic base of detritus, consisting of various combinations of the following: surface soil, litter, and woody debris; bat guano, stream sediments, consisting of a clastic base and particulate organic matter, originating probably from the surface; and potentially, wastes from septic systems. The second trophic level consists of crustaceans and salamanders. The final trophic level contains predators, primarily cavefish.

DISCUSSION

Intensive water and sediment quality sampling for four years (1997 –2001) in Cave Springs Cave indicated that this habitat was consistently contaminated with fecal coliform bacteria, excess nutrients, and metals (Graening and Brown 2003). Furthermore, beryllium, copper, selenium, and zinc were consistently detected in water samples, often at concentrations exceeding the Arkansas MCL's for chronic and acute toxicity to aquatic life (Arkansas Pollution Control and Ecology Commission 1998). Toxic metals were also detected in cave sediments and the tissues of cave isopods and one Ozark cavefish (Graening and Brown 2003). Environmental quality sampling of four additional cave streams for this current study produced similar results – evidence of contamination by fecal coliform bacteria, elevated levels of dissolved nutrients, and toxic metals in samples of water, cave sediment, and tissues of cave animals. Excess nutrients are of particular concern in Cave Springs Cave, Civil War Cave, and Logan Cave, where nitrate-nitrogen concentrations exceeded regional averages by at least a factor of 2 (Adamski 1997).

However, analysis of these food webs using stable isotope ratios failed to detect nutrient pollutants, such as septic and animal wastes, in trophic linkages. Furthermore, indicator species, such as asellid isopods and stygobromid amphipods, were not consistently present or absent to implicate nutrient pollution in the alteration of community assemblage, as reported in Cave Springs Cave (Graening and Brown 2003). Amphipod populations, known to be susceptible to nutrient pollution, are scarce in Bear Hollow Cave, Cave Springs Cave, Logan Cave, Rootville, and but not in Civil War Cave or January-Stansbury Cave. The impact of organic pollutants upon the cave stream community assemblages remains unclear. While this study could not document any direct impact of these pollutants upon the study ecosystems, these pollutants are present and remain a novel stress upon these species adapted to oligotrophic, pristine groundwater habitats.

Perhaps the most valuable information gained from this study is the general elucidation of trophic structure in subterranean streams; very few food webs have been described for ground-water communities (Culver 1994). Graening and Brown (2003) hypothesized that three trophic levels is the norm for cave stream food webs - this study supports that hypothesis. In particular, the importance of cave stream sediment as a trophic resource is emphasized. Culver (1985) predicted an evolutionary shift by cave animals towards a diet of clastic mud in oligotrophic cave environments. The fine benthic organic matter in the sediments apparently sustains crustacean detritivores, including endangered cave crayfish. Only the threatened Ozark cavefish appears to feed consistently at a higher trophic level as a predator. Yet cave sediments have limited nutritional value - analysis of sediment from Cave Springs Cave and Logan Cave revealed a total organic carbon content of only 2 to 3 % (dry mass basis). While restricted in organic matter content, subterranean benthic sediments do contain bacteria and fungi, which are an important food source for cave crustaceans (Dickson 1975). Determining the origin of the organic content of cave sediment was difficult, and probably consisted of a mixture of natural inputs (leaf litter, soil, bat guano) and occasionally, anthropogenic inputs (septic and animal wastes). Heavy metals may accumulate in clastic sediments because of the copious number of binding sites. In this study, excessive concentrations of metals were detected in cave sediments and tissues of cave animals. It is recommended that sediment quality monitoring continue, and that sediment mass flux be monitored as well because of intensive land conversion activities taking place upstream of these cave habitats.

ACKNOWLEDGEMENTS

This study was funded by the Arkansas Field Office of the USA Fish and Wildlife Service (R. Nilius, sponsor). The arduous fieldwork could not have been accomplished without the assistance of many colleagues, especially A. V. Brown and M. E. Slay (both University of Arkansas at Fayetteville), and D. B. Fenolio (University of Oklahoma at Norman). I am also grateful to the landowners who allowed access to their caves and to their dedication to cave conservation.

REFERENCES

Adamski J., 1997, *Nutrients and pesticides in ground water of the Ozark Plateaus in Arkansas, Kansas, Missouri, and Oklahoma*, U.S. Geological Survey Water Resource Investigations Report #96-4313.

Arkansas Pollution Control and Ecology Commission, 1998, *Regulation 2, as amended: Regulation establishing water quality standards for surface waters of the state of Arkansas*, Little Rock, Arkansas.

Culver D. C., 1985, *Trophic relationships in aquatic cave environments*, Stygologia, 1(1), 43-53.

Culver D. C., 1994, *Species interactions*, [in:] *Groundwater ecology*, Academic Press, San Diego, California, 271-286.

DeNiro M., Epstein S., 1981, *Influence of diet on the distribution of nitrogen isotopes in animals*, Geochimica et Cosmochimica Acta 45, 341-351.

Dickson G., 1975, *A preliminary study of heterotrophic microorganisms as factors in substrate selection of troglobitic invertebrates*, National Speleological Society Bulletin, 37(4), 89-93.

Fenolio D. B., Graening G. O., Stout J., *Seasonal Movement Pattern of Pickerel Frogs* (Rana palustris) *through an Ozark Cave and Trophic Implications Supported by Stable Isotope Evidence*, Southwestern Naturalist, in press.

Graening G. O., Brown A. V., 2003, *Ecosystem dynamics of an Ozark cave stream*, Journal of the American Water Resources Association, 39(6), 1497-1507.

Graening, G. O., Slay M. E., Brown A. V., *Subterranean Biodiversity of Arkansas, Part 4: Status Update of the Endangered Benton Cave Crayfish,* Cambarus aculabrum *(Decapoda: Cambaridae*), Southwestern Naturalist, in review.

Kwak T., 1999, *Animal waste nutrient dynamics in the stream food web: evaluation of multiple stable isotopes for detection*, Final Report to the Arkansas Game and Fish Commission, Little Rock, Arkansas, 27 pp.

MacDonald H., Jeffus H., Steele K., Kerr T., Wagner G., 1976, *Groundwater pollution in Northwestern Arkansas*, Special Report 25, Arkansas Agricultural Experiment Station, University of Arkansas, Fayetteville.

McKinney C., McCrea J., Epstein S., Allen H., Urey H., 1950, *Improvements in mass spectrometers for the measurement of small differences in isotope abundance ratios*, Review of Scientific Instruments, 21, 724-730.

Peterson B., Fry B., 1987, *Stable isotopes in ecosystem studies*, Annual Review of Ecology and Systematics, 18, 293-320.

Steele K. 1985, *Groundwater in northwest Arkansas*, Arkansas Naturalist, 3(7), 5-10.