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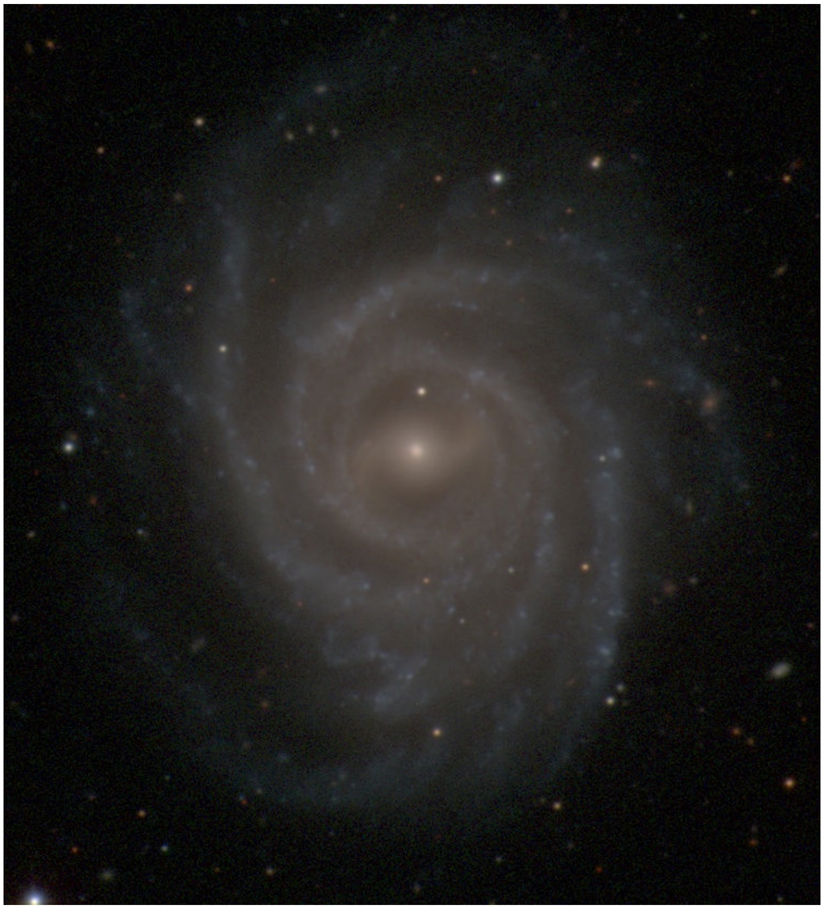

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ARKANSAS TECH UNIVERSITY
DEPARTMENT OF PHYSICAL SCIENCES
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Arkansas Academy of Science, Dept. of Physical Sciences, Arkansas Tech University

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Collis Geren	2008
Joyce Hardin	2009
Scott Kirkconnell	2010
Jeff Robertson	2011

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COVER: The Spiral Galaxy, NGC3124, a Hubble class SAB(rs)bc galaxy. This galaxy has a central bar that appears to contain a counter-rotating spiral. However simulations indicate that this is just a short-lived feature. Provided by Marc Seigar, UALR.

ARKANSAS ACADEMY OF SCIENCE 2011

APRIL 8-9, 2011
95th ANNUAL MEETING

University of Arkansas at Monticello
Arkansas

JOURNAL
ARKANSAS ACADEMY OF SCIENCE

Annual Meeting April 8-9, 2011
University of Arkansas at Monticello

Jeff Robertson
President

Anthony K Grafton
President-Elect

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Vice-President

Jeff Robertson
Secretary

Mostafa Hemmati
Treasurer

Mostafa Hemmati
JAAS Editor-in-Chief

Collis Geren
Historian

Secretary's Report

MINUTES OF THE 95th MEETING

ARKANSAS ACADEMY OF SCIENCE
SPRING 2011 BUSINESS MEETING MINUTES
April 9, 2011
University of Arkansas at Monticello

1. The meeting was called to order by President Jeff Robertson.

2. <u>Local Arrangements Committee, 2011: Morris Bramlett</u>
   Registration information, campus orientation, and meeting schedules were presented by Morris Bramlett and Glenn Manning, LOC. There were ~170 registered participants, 63 oral presentations and 35 posters.

3. <u>Secretary's Report: Jeff Robertson</u>
   Minutes from the 2010 Fall Executive Committee Meeting in November were reviewed and accepted. There were currently approximately 126 AAS members (48 of which are life members) and 26 new members this past year.

4. <u>Treasurer's Report: Mostafa Hemmati</u>
   An accounting of the AAS "net worth" for 2010 was presented and discussed by the membership. The report was reviewed by an auditing team made of selected members of the Academy and accepted by the membership (see 2010 financial statement).

5. <u>Historian's Report: Collis Geren</u>
   The spring meeting of the Arkansas Academy of Science at the University of Arkansas at Monticello is the 95 annual meeting of the Academy. This meeting marks the fifth time that the Academy has held its annual meeting at UAM. Previous meetings were in 1936, 1942, 1985, and 1997. The University of Arkansas at Monticello was formally opened in 1910 as the 4th District Agricultural School. In 1925 the name was changed by the legislature to the Arkansas Agricultural and Mechanical College. The institution was accredited as a junior college in 1928 and as a four year college in 1940. It became part of the University of Arkansas System on July 1, 1971.
   The role of the Academy in Arkansas continues to expand with the addition of funding for Undergraduate Research Awards as well as support of broader studies of problems of general interest to Arkansas. The online presence of the Academy also continues to develop. The proceedings of the Academy are published in the peer-reviewed Journal, which is available online as a link through the AAS membership pages at http://www.ArkansasAcademyofScience.org.

6. <u>Newsletter Editor's Report: Jeff Robertson</u>
   The newsletter was sent out completely electronically and distributed to members past and present, to all academic science department chairs of 4-year and 2-year institutions as well as related institutions throughout the state (e.g. Arkansas Game and Fish, US Forest Service, Natural Heritage Commission, etc).

7. <u>Journal (JAAS #64) Report: Editor-In-Chief Mostafa Hemmati & Managing Editor Ivan Still</u>
   Twenty six manuscripts were submitted for consideration of publication in volume 64 (2010) of the JAAS at the UALR meeting in April 2010. This was a decrease from the 30 submitted in the previous year. This is the second year of declining

submissions. Dr. Still checked each manuscript for style, grammar, format, etc. In several cases, authors did not follow the "Instructions to Authors"; so some manuscripts were not ready for submission from the meeting, and some submitted manuscripts being returned to authors shortly after the meeting.

Abstracts were sent to potential reviewers at the end of May resulting in the recruitment of about 70 reviewers, as well as several more who were added to a reviewer database for future journal editions. Dr. Hemmati handled Physical Science papers and recruited Drs. Collis Geren, Dr. Salomon Itza and Dr. Bill Doria to serve as Associate Editors, while Dr. Still handled Biological Science manuscripts. Manuscripts were sent out electronically for review at the beginning of June and reviews returned to the Managing Editor at the end of June/middle of July. The review process proceeded efficiently, aided by the use of e-mail. We have opened a Yahoo account (jarksci@vahoo.com) specifically for JAAS to overcome some of issues with email servers treating ATU email as a junk. The Yahoo account was used for most outgoing reviews, and communication to authors was handled via Dr Still's ATU account (istill@atu.edu). Between the two email systems, no e-mails appeared to be lost this year!

Most authors were contacted by e-mail in the middle week of July 2010 and informed if their paper was accepted with the need for minor or major revision or whether their paper was rejected. Of the papers sent out for peer review, two manuscripts were unanimously rejected by the three reviewers due to significant issues with and/or lack of novel data. Most required minor revision while five required major revisions. All authors were asked to retum their revisions to the Managing Editor electronically within six weeks of receipt of the review by their e-mail system, with the page charges being submitted to Dr. Hemmati, Editor-in-Chief. Two manuscripts were withdrawn without prejudice by the corresponding authors, and we made the suggestion that authors resubmit their papers at the next meeting. No manuscripts were lost from the meeting, suggesting that the new manuscript submission system prior and at the annual meeting and the complete adoption of electronic manuscript processing, has overcome meeting associated submission issues.

The journal was assembled by the end of December. Vol. 64 is 160 pages long with 125 pages of submitted manuscripts.

We would like to thank the reviewers and Assistant/ Associate Editors for their help in the preparation of volume 64, and finally the corresponding authors of submitted manuscripts and the reviewers for the mostly successful implementation of journal submission requirements.

8. Committee Reports:

a. AAAS Representative Report: Scott Kirkconnell

The American Association for the Advancement of Sciences (AAAS) meetings February 17-22, 2011 Washington DC.

Representing the Arkansas Academy of Science, I attended the annual combined meeting of NAAS/ AAAS in Washington DC.; February 17-22, 2011. The AAAS opening ceremony and President's Address Thursday night involved a broad-ranging discussion of President Alice Huang's scientific life journey, research interests, an interpretation of where science "is" in the United States, recognition of attending Junior Academy members, etc. The affiliates' meeting the next morning included a somewhat shocking yet very engaging description of the recent earthquakes' devastating impact on Haiti. The afternoon (1-3 p.m.) NAAS Council of Science Academy Presidents and Executive Directors meeting included exchanges on numerous topics that are quite pertinent to the Arkansas Academy of Sciences. The following NAAS forum provided an opportunity for extremely rich exchanges between members of the various state academies on issues of common interest (47 academies are in NAAS, although fewer than half of them were represented at this session). I attended a potpourri of sessions during the following four days including discussions of science funding, interdisciplinary biomimetics, the human-biosphere interface and its monitoring through evaluation of metal use patterns by various countries, research frontiers in sustainability, dynamics of conflict and cooperation, integrative approaches to comprehending the politics of natural resource policies, evolutionary and genetic dialectic tensions between self-serving and societal motives, efforts to merge neuroscience; genomics; and anthropology, initiatives to strengthen undergraduate and precollege curricula through introduction and creative uses of new modalities such as M.I.T.' s Open Courseware; HHMI' s institutional grants; three-dimensional complementary protein models; and cost-effective educational laboratory software. Representatives of the Max Plank Institute described some absolutely amazing work entitled "How Organisms Talk to Each other (chemically speaking)." This research was forthrightly (and quite accurately) introduced as "A study of the incomprehensible by the incompetent." The work most elegantly established the explosive power of synergy between the revolutions in information science, instrumentation, and chemistry. These investigators recognize they have barely scratched the surface in cataloging the more than 300,000 metabolites plants produce and often use to communicate with one another and other elements of the biosphere. Participating chemicals are being evaluated at the atomic level and the information processing accomplished by the few plants they have studied in southern Utah has opened the door to comprehension that our ignorance is orders of magnitude greater than we ever suspected. One presenter concluded his talk with the comment, "We are NEVER going to be able to store even a small portion of this biological information in freezers."

b. Development Committee: Anthony Grafton

In April of last year, the AAS authorized me to manage a membership recruitment campaign and seek was to broaden the awareness and impact of the Academy. In support, the Academy provided $2750 to be used for expenses. After the beginning of the new fiscal year in late summer, I requested and received the money from the AAS Treasurer and deposited it in a Lyon College account from which I have spent as follows:

Starting balance:	$2,750.00
Mailing materials (paper, envelopes, ink, etc.):	$ 352.46
Postage:	$ 196.91
Stipend (employee to help prepare the *AAS Spotlight*):	$ 527.03
Total Expenses	$1,076.40
Check back to AAS	$1,673.60
Current Balance	$ 0.00

The expenses have supported direct letters to hundreds prospective members. New members have been sent a membership card and certificate. In addition to the traditional paper method of joining the Academy, I have created a web page (http://www.compchem.org/aas) that allows people to join quickly online and be billed later.

As a way of increasing the visibility and relevance of the Academy, I initiated the creation and distribution of the *AAS Spotlight*, a simple newsletter-style publication designed to highlight one Arkansas scientist in each issue. As described to the Academy leadership when the idea was proposed, I hired a local individual (Leslie Malland) to conduct interviews and prepare the *Spotlight.* Issues can be viewed here: http://www . compchem.org/aas/Spotlight/

Additionally, I have created an online membership database that allows members to update contact information and officers to access all the information for non-student members. This database is current found at http://www.compchem.org/aasmembers.

Since the membership drive began in August, 26 people have joined (or re-joined) the Academy, resulting in an 18% increase in non-student membership. The money received (or due) from these new members totals approximately $900, which is about $200 less than the money spent on the campaign.

I would ask the Executive Committee to decide if this campaign should continue during the coming year, and, if so, determine how best to fund it.

I would also ask the Executive Committee to recognize and discuss the importance of involving and retaining new members for the long-term health of the Academy.

9. Business Old and New:

a. The 96th annual AAS meeting will be April 13-14, 2012 at Southern Arkansas University Hosts for future meetings are solicited.
b. Could there be incentives and rewards for membership? (i.e. cheaper pre-registration, discounts for early renewal of membership, etc.)
c. Fund up to four AAS Undergraduate research awards. Require them to present at annual meeting with a report written upon completion of research due May 1 to Academy (publication in JAAS in lieu of report also acceptable).

10. Actions and Motions Items:

a. AAS constitution and by-laws need review at Executive Committee Meeting.
b. Continuation of AAS Undergraduate Research Awards approved.
c. Submit letter of recognition to $1,000 institutional sponsoring officials and recognition in the JAAS.
d. Non-JAAS budget approved:

$2,500	Undergraduate Research Grants
$2,000	Development/Membership campaign (Kurt Grafton)

$1,000	AAAS representative travel (Scott Kirkconnell)
$ 250	Affiliate student awards (Junior Academy)
$ 400	Affiliate student awards (Arkansas Science Fair)
$ 100	Affiliate student awards (AJSHS)* Affiliate student awards (Arkansas Talent Search, *if requested)
$1,400	AAS Spring meeting student awards
$ 200	AAS Secretary, journal mailings
$**7,850**	**TOTAL** (outside of costs associated with JAAS publication)

e. Bill Doria elected to Vice-president and assuming webmaster duties.

f. Marc Siegar taking over as newsletter editor.

11. Undergraduate Research Awards: Kurt Grafton

We received five applications for funding under the AAS URA program. Three people have reviewed the applications: Dr. Collis Geren, Dr. Jeff Robertson, and myself. Each reviewer ranked the proposals, and the top three were funded, which is the same number we funded last year. I request that the Executive Committee discuss and determine whether the Academy should continue the AAS URA program in its current form. I recommend that we do.

12. Incoming Presidential Address from Kurt Grafton: Thoughts on 2017 and the future of Academy meetings

The 100th annual meeting of the AAS is five years away. This should be a major event, and major events take planning. I propose the following as we approach this major milestone in the history of the Academy.

a. The 100th annual meeting should be held in Little Rock, the capital and clearly the most central location in the state.

b. The 100th annual meeting should be held not on a campus, but at an appropriate convention center or hotel that can accommodate such an event.

c. The 100th annual meeting should be planned by the officers of AAS along with two or three volunteers from the Academy.

d. The 100th annual meeting should be three full days (Thursday through Saturday) and should include things like a speech by the Governor and other activities appropriate to such an occasion.

e. The 100th meeting should be the target date for the Academy to carry out one of our major, Constitutionally-defined functions of "..unification of [scientific] interests in the State." Therefore, we should work to include as many of the following organizations' regular meetings in the annual AAS meeting as possible:

i. The Arkansas Space Grant Consortium
ii. Arkansas INBRE
iii. Arkansas Undergraduate Research Conference
iv. Arkansas State Science Fair
v. Arkansas Junior Academy of Science

f. The ultimate goal should be to have the 100th meeting to be the first meeting that includes all of the organizations mentioned above, and have that cooperation continue after that point. Such inclusion will require some groups to move meetings from the spring to the fall, or vice- versa.

g. The annual meetings after the 100th should all be held in Little Rock. The officers of the AAS should be the primary planners of each subsequent meeting along with a "host" institution that would be involved in the planning and operation of the meeting. Doing it this way will provide ongoing consistency in meeting planning and registration that we lack now. It will also allow the Academy to make long-term planning decisions in how the meetings are conducted that are, now, left up to host institutions.

Meeting adjourned
Jeff Robertson, AAS Secretary

Treasurer's Report
ARKANSAS ACADEMY OF SCIENCE
2011 FINANCIAL STATEMENT
December 21, 2011

Balance – December 21, 2011	**$79,787.95**
Balance – December 16, 2010	**$73,303.29**
Net Gain	**$ 6,484.66**

DISTRIBUTION OF FUNDS

Checking Account Bank of the Ozarks, Russellville, AR, December 21, 2011	**$13,848.63**
Certificate of Deposit Life Membership Endowment, Bank of the Ozarks, Russellville, AR, December 1,2011 Previous CD + $3,000 from the Bank of Ozark's Checking, New Maturity Date 06-11-2012	**$18,358.68**

Dwight Moore Endowment + **$20,617.62**
(Dwight Moore's final balance of $6,002.73+
Short term CD's final balance of $4,157.77+
$9,839.50 from the Bank of the Ozarks checking account = $20,000.
The new CD will mature on 12-10-2011)

Phoebe and George Harp Endowment **+** **$18,745.81**
($7601Harp+$6515.15CD+$3383.85Checking)
=$17500 CD + Interest Paid
After maturity in Bank of America, opened a new CD in Bank of the Ozarks on Nov. 15, 2010. Maturity Date 07-15-2012; December 1, 2011

Short Term CD **$8,217.21**
Bank of the Ozarks, Russellville, AR, October 25, 2010
New Maturity date 03-27-2012, December 1, 2011

Combined interest on all accounts as of December 1, 2011 was $660.55

TOTAL **$79,787.95**

INCOME:

1. Transfer from CD to Checking **-0-**

2. GIFTS RECEIVED

a. Ouachita National Forest - Sponsorship	$1,000
b. Karen Arbuckle, Cossatot	$30
	$1,030

3. INTEREST (Interest Earned Year to Date, ~ December 1, 2011)

a. Checking Account, Bank of the Ozarks, …448	$8.77
b. CD1 (Bank of the Ozarks), …..929	$176.22
c. CD2 (Bank of the Ozarks), ….594	$100.00
d. CD3 (Bank of the Ozarks), …..583	$202.16
e. CD4 (Bank of the Ozarks)……396	$173.40
All interests were added to the CDs	$660.55

4. JOURNAL

a. Page Charges	$8,400
b. Laurence Hardy, 1 copy	$50
c. Copyright Clearance Center	$111.12
d. Two copies, AR Natural Heritage	$107.50
e. Subscriptions, University of Arkansas	$1,500
	$10,168.62

5. JOURNAL CONTRIBUTION **-0-**

6. MEMBERSHIP

a. Associate-Student	$60
c. Individual	$690
d. Institutional	$400
e. Life (Ivan Still)	$125
f. Sponsoring	$90
g. Individual from Annual Meeting (UALR)	$1,140
h. Sustaining	$35
	$2,540

7. MISCELLANEOUS INCOME

a. Returned check from membership drive	$1,673.60
b. Unused undergraduate research grant	$400
c. Returned undergraduate research grant(Joyce)	$500
	$2,573.60

TOTAL INCOME **$16,312.22**

EXPENSES

1. STUDENT AWARDS

1. James Playford	$100
2. Jessica Hartman	$50
3. Roy Downs	$50
4. Magsood Ali Mughal	$100
5. Shyam Thapa	$50
6. Claudia Gonzalez	$100
7. Nicole Segear	$50
8. Drew Jones	$100
9. David Graves	$50
10. Erin Basiger	$50
11. Chris Paight	$100
12. Francis Poole	$100
13. Fanchon Laster	$50
14. Kristopher Watson	$50
	$1,000

2. AWARDS (Organizations)

a. Junior Science and Humanities Sym.	$100
b. Arkansas State Science Fair	$400
c. Arkansas Junior Academy of Science	$250
d. Arkansas Science Talent Search	-0-
	$750

3. UNDERGRADUATE RESEARCH AWARDS

a. Dr. Willyard, Hendrix College	$500
b. Dr. Hardin, Hendrix College	$500
c. Dr. Kissel, UA Monticello	$500
d. Dr. Reyna, OBU	$500
	$2,000

4. JOURNAL

a. Volume 64 Printing Cost	$2,713.54
b. Journal Mailing Cost	$50.76
c. Journal Editorial Cost	-0-
	$2,764.30

5. NEWSLETTER **-0-**

6. MISCELLANOUS EXPENSES

1. Partial Reimbursement, Dr. Kirkconnell's Trip	$855.10
2. Kurt's payment for cost of plaque	$43.44
3. Presentation Awards' mailing cost	$15.12
4. Membership Drive, Kurt	$2000
5. Payment to Secretary of State's Office, Mostafa	$3.50
6. Reimbursement of keynote speaker's plane ticket	$600.03
7. Department of Treasury (IRS)	$100
8. Application for recognition of Tax Exemption	$350
9. Payment of the Biota Committee	$130
	$4,097.19

7. TRANSFER TO CD from Checking **-0-**

TOTAL EXPENSES **$10,611.49**

ARKANSAS ACADEMY OF SCIENCE
COST OF JOURNAL

VOLUME	COPIES	PAGES	PRINTER CHARGE	TOT. VOL. COST	COST/ COPY	COST/ PAGE
35 (1981)	450	96	$3,694.68	$4,620.99	$10.27	$48.14
36 (1982)	450	110	$5,233.28	$5,291.69	$11.76	$48.11
37 (1983)	450	103	$5,326.91	$5,944.44	$13.21	$57.71
38 (1984)	450	97	$5,562.97	$6,167.72	$13.71	$63.58
39 (1985)	450	150	$7,856.20	$8,463.51	$18.81	$56.42
40 (1986)	450	98	$6,175.20	$6,675.20	$14.23	$68.11
41 (1987)	450	116	$7,122.79	$7,811.25	$17.36	$67.34
42 (1988)	450*	116	$7,210.79	$7,710.15	$17.13	$66.47
43 (1989)	450*	119	$8,057.24	$8,557.24	$19.02	$71.91
44 (1990)	450*	136	$9,298.64	$9,798.64	$21.77	$72.05
45 (1991)	450*	136	$9,397.07	$9,929.32	$22.06	$73.01
46 (1992)	450*	116	$9,478.56	$10,000.56	$22.22	$86.21
47 (1993)	400	160	$12,161.26	$12,861.26	$32.15	$80.38
48 (1994)	450	270	$17,562.46	$18,262.46	$40.58	$67.63
49 (1995)	390	199	$14,725.40	$15,425.40	$39.55	$77.51
50 (1996)	345	158	$11,950.00	$12,640.75	$36.64	$80.00
51 (1997)	350	214	$14,308.01	$15,008.01	$42.88	$70.13
52 (1998)	350	144	$12,490.59	$13,190.59	$37.69	$91.60
53 (1999)	350	160	$13,686.39	$14,386.39	$41.10	$89.91
54 (2000)	350	160	$14,149.07	$14,849.07	$42.43	$92.81
55 (2001)	360	195	$16,677.22	$17,498.22	$48.61	$89.73
56 (2002)	350	257	$18,201.93	$19,001.93	$54.29	$73.94
57 (2003)	230	229	$14,415.12	$15,715.12	$68.33	$68.62
58 (2004)	210	144	$7,875.76	$9,175.76	$43.99	$63.72
59 (2005)	215	226	$16,239.04	$17,835.84	$82.96	$78.92
60 (2006)	220	204	$11,348.06	$12,934.30	$58.79	$63.40
61 (2007)	195	150	$8,196.84	$9,914.69	$50.84	$66.10
62 (2008)	220	166	$2,865.00	$2,967.49	$13.49	$17.88
63 (2009)	213	206	$3,144.08	$3,144.08	$14.76	$15.26
64 (2010)	232	158	$2,713.54	$2,764.30	$11.91	$17.50

The Total Volume Cost equals the printer's charge plus the other miscellaneous charges.

- On Volume 42 the Academy received 560 copies, but the printer did not charge us for the extra 110 copies. For comparison purposes the calculated cost/copy is based on 450 copies.
- On Volume 43 the Academy received 523 copies, but the printer did not charge us for the extra 73 copies. For comparison purposes the calculated cost/copy is based on 450 copies.
- On Volume 44 the Academy received 535 copies, but the printer did not charge us for the extra 85 copies. For comparison purposes the calculated cost/copy is based on 450 copies.
- On Volume 45 the Academy received 594 copies, but the printer did not charge us for the extra 144 copies. For comparison purposes the calculated cost/copy is based on 450 copies.
- On Volume 46 the cost was greater than usual due to the high cost of a second reprinting of 54 copies by a different printer.

APPENDIX A

2011 AAS PRESENTATION AWARD WINNERS

GRADUATE STUDENT AWARDS

Poster Awards

1st **Place:** Preliminary Gene Flow Estimates over Small Distances in the Pyramid Elimia, Elimia Potosiensis, from Arkansas by Paight, Chris J.; Minton, Russell L. of the University of Louisiana at Monroe.

Oral Presentation Awards

Life Sciences

1st **Place:** Novel Dual-Phase Ultra Performance Liquid Chromatography–Tandem Mass Spectrometry Assay for Profiling Enantiomeric Hydroxywarfarins and Warfarin in Human Plasma by Jones, Drew R.; Boysen, Gunnar; Miller, Grover P. of the University of Arkansas for Medical Sciences.

2nd **Place:** Flooding Effects on the Space Use of White-Tailed Deer within the Mississippi Alluvial Flood Plain by Graves, David; White Jr., Don, Jr.; Felix-Locher, Alexandra; Weih, Robert C. of the University of Arkansas at Monticello.

3rd **Place:** Status Survey of the Diversity and Distribution of Freshwater Gastropods in the Mississippi Alluvial Plain and South Central Plains of Arkansas by Basiger, Erin L; Minton, Russel L. of the University of Louisiana at Monroe.

Physical Sciences

1st **Place:** Electrodeposition of Indium Sulfide Films From Organic Solutions-Part II by Mughal, Maqsood Ali; Newell, Michael; Vangilder, Josh; Hall, Hall, John; Felizco, Frederick; Thapp, Shayam of Arkansas State University.

2nd **Place:** Optimization and Characterization of Binders, Encapsulants, and Densification for Biofuel Pellets by Thapa, Shyam; Engelken, Robert; Newell, M.J.; Mughal, M.A.; Felizco, F.; Vangilder, J. of Arkansas State University.

UNDERGRADUATE STUDENT AWARDS

Poster Awards

1nd **Place:** Photoinduced Extrusion of Nitric Oxide from a Ruthenium Nitrosyl Complex by Poole, Francis; Felton, Charlette M.; Mebi, Charles A. of Arkansas Tech University.

2nd **Place:** Rapid Quantitative Method for Salicin from a Willow Tree by Utilizing an Attenuated Total Reflectance (ATR) Fourier Transform Infrared (FT-IR) Spectrometer by Laster, Fanchon P.; Anderson II, Terry L.; Hahn Frank of Philander Smith College.

3rd **Place:** Determining Neutron Flux of a Plutonium-Beryllium Source using Neutron Activation of Indium by Watson, Kristopher; Fenske, Jacob D.; Xu, Shuang; Frederickson, Carl F.; Addison, Stephen R.; Mehta, Rahul of the University of Central Arkansas.

Oral Presentation Awards

Life Sciences

1st **Place:** Molecular Genetic Analysis of Microbial Life in Blanchard Springs Caverns, Arkansas by Gonzalez, Claudia P.; Shields, Jonathan M.; Story, Lauren M.; Engman, James A. of Henderson State University.

2nd **Place:** Evolutionary Relationships of the ‘Sky Island’ Pines Based on Nuclear, Chloroplast, and Mitochondrial Data by Segear, Nicole A. of Hendrix College.

Physical Sciences

1st **Place:** Thermal Conductivity of Stainless Steel and Celluar Foams by Playford, James; Kanthabhabha, Rahul; Pidugu, Srikanth B.; Midturi, Swaminadham of University of Arkansas at Little Rock.

2nd **Place:** Styrene and its Metabolites Exhibit Potential for Multiple-Site Interaction with CYP2E1 by Hartman, Jessica H.; Boysen, Gunnar; Miller, Grover P. of the University of Arkansas for Medical Sciences and the University of Arkansas at Little Rock.

3rd **Place:** Determining The Temperature Dependent Young's Modulus of Monolayer and Bilayer Graphene Sheets using Molecular Dynamic Simulation by Downs, Roy; Scrivenner, Dakota; Terdalkar, Scahin S.; Rencis, Joseph J. of the University of Arkansas at Fayetteville.

APPENDIX B
RESOLUTIONS

Arkansas Academy of Science
95th Annual Meeting, 2011 Resolutions

Be it resolved that we, the membership of the Arkansas Academy of Science, offer our sincere appreciation to the University of Arkansas at Monticello for hosting the 95th annual meeting of the Arkansas Academy of Science. We thank the Local Arrangements Committee: Chair, Glenn Manning, Morris Bramlett, Lynne Thompson, Robert Ficklin, Tracie Jones, the faculty of the University of Arkansas at Monticello and all of the student workers and staff, particularly Leslie Lowery, secretary of Mathematical and Natural Sciences, who collectively contributed to such a successful meeting. Appreciation is expressed for the use of these superior facilities at the University of Arkansas Monticello, and the hospitality shown to us by the School of Forest Resources and their staff. We especially thank our keynote speaker, Dr. Don White Jr., for his keynote presentation entitled "The Space Use Ecology of Male Elk in Arkansas". We thank the University of Arkansas at Monticello for their donations to the Mixer and Banquet, which were both excellent and thoroughly enjoyed by all. We thank University of Arkansas at Monticello Chancellor, Jack Lassiter for hosting the AAS, and Provost, David Ray for his welcome address.

The Academy recognizes the important role assumed by Session Chairs and expresses sincere appreciation to: Mostafa Hemmati (Physics 1), Charles Mebi (Chemistry 1), Forrest Payne (Environmental Science), Andres Bacon (Invertebrate Zoology), Carl Fredericson (Physics 2), Hasim Ali (Chemistry 2), Grover Miller (Medical Science), Lynne Thompson (Invertebrate/Vertebrate Zoology), Marc Seigar (Physics 3), Karen Fawley (Botany/Microbiology), John Hunt (Vertebrate Zoology). We also recognize the contribution of the judges who facilitate student participation and awards, in particular Ed Bacon, Mary Stewart, Susanne Wache, Scott Kirkconnell, Tracy Hawkins, Ed Bacon (Life Science Judges), Soloman Itza, Andy Williams, Stephen Addison, Anwar Bhuiyan (Physical Science Judges), Jeff Robertson, Robert Eoff, and Ann Willyard (Poster Judges).

We gratefully acknowledge the various directors of the science and youth activities, which are supported and supervised by the Academy: Betty Crump and Kurt Grafton, Development; Tillmon Kennon, Science Education Committee; William Slaton, Arkansas Science Talent Search; Nolan Carter, Junior Academy of Science; Mark Bland, Arkansas Science Fair; Linda Kondrick, Arkansas Junior Science and Humanities Association; and Scott Kirkconnell, the representative to the AAAS. We wish to thank all those who served as directors at Regional Science Fairs and Junior Academy Meetings.

We congratulate all who presented papers and posters at this meeting. Student participants are especially recognized since their efforts contribute directly to the future success of the Academy and the improvement and advancement of science in Arkansas.

The continued success of the Academy is due to its strong leadership. We offer sincere thanks to our officers for another excellent year: Jeff Robertson (President), Kurt Grafton (President-Elect), Marc Seigar (Vice-President); Scott Kirkconnell (Past-President), Jeff Robertson (Secretary), Mostafa Hemmati (Treasurer), Mostafa Hemmati (Journal Editor-in-Chief), Ivan Still (Journal Managing Editor), Jeff Robertson (Newsletter Editor), Bill Doria (Webmaster), and Collis Geren (Historian).

The Arkansas Academy of Science Executive Committee expresses its profound gratitude to Mostafa Hemmati and Ivan Still for their excellent work on the Journal of the Academy, which has directly and positively affected the excellent financial position of the Academy.

Respectfully submitted this 9th day of April 2011.

Resolution Committee
Marc Seigar, AAS Vice President
Glenn Manning, UAM LOC Chair

2010-2011 MEMBERSHIP

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Joyce	Hardin	Hendrix College
George	Harp	Arkansas State University
Phoebe	Harp	Arkansas State University
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Mostafa	Hemmati	Arkansas Tech University
Philip	Hyatt	Retired
Douglas	James	University of Arkansas
Ronald	Javitch	Natural History Rare Book Found.
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Cindy	Kane	UAMS
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Roland	McDaniel	FTN Associates
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Anne	Willyard	Hendrix College
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MAJOR INSTITUTIONAL SPONSORS

The Arkansas Academy of Science is an essential component in the science, technology, engineering and math pipeline for Arkansas. As a coalition of Arkansas scientists, it provides a local vehicle for presentation and publication of early scientific accomplishments in Arkansas. By promoting the work of Arkansas students, the Academy increases collaboration among the scientific community and provides a comprehensive network for scientific academics. These endeavors promote a higher standard of education within Arkansas and will encourage and promote a higher quality of life through educational opportunities.

As an integral part of the development and promotion of the Academy's mission, we wish to recognize the commitment and continued support of our Institutional Sponsors, The Arkansas Natural Heritage Commission and the Ouachita National Forest.

ARKANSAS NATURAL HERITAGE COMMISSION

Since 1973, the Arkansas Natural Heritage Commission (ANHC) has been working to conserve Arkansas's natural landscape. ANHC conducts research to determine which elements (species and natural communities) are most in need of protection. Field inventory documents the locations of elements of conservation concern. Information is also gathered from other sources, such herbarium and museum collection records, and scientific publications such as the *Journal of the Arkansas Academy of Science*. ANHC's current strategic planning goals include working to expand the ecological literacy of Arkansans. The Arkansas Academy of Science is a critical partner in helping to address this goal and, in the long term, protect the natural heritage of our state. For more information about the ANHC research, inventory and protection efforts, including the System of Natural Areas around the state, visit the agency website at www.naturalheritage.com. Here is a link to the current enewsletter featuring our support info as well. http://www.naturalheritage.com/enews/archive.aspx?mid=13361.

OUACHITA NATIONAL FOREST

Stretching from near the center of Arkansas to southeast Oklahoma, the pristine 1.8 million acre Ouachita National Forest is the South's oldest national forest, established on December 18, 1907 by President Theodore Roosevelt. Rich in history, the rugged Ouachita Mountains were first explored in 1541, by Hernando DeSoto's party of Spaniards. French explorers followed, flavoring the region with names like Fourche la Fave River. "Ouachita" is the French spelling of the Native American word "Washita" which means "good hunting grounds." The Forest's ecosystem management policy guarantees its management regime as an ecological approach, based upon the most current knowledge and best science, for providing multiple benefits from the Forest and encouraging careful use of the forest for the future. The research local to Arkansas and the Forest published by the Journal of the Arkansas Academy of Science is critical to informing and supporting appropriate management decisions, environmental assessments and biological evaluations. The Ouachita National Forest extends support of the Academy's efforts through this sponsorship.

For more information about the Forest, visit our webpage at: http://www.fs.fed.us/r8/ouachita.

A TRIBUTE TO Dr. JOYCE M. HARDIN

Joyce M. Hardin, Ph.D., has been the Judy and Randy Odyssey Professor of Biology at Hendrix College since 1989, and is currently the Environmental Studies Chair at Hendrix University. She received her PhD. (1981), and M.S. (1979) from the University of Arkansas and her B.S. from the College of Charleston (1975). She currently works in the D. W. Reynolds building (Rm 231), and can be reached at (501) 450-1484; (501) 450-1455(Fax) or Email: hardin@hendrix.edu

Dr. Joyce Hardin has been long recognized as a stalwart worker in the Arkansas Academy of Sciences. Although her tangible and intangible contributions are too numerous to enumerate, below are listed some of her notable activities within and for the Academy as well as to promote science education at her home University and throughout the state of Arkansas:

Dr. Hardin has worked with and mentored numerous students in research projects on a wide variety of topics focused on a broad diversity of organisms including algae, cyanobacteria, fungi, lichens, and vascular plants. True to form as a dedicated teacher, Joyce believes, “My major contribution to science during my career has been mentoring young scientists and fostering scientific literacy in those students who aren’t scientists. (I love teaching nonmajors biology.)”

Joyce won teaching awards at Central State University (now University of Central Oklahoma) and Hendrix College and was recognized by the Department of Crop, Soil, and Environmental Sciences (UAF) as their outstanding graduate for 2004 (An award given to exceptional alumni).

Joyce served as treasurer for AAS from 1997 to 2006 and president in 2009 (also filling other official roles that rotated up to president).

Dr. Hardin served as Chair (equivalent to Dean) of the Natural Science Area and Vice President for Student Affairs at Hendrix University, and was honored as the Judy and Randy Wilburn Odyssey Professor; a three year research professorship held with two other colleagues. She is currently Chair of the Environmental Studies Program, an area of investigation that is growing very rapidly at Hendrix.

FEATURED GUEST SPEAKER

The Space Use Ecology of Male Elk in Arkansas

Presented by

Dr. Don White Jr. Forest Resources (SFR) at the University of Arkansas-Monticello

The traditional definition of habitat includes 4 basic components: food, cover, water, and space. The spatial arrangement of these components on the landscape relates closely to how ungulates such as elk (*Cervus elaphus*) distribute themselves. How well wildlife biologists and managers understand the behavior/habitat relationships of elk may determine how well they are able to maintain and improve the essential habitat elements necessary for elk survival. In this presentation, I will describe a progression of telemetry-based field studies several of my graduate students and I have con-ducted since 2003 in the Buffalo River watershed in north Arkansas that document male elk movements and habitat use. For male elk, landscapes are a mosaic of different re-sources that are explained in well defined seasonal and daily cycles to meet metabolic and security needs. Both the juxtaposition and grain of habitat patches within a home range were strong determinants of movement patterns and overall habitat suitability. Habitat management for male elk in a predominately forested environment, such as that found in the Buffalo River watershed, should include maintenance of agricultural fields and forage openings on flat, low elevation sites such as valley bottoms.

Dr. Don White, Jr. is the James M. White Professor of Wildlife Ecology in the School of Forest Resources (SFR) at the University of Arkansas-Monticello.

Prior to joining the SFR in 2000, Dr. White was Assistant Professor of Biology at Drury University in Springfield, Missouri from 1998 to 2000. From 1996 to 1998, Dr. White was a Postdoctoral Fellow the University of Montana studying hantavirus in wild rodent populations in western Montana. Dr. White earned his Ph.D. in 1996 in Wildlife Science from Montana State University-Bozeman, studying grizzly bears in Glacier National Park.

Dr. White is broadly interested in the biology, ecology, conservation, and management of vertebrates, particularly large mammals. His research is focused around science issues relevant to wildlife management needs. The over-arching theme be-hind his research interests is developing scientific tools and knowledge to support sound natural re-source management.

Dr. White and his graduate students conduct field research on a variety of wildlife species, including grizzly bears, black bears, elk, white-tailed deer, mountain goats, and small mammals in the western, midwestern, and southeastern U.S. Dr. White is a Certified Wildlife Biologist®.

SECTION PROGRAMS
ORAL PRESENTATIONS

SESSION 1: FRIDAY 1:00-2:45.
CHAIR: MOSTAFA HEMMATI
C-18, SCIENCE CENTER
Topics: Physics

1:00
CURRENT BEARING ELECTRON SHOCK WAVES
Childs, William; Hemmati, Mostafa. Arkansas Tech University

1:15
NUMERICAL SOLUTION OF CURRENT BEARING BREAKDOWN WAVES
Waters, Dacen; Hemmati, Mostafa Hemmati. Arkansas Tech University

1:30
A MODEL OF INTERACTING DARK ENERGY TO EXPLAIN THE HISTORY OF THE UNIVERSE
Shojaei, Hamed; Smylie, James; Houle, Chenoa. Arkansas Tech University

1:45
ABUNDANCE COMPARISON OF NEUTRON CAPTURE ELEMENTS IN GALACTIC HALO STARS: KNOWN VS. UNKNOWN
Teffs, Jacob; Odekirk, Tristan; Burris, Debra L. University Of Central Arkansas

2:00
DEFORMATION MECHANISMS IN ANISOTROPIC OPEN CELL ALUMINUM AND STAINLESS STEEL FOAMS
Playford, James D.; Stange, Samuel; Palaniappan, Rahul K.; Steuber, James G.; Swaminadham, Midturi; Post, Julian. University of Arkansas Little Rock and Arkansas Tech University

2:15
THERMAL CONDUCTIVITY OF STAINLESS STEEL AND CELLULAR FOAMS
Playford, James; Kanthabhabha, Rahul; Pidugu, Srikanth B.; Midturi, Swaminadham. University of Arkansas at Little Rock

2:30
IMPROVEMENT OF ELECTRODEPOSITED CADMIUM TELLURIDE FILM UNIFORMITY AND ADHERENCE BY PH, TEMPERATURE, AND MASS TRANSPORT CONTROL
Vangilder, Joshua A.; Engelken, Robert D.; Felizco, Frederick M.; Hall, John; McNew, David; Hill, Zachery. Arkansas State University

SESSION 1: FRIDAY 1:00-2:45.
CHAIR: CHARLES MEBI
C-19, SCIENCE CENTER
Topics: Chemistry

1:00
HYDROGENASE MODELS: DESIGNING THE ELECTRON TRANSPORT CHAIN
Rosenthal, Briteney; Karr, Derek; Ruixiao, Gao; Williams, Andrew; Mebi, Charles. Arkansas Tech University

1:15
STYRENE AND ITS METABOLITES EXHIBIT POTENTIAL FOR MULTIPLE-SITE INTERACTION WITH CYP2E1
Hartman, Jessica H.; Boysen, Gunnar; Miller, Grover P. University of Arkansas for Medical Sciences. University of Arkansas at Little Rock

1:30
SYNTHESIS AND PHOTOCHEMISTRY OF A WATER-SOLUBLE RUTHENIUM NITROSYL COMPLEX
Felton, Charlette M.; Poole, Francis; Mebi, Charles A. Arkansas Tech University

1:45
IMPROVEMENT IN PHOTOCONDUCTANCE OF CHEMICALLY DEPOSITED BISMUTH SULFIDE FILMS BY ANNEALING
Felizco, Frederick M.; Engelken, Robert D.; Vangilder, Joshua A.; Hall, John W.; Newell, Jason M.; Thapa, Shyamm. Arkansas State University

2:00
ELECTRODEPOSITION OF INDIUM SULFIDE FILMS FROM ORGANIC SOLUTIONS-PART II
Mughal, Maqsood Ali; Newell, Michael; Vangilder, Josh; Hall, Hall, John; Felizco, Frederick; Thapp, Shayam. Arkansas State University

2:15
ELECTRODEPOSITION OF INDIUM SULFIDE FILMS FROM ORGANIC SOLUTIONS-PART I
Hall, John; Engelken, Robert; Moghul, Maqsood; Vangilder, Josh; Newell, Jason; Felizco, Frederick. Arkansas State University

SESSION 1: FRIDAY 1:00-2:45.
CHAIR: FOREST PAYNE
B-19, SCIENCE CENTER
Topics: Environmental Science

1:00
USING CHLOROPHYLL FLUORESCENCE TO COMPARE IRRADIANCE EFFECTS ON PHOTOSYSTEM II (PSII) PHOTOCHEMISTRY IN ADVANCED REPRODUCTION OF FIVE UPLAND HARDWOOD SPECIES
Cunningham, Kutcher K; Grace, Stephen C. University of Arkansas Division of Agriculture. University of Arkansas at Little Rock

1:15
ASSESSMENT OF THREE CREEKS IN THE UPPER WATERSHED OF THE STRAWBERRY RIVER, AR, FULTON CO, USA
Brueggen, Teresa R.; Bouldin, Jennifer L. Arkansas State University

1:30
ASSESSMENT AND CHARACTERIZATION OF WATER QUALITY AND BIOTIC ASSEMBLAGES OF THE TYRONZA RIVER, ARKANSAS
Wentz, N.J., Henderson, N.D.; Christian, A.D. Christian. Arkansas State University. Arkansas Department of Environmental Quality. University of Massachusetts, Boston

1:45
MOLECULAR GENETIC ANALYSIS OF MICROBIAL LIFE IN BLANCHARD SPRINGS CAVERNS, ARKANSAS
Gonzalez, Claudia P.; Shields, Jonathan M.; Story, Lauren M.; Engman, James A. Henderson State University

2:00
EVALUATING LOBLOLLY PINE MANAGEMENT SCENARIOS CONSIDERING CARBON MARKETS
Chaudhari, Umesh K.; Pelkki, Matthew H. University of Arkansas at Monticello

SESSION 1: FRIDAY 1:00-2:45.
CHAIR: PABLO BACON
B-18, SCIENCE CENTER
Topics: Invertebrate Zoology

1:00
FIRE INFLUENCES ANT COMMUNITY STRUCTURE IN OZARK HARDWOOD FORESTS
Verble, Robin M. University of Arkansas at Little Rock

1:15
THE INFLUENCE OF MISIDENTIFICATION ON SPECIES RICHNESS MEASURES FROM LAND SNAIL BIOINFORMATICS
Nolan, Casey B.; Minton, Russel L. University of Louisiana at Monroe

1:30
STATUS SURVEY OF THE DIVERSITY AND DISTRIBUTION OF FRESHWATER GASTROPODS IN THE MISSISSIPPI ALLUVIAL PLAIN AND SOUTH CENTRAL PLAINS OF ARKANSAS
Basiger, Erin L; Minton, Russel L. University of Louisiana at Monroe

1:45
DISTRIBUTION AND LIFE HISTORY ASPECTS OF THE FRESHWATER SHRIMPS, MACROBRANCHIUM AND PALAEMONETES (DECAPODA: PALAEMONIDAE), IN ARKANSAS.
Robison, Henry W.; McAllister, Chris T.; Harp, George L. Southern Arkansas University. Eastern Oklahoma State College, Idabel. Arkansas State University

2:00
OCCURRENCE OF TWO RARE PRAIRIE INSECTS, TETRALONIELLA ALBATA AND MICROSTYLUM MOROSUM, AT TERRE NOIRE NATURAL AREA, CLARK COUNTY, ARKANSAS
Tumlison, R; Benjamin, K. Henderson State University

2:15
NOTES ON TARANTULA (*APHONOPELMA HENTZI*) REPRODUCTION IN THE OZARKS
Jamieson, David H. Jamieson; Jones, Austin; Jamieson, Terry. NorthWest Arkansas Community College. Crowder College, Cassville

SESSION 2: FRIDAY 3:00-4:45.
CHAIR: CARL FREDRICKSON
C-18, SCIENCE CENTER
Topics: Physics

3:00
DETERMINING THE TEMPERATURE DEPENDENT YOUNG'S MODULUS OF MONOLAYER AND BILAYER GRAPHENE SHEETS USING MOLECULAR DYNAMIC SIMULATION
Downs, Roy; Scrivenner, Dakota; Terdalkar, Scahin S.; Rencis, Joseph J. University of Arkansas at Fayetteville

3:15
SURVEY OF THE CASE FOR THE ENVIRONMENTAL EFFICACY OF CADMIUM TELLURIDE SOLAR CELLS
Newell, Jason M.; Egelken, Robert; Mughal, Maqsood; Thapa, Shyam; Vangilder, Joshua; Felizco, Frederick. Arkansas State University

3:30
COSMIC FLUX AND GAMMA RAYS ANALYSIS
Ramesh, Nepal; Martin, Clayton; Hawron, Martin; Bachri, Abdel. Southern Arkansas University

3:45
BACKGROUND FROM LOW ENERGY NEUTRONS IN A HIGH PRESSURE XENON TIME PROJECTION CHAMBER FOR NEUTRINOLESS DOUBLE BETA DECAY
Grant, Perry C.; Bachri, Abdel; Goldschmidt, Azriel. Southern Arkansas University. Lawrence Berkeley National Laboratory

4:00
(α, n) INDUCED BACKGROUND RADIATION RATES IN NEUTRINOLESS DOUBLE BETA DECAY OF XENON-136
Martin, Clayton B.; Bachri, Abdel; Goldschmidt, Azriel. Southern Arkansas University. Lawrence Berkeley National Laboratory

4:15
GAMMA RADIATION BACKGROUND RATES FOR NEUTRINOLESS DOUBLE BETA DECAY IN Xe-136
Hawron, Martin; Bachri, Abdel; Goldschmidt, Azriel. Southern Arkansas University. Lawrence Berkeley National Laboratory

4:30
DIELECTRIC RELAXATION OF MACRO-CRYSTALLINE ROCHELLE SALT CRYSTALS IN A VISCOUS MEDIUM
O'Toole, S.; Alpuerto, L.; Jones, T.; Todd, A.; Pancheco, N.; Hutton, S.L. Lyon College

SESSION 2: FRIDAY 3:00-4:45.
CHAIR: HASIM ALI
C-19, SCIENCE CENTER
Topics: Chemistry

3:00
OPTIMIZATION AND CHARACTERIZATION OF BINDERS, ENCAPSULANTS, AND DENSIFICATION FOR BIOFUEL PELLETS
Thapa, Shyam; Engelken, Robert; Newell, M.J.; Mughal, M.A.; Felizco, F.; Vangilder, J. Arkansas State University

3:15
FABRICATION AND CHARACTERIZATION OF GRAPHENE/ SILICON SCHOTTKY DIODE
Mohammed, Mohammed; Abdulrazzaq, Omar; Biris, Alexandru; Abdulalmohisn, Samir; Al-Hilo, Alaa; Zeid, Nima. University of Arkansas Little Rock

3:30
RAMAN SPECTROSCPY AND PHOTOELECTROACTIVITY OF TITANIA NANOTUBULAR CATALYSTS
Hardcastle, Franklin D.; Sharma, Rajesh; Ishihara, Hidetaka; Biris, Alexandru S. Arkansas Tech University. Arkansas State University. University of Arkansas at Little Rock

SESSION 2: FRIDAY 3:00-4:45.
CHAIR: GROVER MILLER
B-19, SCIENCE CENTER
Topics: Medical Sciences

3:00
NOVEL DUAL-PHASE ULTRA PERFORMANCE LIQUID CHROMATOGRAPHY–TANDEM MASS SPECTROMETRY ASSAY FOR PROFILING ENANTIOMERIC HYDROXYWARFARINS AND WARFARIN IN HUMAN PLASMA
Jones, Drew R.; Boysen, Gunnar; Miller, Grover P. University of Arkansas for Medical Sciences

3:15
EXPANDING WARFARIN METABOLITE ANALYSES TO GLUCURONIDES IN PATIENT PLASMA
Kang, Ji-Yeon; Jones, Drew R.; Yun, Chul-Ho; Boysen, Gunnar, Miller, Grover P. Chonnam National University. University of Arkansas for Medical Sciences

3:30
ANALYSIS OF HUMAN TACC3 IN CELLULAR RESPONSES TO POLYCYCLIC AROMATIC HYDROCARBONS
Still, Ivan H.; Lauffart, Brenda. Arkansas Tech University

3:45
MALARIA, INTESTINAL PARASITIC INFECTION, ANEMIA, AND MALNOURISHMENT IN RURAL CAMEROONIAN VILLAGES WITH A PRELIMINARY ASSESSMENT OF EFFICACY OF INTERVENTIONS
Richardson, Dennis J; Richardson, Katherine R.; Richardson, Kristen E.; Gross, Jeanette; Tsekeng, Pierre; Dondji, Blaise. Quinnipiac University

SESSION 2: FRIDAY 3:00-4:45.
CHAIR: LYNNE THOMPSON
B-18, SCIENCE CENTER
Topics: Invertebrate, Vertebrate Zoology

3:00
TARDIGRADES OF THE UNIVERSITY OF CENTRAL ARKANSAS CAMPUS
Land, M.; Musto, A.; Miller, W.R.; Starkey, D.E.; Miller, J.D. University of Central Arkansas. Baker University

3:15
ARKANSAS "BUG" UPDATE 2011 INCLUDING 22 NEW STATE RECORDS
Chordas III, Steve W.; Tumlison, Renn; Robison, Henry W.; Kremers, Joe. Ohio State University

3:30
THE EFFICACY OF THERMAL IMAGING TECHNOLOGY FOR DOCUMENTING AMERICAN WOODCOCK ON PINE CLEARCUTS
Long, Andrea; Felix-Locher, Alexandra. University of Arkansas at Monticello

3:45
PREDICTING SEASONAL OCCURRENCE OF MALE ELK IN ARKANSAS
Wolf, Christine E.; White Jr., Don; Felix-Locher, Alexandra; Watt, Chirstopher L. University of Arkansas at Montciello

4:00
FLOODING EFFECTS ON THE SPACE USE OF WHITE-TAILED DEER WITHIN THE MISSISSIPPI ALLUVIAL FLOOD PLAIN
Graves, David; White Jr., Don, Jr.; Felix-Locher, Alexandra; Weih, Robert C. University of Arkansas at Monticello

SESSION 3: SATURDAY 8:30-10:30.
CHAIR: MARC SEIGER
C-18, SCIENCE CENTER
Topics: Physics

8:30
A NEW METHOD FOR DETERMINING RESONANCE LOCATIONS IN SPIRAL GALAXIES
Seigar, March S.; Sierra, Amber D.; Treuthardt, Patrick M.; Peurari, Ivanio. University of Arkansas at Little Rock. Instituto Nacional de Astrofisica

8:45
ACCRETION DISK SIZE IN UU AQUARII
Robertson, Jeff W. Arkansas Tech University

9:00
MODELING OF MICROMIXERS FOR LAB ON A CHIP APPLICATIONS
Bedinghaus, Andrew; Pidugu, Srikanth B. University of Arkansas at Little Rock

9:15
SIMULATION OF POWDER X-RAY DIFFRACTION USING A POLYCRYSTALLINE FILM OF SPHERICAL COLLOIDS
Smith, Jacob C.; Tacket, Ronald J. Arkansas Tech University

SESSION 3: SATURDAY 8:30-10:30.
CHAIR: MARVIN FAWLEY
B-19, SCIENCE CENTER
Topics: Botany, Microbiology

8:30
EVOLUTIONARY RELATIONSHIPS OF THE 'SKY ISLAND' PINES BASED ON NUCLEAR, CHLOROPLAST, AND MITOCHONDRIAL DATA
Segear, Nicole A. Hendrix College

8:45
DIFFERENT ABOVEGROUND LIVE BIOMASS MODELS YIELD INCREASINGLY DISPARATE ESTIMATES AS TREE DIAMETER INCREASES
Bragg, Don C. USDA Forest Service Southern Research Station

9:00
RIBOSOMAL RNA SPACER SEQUENCES AS A TOOL TO IDENTIFY CAREX SPECIES (SEDGES)
Fawley, Marvin W.; Fawley, Karen P. University of Arkansas at Monticello

9:15
***NEPTUNIA OLERACEA* LOUR. (FABACEA) NEW TO THE CONTINENTAL UNITED STATES, WITH NEW AND NOTEWORTHY RECORDS OF SEVERAL ANGIOSPERMS IN ARKANSAS**
Palmer, Jeremy; Serviss, Brett; Peck, Jim. Henderson State University. University of Arkansas at Little Rock.

9:30
ESTIMATING THE SPECIES TREE FOR HAWAIIAN SCHIEDEA (CARYOPHYLLACEAE) FROM MULTIPLE LOCI IN THE PRESENCE OF RETICULATE EVOLUTION
Willyard, Ann; Wallace, Lisa E.; Wagner, Warren L.; Weller, Stephen G.; Saki, Ann K.; Nepokroeff, Molly. Hendrix College

9:45
PHYLOGENY OF FRESHWATER EUSTIGMATOPHYCEAE
Fawley, K.P.; Fawley, M.W.; Eliáš, M.; Nemjová, K.; Probst, N. University of Arkansas at Monticello. Charles University in Prague

10:00
ULTRASTRUCTURAL CHANGES IN A NEW ISOLATE TERPINOPHILIC ARTHROBACTER WHEN GROWING IN EITHER CIS-TERPIN, GLUCOSE, OR ALPHA TERPINEOL AS SOLE CARBON AND ENERGY SOURCE
Mwasi, Lawrence M. University of Arkansas at Pine Bluff

SESSION 3: SATURDAY 8:30-10:30.
CHAIR: JOHN HUNT
B-18, SCIENCE CENTER
Topics: Vertebrate Zoology

8:30
NEW RECORDS AND NOTES ON THE NATURAL HISTORY OF VERTEBRATES FROM ARKANSAS
Connior, M.B. Connior; Tumlison, R.; Robison, H.W. Robison. South Arkansas Community College. Henderson State University. Southern Arkansas University

8:45
ADDITIONAL INSECT SAMPLING IN THE BURROWS OF BAIRD'S POCKET GOPHER IN ARKANSAS
Kovarik, Peter W.; Connior, Matthew B.; Chordas III, Stephen W.; Skelly, Paul E.; Robison, Henry W. Columbus State Community College. South Arkansas Community College. The Ohio State University. Florida State Collection of Arthropods. Southern Arkansas University

9:00
DISTRIBUTION OF SHREWS IN ARKANSAS WITH SPECIAL EMPHASIS ON *BLARINA BREVICAUDA* OCCURRING IN THE STATE
Pfau, RS; Sasse, DB; Connior, MB; Guether, IF. Tarleton State University. Arkansas Game and Fish Commission. South Arkansas Community College. Arkansas Tech University

9:15
STATUS OF LITTLE BROWN BATS (*MYOTIS LUCIFUGUS*) IN ARKANSAS
Sasse, D. Blake. Arkansas Game and Fish Commission

9:30
WINTER/SPRING PRECIPITATION IN NORTHERN ARKANSAS AND RAPID RESERVOIR INUNDATION: HISTORIC CASE OF THE EASTERN COLLARED LIZARD, *CROTAPHYTUS COLLARIS*
Trauth, Stanley E. Arkansas State University

9:45
***CARYOSPORA DUSZYNSKII* (APICOMPLEXA: EIMERIIDAE) FROM THE SPECKLED KINGSNAKE, *LAMPROPELTIS HOLBROOKI* (REPTILIA: OPHIDIA), IN ARKANSAS: A NEW HOST RECORD WITH A SUMMARY OF PREVIOUS RECORDS**
McAllister, Chris T.; Robison, Henry W.; Seville, R. Scott; Roehrs, Zachary. Eastern Oklahoma State College, Idabel. Southern Arkansas University. University of Wyoming/Casper Center

10:00
THE FISHES OF CROOKED CREEK (WHITE RIVER DRAINAGE) IN NORTHCENTRAL ARKANSAS, WITH NEW RECORDS AND A LIST OF SPECIES
Robison, Henry W.; McAllister, Chris T.; Shirley, Ken Shirley. Southern Arkansas University. Eastern Oklahoma State College. Arkansas Game & Fish Commission

10:15
SUMMARY OF PREVIOUS AND NEW RECORDS OF THE ARKANSAS DARTER (*ETHEOSTOMA CRAGINI*) IN ARKANSAS
Wagner, Brian K.; Kottmyer, Mark D.; Slay, Michael E. Arkansas Game and Fish Commission. The Nature Conservancy

POSTER PRESENTATION

BIOLOGY POSTERS

1. **THE USE OF MICROBIAL EXOPOLYSACCHARIDES TO AID IN THE REDUCTION OF SOIL EROSION**
Jamison, Janet; Gilmore, David. Arkansas State University

2. **PHYSIOLOGICAL EVALUATION OF GLADIOLUS GENOTYPES FOR FLOWER PRODUCTION IN THE SOUTHEAST ARKANSAS**
Anderson, Lurie Lee; Islam, Shahidul. University of Arkansas at Pine Bluff

3. **WATER AND SEDIMENT QUALITY ASSESSMENT OF COTTON PRODUCTION**
Carter, Tiffany; Yu, Peng; Teague, Tina G.; Bouldin, Jennifer. Arkansas State University

4. **EVALUATION OF ANTIOXIDANT CAPACITY OF SWEETPOTATO LEAVES, FISH DIETS, AND FISH SAMPLES**
Everette, Jace D.; Adam, Zelalem; Islam, Shahidul. University of Arkansas at Pine Bluff

5. **DIVERSITY OF FRESHWATER EUSTIGMATOPHYCEAE**
Probst, Nathan; Fawley, Marvin W.; Fawley, Karen P. University of Arkansas at Monticello

6. **ANTIBIOTIC RESISTANCE OF STAPHYLOCOCCI OBTAINED FROM PET INDUSTRY EMPLOYEES**
Gilmore, David F.; Fu, Xing. Arkansas State University

7. **INFLUENCE OF STAND QUALITY MANAGEMENT ON MAST QUANTITY AND QUALITY IN QUERCUS PAGODA RAF**
Hawkins, Tracy S.; Meadows, James S. USDA Forest Service

8. **SIMPLE SCIENCE: INITIATION OF BASELINE DATA SETS**
Jennier, Jo-Ann C. Ouachita Mountains Biological Station

9. **SEARCHING FOR HARVESTER ANTS (*POGONOMYRMEX*) IN ARKANSAS**
Thompson, Lynne C.; General, David M. University of Arkansas at Monticello

10. **NEW DISTRIBUTIONAL RECORDS OF ANTS IN ARKANSAS FOR 2009 AND 2010 WITH COMMENTS ON PREVIOUS RECORDS**
General, David M.; Thomson, Lynne C. University of Arkansas at Monticello

11. **PRELIMINARY GENE FLOW ESTIMATES OVER SMALL DISTANCES IN THE PYRAMID ELIMIA, ELIMIA POTOSIENSIS, FROM ARKANSAS**
Paight, Chris J.; Minton, Russell L. University of Louisiana at Monroe

12. **A QUANTITATIVE COMPARISON OF AN URBAN STREAM TO LEAST-DISTURBED REFERENCE STREAMS**
Powers, Zachary A.; Ducket, Brian; Shaver, Richard R. University of Arkansas at Little Rock

13. **FORAGING BEHAVIOR OF THREE SYMPATRIC AND CONGENERIC TYRANNIDS (*TYRANNUS* SPP.) IN WESTERN ARKANSAS**
Kannan, Ragupathy; James, Douglas A. University of Arkansas at Fort Smith

14. **EFFECTS OF DROSOPHILA P70S6 KINASE VARIANTS ON CELL SIZE**
Stewart, Mary J.; Hunt, John. University of Arkansas at Monticello

15. **INVESTIGATION OF TWO GENES IN GROWTH AND TUMOR SUPPRESSION**
Rose, Robert Rose; Stewart, Mary J. University of Arkansas at Monticello

16. **WASTE WATER EFFLUENT EFFECTS ON VIABILITY OF SAGER CREEK**
Constantin, Rebekah; Lane, Anna; Meinzer, Jake; Slagter, Christa; Wakefield, Timothy S. John Brown University

17. **AN EFFICIENT FLOOD BASIN WATER DEPTH SENSOR**
Bland, Petey; Slaton, William. University of Central Arkansas

18. **BALLOONSAT AND HOBOWARE**
White, Jonathan R.; Slaton, William V. University of Central Arkansas

19. **THE BROADMOOR LAKE PROJECT**
Freeman, Nicole D.; Cornwell, Andrew; Somers, M.; Combs, Melanie. University of Arkansas at Little Rock

20. **SLOPE MATTERS: CAN SLOPE MEASUREMENT BY INDIVIDUALS BE OBJECTIVE?**
Hastings, Cara, Harris, Ron, Weih Jr., Robert C., Liechty, Hal O. University of Arkansas at Monticello

CHEMISTRY AND PHYSICS POSTERS

1. **RAPID QUANTITATIVE METHOD FOR SALICIN FROM A WILLOW TREE BY UTILIZING AN ATTENUATED TOTAL REFLECTANCE (ATR) FOURIER TRANSFORM INFRARED (FT-IR) SPECTROMETER**
Laster, Fanchon P.; Anderson II, Terry L.; Hahn Frank. Philander Smith College

2. **SYNTHESIS AND CHARACTERIZATION OF PYRAZOLYL METHANE NICKEL CYANIDE COMPLEX**
Lyubartseva, Ganna; Parkin, Sean. Southern Arkansas University. University of Kentucky

3. **SYNTHESIS AND CHARACTERIZATION OF RUTHENIUM MONOMER AND DIMER COMPLEXES**
Bhuiyan, Anwar A.; Kudo, Shotaro. Arkansas Tech University

4. **PHOTOINDUCED EXTRUSION OF NITRIC OXIDE FROM A RUTHENIUM NITROSYL COMPLEX**
Poole, Francis; Felton, Charlette M.; Mebi, Charles A. Arkansas Tech University

5. **DETERMINATION OF ELASTIC MODULI IN BRASS, ALUMINUM, WOOD, AND PLASTIC RODS USING RESONANCE**

French III, Roy T.; Slaton, William V. University of Central Arkansas

6. **EFFECTS OF ANNEALING ON THE ELECTRONIC TRANSITIONS OF ZNS THIN FILMS**

Jabbar, Wasmaa; Habubi, Nadir Fadhil; Chiad, Sami Salman.

7. **WAVE EXPERIMENTS USING LOW-COST 24.5 KHZ ULTRASONIC TRANSDUCERS**

Davis, Mary C.; Slaton, William V. University of Central Arkansas

8. **DETERMINING NEUTRON FLUX OF A PLUTONIUM-BERYLLIUM SOURCE USING NEUTRON ACTIVATION OF INDIUM**

Watson, Kristopher; Fenske, Jacob D.; Xu, Shuang; Frederickson, Carl F.; Addison, Stephen R.; Mehta, Rahul. University of Central Arkansas

9. **ANGULAR CORRELATION OF TWO 511 KEV GAMMA-RAYS FROM SODIUM-22**

Tubbs, Matthew; Patel, Niravkumar D.; Lu, Vinh; Frederickson, Carl F.; Addison, Stephen R.; Mehta, Rahul. University of Central Arkansas

10. **COSMIC FLUX AND GAMMA RAYS ANALYSIS**

Ramesh, Nepal; Martin, Clayton; Hawron, Martin; Bachri, Abdel. Southern Arkansas University

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11. **BACKGROUND FROM LOW ENERGY NEUTRONS IN A HIGH PRESSURE XENON TIME PROJECTION CHAMBER FOR NEUTRINOLESS DOUBLE BETA DECAY**

Grant, Perry C.; Bachri, Abdel Bachri; Goldschmidt, Azriel. Southern Arkansas University. LawrenceBerkeley National Laboratory

12. **(α, n) INDUCED BACKGROUND RADIATION RATES IN NEUTRINOLESS DOUBLE BETA DECAY OF XENON-136**

Martin, Clayton B.; Bachri, Abdel Bachri; Goldschmidt, Azriel. Southern Arkansas University. Lawrence Berkeley National Laboratory

13. **GAMMA RADIATION BACKGROUND RATES FOR NEUTRINOLESS DOUBLE BETA DECAY IN Xe-136**

Hawron, Martin Bachri, Abdel Bachri; Goldschmidt, Azriel. Southern Arkansas University. Lawrence Berkeley National Laboratory

14. **CONDITIONS IN THE UPPER TROPOSPHERE AND THEIR RELATION TO CLIMATE CHANGE**

Goins, Adam; Kennon, Tillman; Ali, Hashim. Arkansas State University

15. **VIRTUAL NANO-INDENTATION OF STONE-WALES DEFECT MIGRATION IN GRAPHENE SHEETS AT CONSTANT TEMPERATURE**

Downs, Roy; Scrivener, Dakota; Terdalker, Sadchin S.; Rencis, Joseph J. University of Arkansas

In Memoriam: John Kenneth Beadles, 1931-2011

Dr. John Kenneth ("Ken") Beadles passed away from complications of pulmonary fibrosis at his home on August 30, 2011 in Jonesboro, Arkansas. He is survived by his wife of 55 years, Sharon Ruch Beadles, two children, son John David Beadles of Jonesboro, daughter Kristi Diane Trotter of Jonesboro, grandchildren, Terry Anthony "Tony" Trotter, John Phillip and his wife Ciara Cunningham Trotter, and Matthew and Tara Trotter Joplin all of Jonesboro, and great-granddaughter, Haven Leigh Anne Joplin; and six brothers, as well as nine nieces and nephews.

Ken was born on September 22, 1931 in the small prairie town of Alva, Oklahoma to Joseph Haven and Ellen Amanda Beadles. After high school, Ken served in the US Navy from 1950–54 as Dental Technician III (DT3) during the Korean Conflict before starting his higher educational career in 1957 at Northwestern State College in Alva (now Northwestern Oklahoma State University) where he earned a BS degree with a double major in biology and chemistry. After graduation, Ken taught in the Alva Public School System as a science teacher and football coach from 1957–62. He entered graduate school in 1962 at Oklahoma State University and received the MS degree in 1963 in zoology and natural science. Continuing his graduate education at OSU, Ken studied under the renowned ichthyologist, Dr. George A. Moore, and specialized in ichthyology and vertebrate zoology. He received his Ph.D. degree from OSU in zoology in 1965.

That same year, Ken came to Arkansas State University (ASU) in the Department of Biology as an Assistant Professor of Biology. After just one year, he left briefly from 1966–1968 to work with USAID in the Ethiopia-Oklahoma A&M project in Alemaya, Ethiopia, as a science teacher, researcher, and advisor to Haille I University. Returning to Arkansas in 1968, Ken assumed the rank of Professor of Biology and Chairman of the Department at ASU, a position he held for the next 16 yr. During his tenure as Chairman, Ken became active in the Arkansas Academy of Science (AAS) and, until his retirement, never missed an annual meeting. He regularly presented papers, as well as authored and co-authored numerous papers at AAS for publication in the *Proceedings*. In 1982, Ken was elected President of AAS by his scientific peers.

He was an active leader in the Conference of Southern Graduate Schools, serving two terms on its Executive Committee and as a member of the Committee on Committees. In 1984, Ken was selected Dean of the Graduate School and Director of Organized Research at ASU where he served until his retirement in 1993. During his time as Dean, he played a key role in the successful establishment of the School of Nursing and the Doctor of Education degree in Educational Leadership, the university's first doctoral program. For his unstinting work and service to ASU, Ken was honored as one of the "First 100 Distinguished Faculty" at ASU in 2010.

In addition to AAS, Ken was an active member of the American Fisheries Society, Southwestern Association of Naturalists, American Society of Ichthyologists and Herpetologists, Sigma Xi, Phi Kappa Phi, Tri Beta, and Phi Delta Kappa, and was also a Danforth Fellow.

Although Dr. Beadles spent much of his academic career in administration, he was a pioneer in catfish farming and research in northeast Arkansas during the period from 1965 –1978 on the eight pond complex at ASU's farm in Walcott. At that facility, many ASU students conducted research and learned new techniques in catfish farming during those years, and some of these very students went on to become catfish farmers. Ken authored or co-authored 29 publications and environmental reports dealing with fishes and mammals during his career, over half of which were published in AAS publications. In addition, he presented 21 papers at professional meetings. Ken Beadles was much more than a scientist and teacher. He loved people and was a natural leader. Following his retirement, Ken became involved in Jonesboro civic activities serving as Chair of the Jonesboro Ecumenical Council and helping construct two Habitat for Humanity houses. In addition he served on the advisory board of the Women's Recovery Council, the Jonesboro Urban Renewal and Housing Authority, and was for many years, Chair of the Metropolitan Area Planning Commission. He was an active member of the Jonesboro Rotary Club and had a perfect attendance for 38 years! He served as President in 1978–79, Governor of District 6150 in 1985–86, and was a Paul Harris Fellow, and a recipient of the James F. Gramling Award for outstanding and dedicated service to the Rotary Foundation. In addition, Ken served as a United Way volunteer, was on their Board of Trustees and was selected "Outstanding United Way Volunteer of the Year for 1999–2000."

Ken was a deeply religious and caring man who served as a Sunday school teacher for the past 28 yr at Jonesboro's First Baptist Church in addition to being a Deacon and serving as Chairman of the Deacons, Stewardship Chairman, and Finance Chairman. In recent years, he taught Sunday school classes to residents of Skillcare Nursing Home, Ridgecrest Rehabilitation Center, and St. Bernard Village. Ken served on a committee called "Embracing the Promise" which raised several million dollars to renovate and repair facilities throughout the state of the Arkansas Baptist Children's Homes and Family Ministries.

Ken Beadles was the most positive man we ever knew and was an utmost supporter of the AAS, ASU, and students in general. He was a teacher's teacher! At every AAS meeting he attended, Ken could be seen with coffee cup in hand, going through the hallways greeting old friends, making new ones, and asking undergraduate students about their research, or trying to get them to consider ASU as a place to start or continue their graduate studies.

Perhaps a few sentences from "A History of the Biological Sciences at Arkansas State University" sum up this great man: "During his career, he demonstrated great personal commitment to student diversity at the graduate level, recruiting minority students from throughout the traditionally all-black institutions of the Mid-South. And regardless of his other responsibilities, Dean Beadles always had time for students, continuing to teach Fisheries Biology and Ichthyology even after assuming the duties of the Graduate Dean. Across the nation today is a generation of teachers, researchers, and fisheries personnel who began their professional education in Dr. Beadle's classroom."

Ken Beadles was a dear personal friend of ours and steadfast mentor, a kind and compassionate man, a lover of his fellow man, an unwavering supporter of AAS, a first-rate ichthyologist and zoologist, and a consummate teacher. He will be sorely missed throughout the Arkansas academic community. Ken led an exemplary life of service to his fellow man and students were always his first priority. Although neither of us had the privilege of having Ken as a teacher in class (although he served expertly on CTM's thesis committee), we feel extremely fortunate and privileged to have known him for over 40 yr, and we are better people for having his life intersect with ours. We will long remember this gifted scientist, compassionate teacher, and dedicated humanitarian, and miss him dearly.

Henry W. Robison, *9717 Wild Mountain Drive, Sherwood, AR 72120.*

Chris T. McAllister, *Division of Science and Mathematics, Eastern Oklahoma State College, 2805 NE Lincoln Road, Idabel, OK 74745*

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Synthesis, Characterization, and Properties of Homometallic Dinuclear Ruthenium Complex Containing Chloro-Phenanthroline and Bipyridine

A.A. Bhuiyan[1,2] and S. Kudo[1]

[1]*Department of Physical Sciences, Arkansas Tech University, Russellville, AR 72801*

[2]Correspondence: abhuiyan@atu.edu

Abstract

This paper deals with the synthesis and spectroscopic investigation of homometallic dinuclear ruthenium(II) complex containing chloro-phenanthroline and bipyridine ligands. This bimetallic ruthenium polypyridine complex may be useful for biological electron transfer studies. Heteroleptic ruthenium monomer complex $Ru(bpy)_2$(Cl-phen) (where bpy = 2,2'-bipyridine and Cl-phen = 5-chloro-1,10-phenanthroline) was prepared in a two step procedure previously developed in our laboratory. This monomer complex was used to prepare the ruthenium dimer complex, $(bpy)_2$Ru(phen-phen)Ru$(bpy)_2$, by utilizing the Ni-catalyzed coupling reaction. Both the complexes were purified by column chromatography. The identity and the integrity of the complexes were confirmed by elemental analysis as well as mass spectroscopy. The calculated and the experimental values for the elemental analysis were in good agreement. The calculated and experimental molar masses of the dimer complex were also identical. UV/Vis absorption, emission spectroscopic method, and cyclic voltammetric method were used to investigate the properties of the dimer complex.

Introduction

The study of the photophysical and photochemical properties of transition metal complexes is of great interest for a variety of fundamental and practical reasons (Kalyanasundaram 1987). In the past few years most of the attention in this field has been focused on the polypyridine complexes of ruthenium(II) as components of solar energy conversion schemes (Jures et al. 1988, Kalyanasundaram 1982). These complexes offer desirable redox potential, excited state properties, photophysical properties, and excited state lifetimes. Ruthenium polypyridine complexes have been investigated for use in artificial photosynthesis and many biological electron transfer processes. Electron transfer reactions play essential roles in numerous important biological processes such as photosynthesis, mitochondrial respiration, and intermediary metabolism. It has been documented that ruthenium polypyridine complexes have potential use as efficient photoinitiators in electron transfer studies (Winkler et al. 1982). This has prompted us to investigate the properties of such complexes.

Despite the importance of biological electron transfer reactions to numerous processes, only few techniques are available to measure the actual rate of electron transfer between two redox partners in proteins. Many of these reactions are extremely fast with redox partners in nature (Sadoski et al. 2000). Accurate measurement of electron transfer rates of this magnitude is very difficult. Zaslavsky and coworkers (1998) introduced a new method to study biological electron transfer that utilizes a photoactive ruthenium(II) polypyridine complex which is covalently or electrostatically attached to a protein such as cytochrome c. Photoexcitation of Ru(II) to the metal-to-ligand charge-transfer state, Ru(II*), a strong reductant, leads to rapid electron transfer to the ferric heme group in cytochrome c. Subsequent electron transfer from photoreduced heme c to redox center(s) in another protein can be measured on a time scale as fast as 50 nanoseconds (Pan et al. 1988).

It was found that the overall charge on the complex plays a critical role in protein binding and photoreduction or photooxidation efficiency. Ruthenium complexes with higher charge bind more tightly with the protein by electrostatic interaction. Dinuclear ruthenium complexes with an overall charge of +4 are capable of photoreducing protein with a 5-fold greater yield than mononuclear complexes (Sadoski et al. 2000). In this manuscript we report the efficient synthetic method, purification and characterization of $(bpy)_2$Ru(phen-phen)Ru$(bpy)_2$ dimer complex. The dimer complex was synthesized from the monomer complex by the nickel-catalyzed direct coupling reaction shown in Figure 1. The phenanthroline moieties couple together producing about 75% yield of the dimer. The synthetic strategy was based on the coupling reaction of 5-Cl-phen ligand developed by Toyota and coworkers (2005).

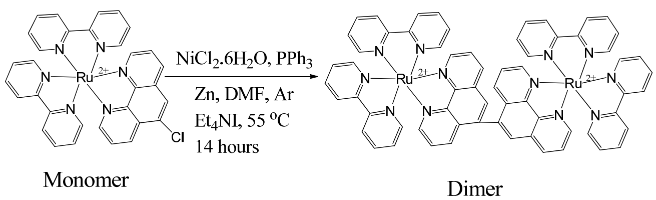

Figure 1: Synthetic scheme of ruthenium dimer, $(bpy)_2Ru(phen\text{-}phen)Ru(bpy)_2^{4+}$, complex.

In this work, we report the efficient synthetic method for the preparation of the ruthenium dimer complex $[(bpy)_2Ru(phen\text{-}phen)Ru(bpy)_2]$ (where Cl-phen = 5-chloro-1,10 phenanthroline, phen = 1,10 phenanthroline and bpy = 2,2′ bipyridine) from the monomer complex $[Ru(Cl\text{-}phen)(bpy)_2(PF_6)_2]$ by the metal-catalyzed coupling reaction. The complexes were purified by repeated column chromatography. The identity and the integrity of the complexes were confirmed by elemental analysis as well as mass spectroscopy. UV/Vis absorption, emission spectroscopic method, and cyclic voltammetric method were used to investigate the properties of these complexes. Spectroscopic studies document that inherently favorable photophysical properties are not substantially altered by dimer formation.

Materials and Methods

Chemicals

$RuCl_3{\cdot}3H_2O$, 5-chloro-1,10-phenanthroline (Cl-phen), 2,2′-bipyridine (bpy), NH_4PF_6, LiCl, N,N-dimethylformamide (DMF), tetraethyl ammonium iodide (Et_4NI), Nickel(II) chloride hexahydrate ($NiCl_2.6H_2O$), triphenylphosphine (PPh_3), alumina, and high-purity silica gel were purchased from the Aldrich Chemical Company. All the chemicals were used as purchased without further purification. All solvents used were reagent grade or better.

Measurements

Elemental analysis was performed by Columbia Analytical Services, Tucson, AZ. Electrospray ionization mass-spectral (ESI-MS) measurements were performed with a Bruker Esquire LCMS by the Arkansas State Wide Mass Spectromety Facility at the University of Arkansas, Fayetteville. The samples were dissolved in acetonitrile and were injected directly with nitrogen nebulizing gas at a flow rate of approximately 50 µL min^{-1}. Electronic absorption spectra were obtained with a Shimadzu model UV-2501 PC UV-Vis recording spectrophotometer using a 1-cm quartz cuvette. Spectra were obtained in the absorbance mode. The electronic absorption spectra of all the complexes were measured in acetonitrile solution. The electronic emission spectra were obtained with a PerkinElmer Model LS 55 luminescence spectrometer at 450nm λ_{exc}. The emission spectra of the monomer and the dimer complexes were measured in acetonitrile solution at room temperature. Cyclic voltammetry was performed with an Epsilon BASi Instruments Electrochemical Analyzer. The working electrode was a 2-mm-diameter platinum-disk electrode, the auxiliary electrode was platinum wire and the reference electrode was a saturated calomel electrode from BASi Instruments. Cyclic voltammograms were recorded in 0.1 M $(Bu_4N)(PF_6)$ (tetrabutylammonium hexafluorophosphate) in CH_3CN.

Preparation of Compounds

The monomer complex, $Ru(bpy)_2(Cl\text{-}phen)(PF_6)_2$, was prepared in a two step process by a method previously developed in our laboratory (Bhuiyan et al. 2010). The precursor complex, cis-$Ru(bpy)_2Cl_2$, was prepared by following the literature method proposed by Sullivan et al. (1978). The identity of the prepared precursor complex was confirmed by absorption spectroscopy. $Ru(bpy)_2(Cl\text{-}phen)(PF_6)_2$ was prepared from the reaction of $Ru(bpy)_2Cl_2$ (0.5 mmol) and Cl-phen ligand (1.0 mmol) under reflux condition in aqueous solution. The solution was cooled to room temperature, filtered, and saturated aqueous NH_4PF_6 was added to the filtrate to precipitate the product as a PF_6 salt. The orange precipitate was collected by vacuum filtration and washed with cold water and diethyl ether. The product was purified by silica-gel column with CH_3CN as an eluent. The first band was collected and added dropwise to diethyl ether to reprecipitate. The typical yield was 65-75% (Bhuiyan et al. 2010). Elemental analysis calculated for $RuC_{32}H_{23}N_6ClP_2F_{12}$: C = 41.87%, H = 2.53%, N = 9.15%; experimentally found: C = 41.51%, H = 2.46%, N = 9.12%.

The dimer complex, $(bpy)_2Ru(phen\text{-}phen)Ru(bpy)_2^{4+}$, was prepared from the precursor monomer complex, $Ru(bpy)_2(Cl\text{-}phen)(PF_6)_2$, by the metal-catalyzed direct coupling reaction, which is a modification of a method developed by Griffiths et al. (2000). Typically 0.076 g (0.321 mmol) $NiCl_2.6H_2O$ and 0.281g (1.07 mmol) PPh_3 was taken in a dry three neck 100 mL round bottom flask. The flask and the sample was flushed with argon for few minutes and then filled with argon. Then 10 mL dry DMF was added by syringe and the resulting blue solution was stirred and purged with argon for about 30 minutes. Zinc dust (0.021 g, 0.310 mmol) was added under strong flow of argon to the deep blue solution and then the reaction mixture was stirred under argon for 3 hours. During the first 30 minutes, the color of the reaction mixture changed from deep blue to green, then yellow, then orange, and finally reddish brown color. Ruthenium monomer complex (0.251 g, 0.534 mmol) and tetraethylammonium iodide (0.069 g, 0.534 mmol) were then added to the reaction mixture under a strong flow of argon. The resulting reaction mixture was stirred for 14 hours under argon at 55 ^oC. The resulting solution was then cooled to room temperature and filtered. The ruthenium dimer product was precipitated as a PF_6 salt by adding aqueous ammonium hexafluorophosphate (NH_4PF_6). This mixture was refrigerated a few hours to enhance the precipitation, and the precipitate was collected by vacuum filtration. The precipitate was washed with cold water to remove excess NH_4PF_6, and was finally washed with diethyl ether. After the precipitate was dried in a desiccator, 0.245 g product was obtained. The crude compound was purified by column chromatography using a silica-gel stationary phase and acetonitrile as an eluent. The first band was collected and added dropwise to diethyl ether to reprecipitate and 0.187 g (75% yield) product was obtained. Elemental analysis calculated for $Ru_2C_{64}H_{46}N_{12}P_4F_{24}$: C = 43.55%, H = 2.63%, N = 9.52%; experimentally found: C = 41.86%, H = 2.56%, N = 9.00%.

Results and Discussion

The monomer complex, $Ru(bpy)_2(Cl\text{-}phen)(PF_6)_2$, was prepared by following the method previously developed in our laboratory (Bhuiyan et al. 2010). The heteroleptic monomer complex was prepared by a two-step process. In the first step, the precursor complex $Ru(bpy)_2Cl_2$ was prepared according to published methods (Sullivan et al. 1978). Sufficiently pure precursor complex was obtained and no further purification was necessary. The second step involved the reaction of the previously prepared precursor complex and additional Cl-phen ligand. This type of procedure is common for mixed-ligand complexes (Bhuiyan 2008, Bhuiyan et al. 2008, Bhuiyan and Kincaid 1999, Bhuiyan et al. 2009). Thin-layer chromatography indicated that the monomer compound was slightly contaminated. We used the most common purification method of column chromatography on silica with acetonitrile as an eluent for the complex (Bhuiyan et al. 2010).

The homometallic dinuclear ruthenium dimer complex, $(bpy)_2Ru(phen\text{-}phen)Ru(bpy)_2$, was formed by the nickel-catalyzed direct coupling of the monomer complex with a very satisfactory 75% yield. This synthetic strategy was based on the pioneering work of Toyota and coworkers (2005) on the coupling of free ligands. The yield was very low and it was very difficult to purify the coupled ligand. So we attempted to apply the nickel coupling reaction directly to the monomer complex, which is similar to the procedure mentioned in the literature for other complexes (Griffiths et al. 2000, Johansson et al. 2000). We would like to mention here that the requirement to maintain an inert atmosphere during the synthesis is very critical. This nickel catalyzed coupling reaction is very sensitive to traces of oxygen. The mass spectrum indicated that the product was contaminated with trace amount of monomer complex, which we then removed by column chromatography.

The calculated and experimental results of the elemental analysis of the monomer and the dimer complexes are shown in the Material and Method section. The experimental results are in close agreement with the calculated results for both the complexes, which confirms the identity of the prepared complexes.

The mass spectrum of the ruthenium dimer complex, $(bpy)_2Ru(phen\text{-}phen)Ru(bpy)_2$, is shown in Figure 2. The calculated molar mass of the dimer complex is 1185.27 g/mol $[(bpy)_2Ru(phen\text{-}phen)Ru(bpy)_2^{4+}]$.

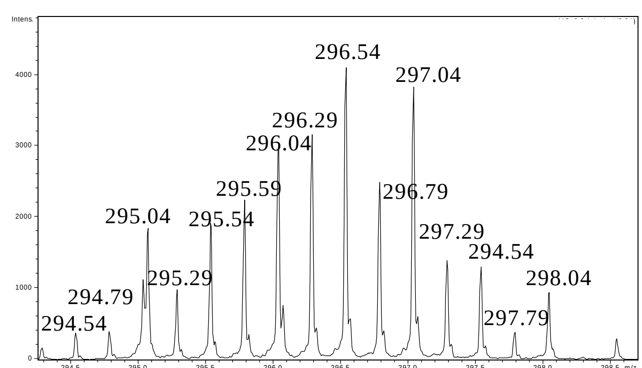

Figure 2. The electrospray mass spectrum of the prepared ruthenium dimer complex, showing the major fragment cluster.

The electrospray mass spectrometry of the complexes showed a consistent fragmentation pattern

(Figure 2). The experimental isotopic patterns are consistent with the calculated isotopic patterns. The mass spectrum showed that the molecular-ion peaks appear at m/z (mass/charge) = 296.29. From the isotopic patterns, it was confirmed that the molecular ion has an overall charge of 4+, so the experimental molar mass of the dimer complex is 1185.16 (4 x 296.29) g/mol. The experimental molar mass is in very good agreement with the calculated molar mass, which confirms the identity and the integrity of the prepared dimer complex.

Electronic absorption spectra of the prepared dimer and the monomer complexes are shown in Figure 3. The solid-line spectrum is for the dimer complex (trace A) and the dashed line is for the monomer complex (trace B). The absorption spectrum of the dimer complex is very similar to the monomer complex, which is also similar to the methyl-substituted complexes previously reported by Bhuiyan et al. (2009). Both the spectra consist of a series of absorption bands in the UV and visible regions. A very strong transition at 268 nm is assigned to a spin-allowed ligand-centered π–π^* transition of the Cl-phen ligand, and a 284 nm peak is assigned to a π–π^* transition of bpy ligand (Kalyanasundaram and Nazeeruddin 1990). In the dimer complex, the relative intensity of the 284 nm band increases in comparison with the 268 nm band. The broad, relatively intense visible band at 450 nm is assigned to a metal-to-ligand charge-transfer (MLCT) transition by comparing with other ruthenium(II) polypyridine complexes (Denti et al. 1990). The higher-energy shoulder observed is assigned to a second MLCT transition. It was observed that dimer formation did not affect the absorption pattern.

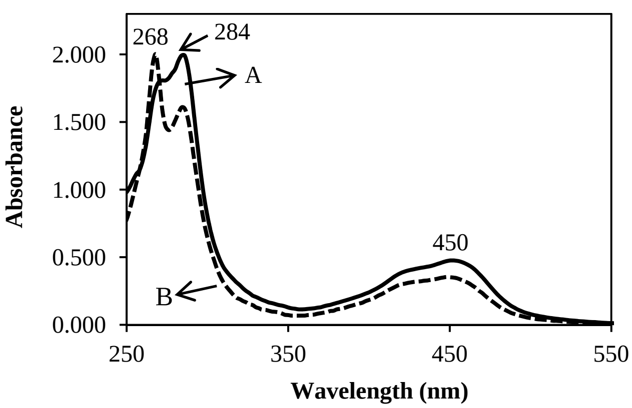

Figure 3. Electronic absorption spectra of the prepared complexes in acetonitrile: dimer (trace A) and monomer (trace B).

The room-temperature emission spectra of the dimer and the monomer complexes are shown in Figure 4. The excitation wavelength was determined by scanning the excitation spectra at a fixed emission wavelength. The excitation wavelength is 450 nm for both the complexes. The solid line is for the dimer complex (trace A) and the dashed line is for the monomer complex (trace B). The electronic emission spectra of the complexes exhibit strong emission bands at 608 nm for the dimer and 613 nm for the monomer. Both complexes exhibit a single emission band, which confirms the purity of the prepared complexes.

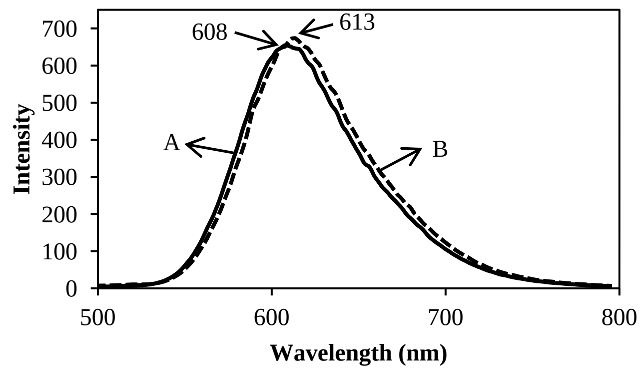

Figure 4. Electronic emission spectra of the prepared complexes in acetonitrile: dimer (trace A) and monomer (trace B).

The emission spectrum of the dimer complex is similar to the monomer complex which is also very similar to methyl-substituted complexes previously reported by Bhuiyan et al. (2009). As for other polypyridine complexes of Ru(II), these luminescence bands have been assigned as the phosphorescent process ^{3}MLCT (triplet metal-to-ligand charge transfer) $\rightarrow$ ^{1}GS (singlet ground state) (Lytle and Hercules 1969, Bhuiyan and Kincaid 2001). The emission band for the monomer compound is slightly red shifted from that observed for the dimer compound (613 nm vs 608 nm). This observation is consistent with the previously reported spectra of similar ruthenium(II) polypyridine complexes (Griffiths et al. 2000, Johansson et al. 2000).

Cyclic voltammograms of the prepared monomer and dimer complexes are shown in Figure 5. The solid line is for the monomer complex and the dashed line is for the dimer complex. Both the complexes exhibit a single reversible electrochemical wave over the range examined. For each of the complexes, the potential corresponds to oxidation of ruthenium(II) to ruthenium(III). The potentials are $E_{1/2}$ = +1.32 V for the monomer complex and $E_{1/2}$ = +1.36 V for the dimer complex. The single wave for each complex confirms the purity of the prepared complexes. The formation of dimer shifts the wave to slightly higher potential. This phenomenon indicates that the dimer formation did not change the energy levels significantly (Rillema et al. 1987).

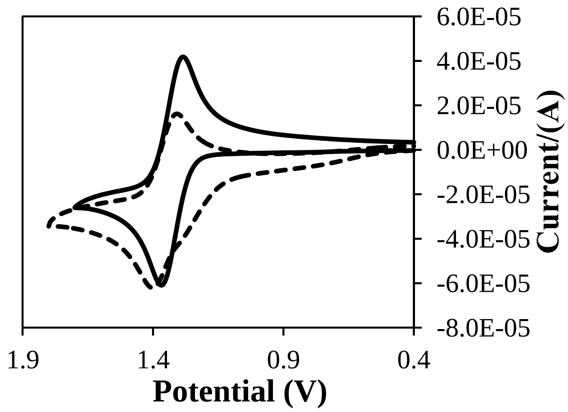

Figure 5. Cyclic voltammograms of the prepared complexes: solid line is for the monomer and the dashed line is for the dimer.

Conclusions

The present report summarizes efficient synthetic procedures to construct a homometallic dinuclear ruthenium dimer complex, $(bpy)_2Ru(phen-phen)Ru(bpy)_2$, containing chloro-phenanthroline and bipyridine. The dimer complex is formed by the nickel-catalyzed direct coupling of the monomer complex with a very good yield (75%). Elemental analysis and mass spectroscopy confirm the identity and structural integrity of the prepared monomer and the dimer complexes. Absorption, emission, and cyclic voltammetric results of the dimer complex were very comparable with the monomer complex. It was observed that the inherently favorable photophysical properties are not substantially altered by dimer formation. This high charge dimer complex can be used for metallo-protein electron transfer studies.

Acknowledgments

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Modeling Loblolly Pine Aboveground Live Biomass in a Mature Pine-hardwood Stand: A Cautionary Tale

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Abstract

Carbon sequestration in forests is a growing area of interest for researchers and land managers. Calculating the quantity of carbon stored in forest biomass seems to be a straightforward task, but it is highly dependent on the function(s) used to construct the stand. For instance, there are a number of possible equations to predict aboveground live biomass for loblolly pine (*Pinus taeda*) growing in southeastern Arkansas. Depending on stem diameter at breast height (DBH), biomass varied considerably between four different prediction systems for loblolly pine. According to the tested models, individual tree oven-dry biomass for a 50 cm DBH loblolly pine ranged between 1,085 kg and 1,491 kg. Beyond this point, departures between these models became increasingly pronounced, with one even projecting an irrational decline to negative biomass for trees > 138.7 cm DBH, while the others varied between 12,447 and 15,204 kg. Although some deviation is not surprising given the inherent differences in model form and three of the models were extrapolations across much of this diameter range, the difference between the extremes was unexpected. Such disparities significantly impact stand-level (cumulative) predictions of biomass in forests dominated by large-diameter individuals, as demonstrated for an existing stand (Hyatt's Woods) in Drew County, Arkansas. Differences between these models caused loblolly pine aboveground live-tree biomass estimations in Hyatt's Woods to vary by almost 34,000 kg/ha.

Introduction

Loblolly pine (*Pinus taeda*) is probably the most economically important conifer in North America, if not the world (Schultz 1997). Loblolly is found across a wide range of site conditions, grows quickly to large size, has considerable commercial value, can be successfully used in both natural and artificial regeneration systems, and has been well-studied. The productivity of loblolly pine has made it particularly desirable for those looking to maximize woody fiber production in the southeastern U.S. In Arkansas, biomass from forested ecosystems, especially loblolly pine stands, has received increasing attention for its contribution (realized or potential) towards carbon sequestration or bioenergy (e.g., Schuler et al. 2009, Mehmood and Pelkki 2009, Bragg and Guldin 2010).

Most of these studies make a series of assumptions regarding how live-tree biomass is determined. Typically, an allometric equation associating tree diameter at breast height (DBH) and biomass is applied on individual stems, and then summed to yield biomass per unit of land surface area. For commercially important species such as loblolly pine, multiple biomass equations are available. One of the challenges to forecasting tree and stand-level biomass is the accuracy and precision of these models, which leads to a number of relevant questions. Which prediction system yields the most reliable estimates across a range of possible tree sizes? How will differences at the individual stem level translate into real-world conditions at the scale of stands, landscapes, or even regions?

A limited body of research has suggested that there are noticeable differences between biomass equations for loblolly pine in the southeastern U.S. (e.g., Van Lear et al. 1986, Baldwin 1987, Johnsen et al. 2004). Their preliminary assessments are limited to certain forest conditions (in these cases, relatively young loblolly pine plantations) and only suggests of the possibility for departures for other circumstances (for example, mature, pine-dominated stands of natural origin). Furthermore, there may be some fundamental differences in loblolly pine allometry as a function of conditions such as genetics, site quality, and stocking, making it imperative that multiple equations be tested to determine the predictive accuracy for loblolly pine grown in Arkansas. Hence, this study has been designed to evaluate biomass predictions of four different model systems for loblolly pine trees from southern Arkansas.

Table 1. Attributes of the equations tested in this paper, including the DBH range for which the model was derived.

Model reference	Geographic source	Pine stand origin and type	DBH range (cm)
Farrar et al. (1984)	southeast Arkansas	Natural-origin, uneven-aged	9 – 83
Baldwin (1987)	central Louisiana	Planted (even-aged)	5 – 53
Doruska and Patterson	southeast Arkansas	Planted- and natural-origin even-aged	15 – 75
Jenkins et al. (2003)	U.S.-wide	Various origins and age structures	2.5 – 56 [a]

[a] For only the loblolly pine used in their derivations.

Materials and Methods

Research on carbon sequestration almost always involves the quantification of biomass, typically in terms of oven-dry aboveground yield of living trees. Rather than destructively sampling loblolly pines to predict aboveground biomass as a function of diameter at breast height (DBH), four existing allometric models were adapted for this purpose (Table 1). Some of these models were initially designed to predict sawtimber (wood only) or merchantable bole volumes (including wood and bark), not total aboveground biomass, and thus had to be adapted to produce the desired output. All stem volume model predictions were converted to cubic meters, then multiplied by the oven-dry weight of loblolly pine (in kg/m^3) to yield aboveground stem biomass for a loblolly pine of the given DBH. Models that predicted bole biomass only were also converted to total tree biomass using factors based on tree size.

Three of these models were derived from naturally or artificially regenerated loblolly pine stands in Arkansas and Louisiana. The first example used a set of polynomial equations to predict the growth and yield of uneven-aged pine stands on or near the Crossett Experimental Forest in Ashley County, Arkansas (Farrar et al. 1984). Of these, the equation that predicted merchantable wood volume (V_M) to an 8.9 cm top was used:

$$V_M = \left[-1.41726 - 0.02484\left(\frac{DBH}{2.54}\right) + 0.09948\left(\frac{DBH}{2.54}\right)^2 + 0.00748\left(\frac{DBH}{2.54}\right)^3 - 0.00017\left(\frac{DBH}{2.54}\right)^4\right] \times 0.02832 \quad (1)$$

An additional adjustment to produce total loblolly pine bole biomass was needed. Clark and Saucier (1990) estimated a nonlinear ratio (Y_R, where $0.0 < Y_R \leq 1.0$) between these volumes:

$$Y_R = e^{-2.45015(d^{4.64713} DBH^{-4.81445})} \quad (2)$$

where d is the upper (stem-top) tree diameter (for this study, fixed at 8.3 cm). Thus, total bole wood volume (V_T) follows:

$$V_T = V_M / Y_R \quad (3)$$

According to the work of Patterson et al. (2004), one cubic meter of green (100% moisture content) loblolly pine wood from southeastern Arkansas averages 1,025 kg and weighs 50% less (512.5 kg) when oven-dry. Thus, oven-dry bole biomass (b_D) was determined by multiplying the volume (V_T) by its green weight per unit volume, then halving that quantity, i.e., $b_D = b_G \times 0.5$. All final biomass values are oven-dry weights.

The second model system was developed from field data collected in a log weight scale study in southern Arkansas (Posey et al. 2005, Doruska and Patterson 2006). For pulpwood-sized (stems < 25 cm DBH) loblolly pines, the following equation was used:

$$b_G = \left[-26.23697 + 0.1431\left(\left(\frac{DBH}{2.54}\right)^2 \times \left(\frac{H}{0.3048}\right)\right) + 0.00481\left(\left(\frac{DBH}{2.54}\right)^2 \times \left(\frac{H}{0.3048}\right)\right)\right] / 2.2 \quad (4)$$

where b_G equals green bole biomass to a 7.6-cm diameter top and H is total tree height. Sawtimber-sized loblolly pine bole biomass was calculated somewhat differently:

$$b_G = \left[e^{-0.1341 + 2.0178\left(ln\left(\frac{DBH}{2.54}\right)\right) + 0.5726\left(ln\left(\frac{H}{0.3048}\right)\right)}\right] / 2.2 \quad (5)$$

Equations (4) and (5) also require height, so a model developed for loblolly pine in southeastern Arkansas was used to predict total tree height from DBH (Bragg 2008):

$$H = 1.37 + 41.9641(1 - e^{-0.0247 DBH})^{1.1496} \quad (6)$$

Equations (4) and (5) were then converted to b_D.

The third bole biomass equation was developed by Baldwin (1987) for loblolly pine plantations in central

Table 2. Species composition and stand density of Hyatt's Woods in Drew County, Arkansas, measured in 2009.

Species	Trees per ha	Basal area (m^2/ha)
Baldcypress (*Taxodium distichum*)	5.8	3.6
Loblolly pine (*Pinus taeda*)	54.6	15.7
Red maple (*Acer rubrum*)	2.5	0.2
American hornbeam (*Carpinus caroliniana*)	19.0	0.2
Water hickory (*Carya aquatica*)	7.4	0.4
Bitternut hickory (*Carya cordiformis*)	0.8	0.3
Black hickory (*Carya texana*)	2.5	0.2
Mockernut hickory (*Carya tomentosa*)	32.2	2.0
Flowering dogwood (*Cornus florida*)	1.7	0.0
Common persimmon (*Diospyros virginiana*)	2.5	0.1
Green ash (*Fraxinus pennsylvanica*)	3.3	0.2
American holly (*Ilex opaca*)	3.3	0.1
Sweetgum (*Liquidambar styraciflua*)	23.1	2.5
Red mulberry (*Morus rubra*)	0.8	0.1
Blackgum (*Nyssa sylvatica*)	11.6	0.8
Eastern hophornbeam (*Ostrya virginiana*)	38.0	0.5
Black cherry (*Prunus serotina*)	1.7	0.0
White oak (*Quercus alba*)	20.7	4.4
Cherrybark oak (*Quercus pagoda*)	18.2	1.4
Swamp chestnut oak (*Quercus michauxii*)	3.3	0.9
Water oak (*Quercus nigra*)	3.3	0.2
Willow oak (*Quercus phellos*)	1.7	0.2
Shumard oak (*Quercus shumardii*)	9.1	1.0
Post oak (*Quercus stellata*)	2.5	0.5
Sassafras (*Sassafras albidum*)	4.1	0.2
Winged elm (*Ulmus alata*)	60.3	1.4
Totals =	333.9	37.1

Louisiana. Baldwin's exponential model also included an age (A) component:

$$b_D = e^{-3.31353+1.91029(ln(DBH))+1.19118(ln(H))+0.000076A^2} \quad (7)$$

Since there was no age data for any of the trees simulated, a DBH-age relationship was adapted from data collected on an uneven-aged loblolly pine-dominated stand on the Crossett Experimental Forest:

$$A = 9.5088DBH^{0.6244} \quad (8)$$

Although the relationship between age and diameter is fairly weak in uneven-aged stands, this particular nonlinear function accounted for approximately 87% of the variance in the 125 tree data set used to derive it (D.C. Bragg, unpublished data). Absent better age data, equation (8) should suffice for the purposes of this work (especially given the limited impact of tree age on biomass using Baldwin's model).

Additionally, for all of these bole biomass-only models it was necessary to use softwood-only scalars (from Jenkins et al. 2003) to produce total aboveground tree biomass (= foliage biomass + branch biomass + bole bark biomass + bole wood biomass). The general form of these scalars follows:

$$\varphi_i = e^{\beta_0+\frac{\beta_1}{DBH}} \quad (9)$$

Where β_i are component-specific parameters and φ_i is a ratio (between 0.0 and 1.0) for one of four possible aboveground components: foliage, branches, bole bark, and bole wood (all of these sum to 1.0, or $\varphi = \Sigma\varphi_i = 1.0$). Hence, aboveground total biomass (in oven-dry terms) is the product of the sum of the components from equation (9) and model's specific biomass estimates, or $B_D = b_D \times \varphi$. For the Farrar et al. model, this ratio scalar incorporated foliage, bark, and branches, while the Doruska and Patterson and Baldwin models used only foliage and branches (both bole bark and stem wood were included in their bole biomass estimates).

The final model used for this analysis was the National Biomass Estimator by Jenkins et al. (2003). Their model directly predicts total aboveground tree oven-dry biomass (in kg):

$$B_D = e^{-2.5356+2.4349(ln(DBH))} \tag{10}$$

Unlike the first three systems, the Jenkins et al. (2003) approach was developed from an amalgamation of "pseudodata" generated using 43 different equations from 14 different pine species. Of these equations, only four were loblolly pine. Hence, the Jenkins et al. (2003) pine is the least "pure" set of information, although all of the models had some issue with their applicability. For example, equation (1) was calculated for a specific merchantable top diameter, and thus had to use equations (2) and (3) to correct for the "missing" biomass (the rest of the bole). Baldwin's study was for planted loblolly pine in central Louisiana (Baldwin 1987), and the Doruska and Patterson data included both planted and naturally regenerated loblolly (Doruska and Patterson 2006). The Jenkins et al. model used pines up to 180 cm in DBH, although none of their data sets included loblolly pine > 56 cm DBH (Jenkins et al. 2004). The other three loblolly pine-only equations incorporated stems between 5 and 83 cm (Table 1).

Thus, none of these models are "ideal" for calculating total aboveground tree biomass for large diameter loblolly pines in southern Arkansas. This work is not intended as a criticism of the original models, but rather to highlight how their predictions, when extrapolated beyond the range of data, will produce results that can differ substantially, even when other aspects are held constant.

To help evaluate differences in biomass projections as a function of model, a mature, unmanaged stand (Hyatt's Woods) in southern Drew County, Arkansas, was used as an example. In composition, landform position, and management history, Hyatt's Woods is comparable to many other naturally regenerated stands in this part of Arkansas. This 1.2-ha stand, located along a stream terrace of Brown's Creek, is primarily hardwood but has a prominent (42% of total stand basal area) loblolly pine component in the overstory (Table 2). A stand table comprised of loblolly pine counts per hectare by 10 cm DBH class was entered into a spreadsheet. Biomass volumes for trees of a specified diameter class midpoint were calculated using each of the four models in this study, multiplied by the number of pines in each size class, and then summed across all size classes to approximate the total aboveground live-tree, oven-dry loblolly pine biomass for this stand.

Results and Discussion

Small to moderate diameter loblolly pine predictions

Figure 1 shows similarity in both the shape and magnitude of the curves up to 50 cm DBH. Across this range, three of the models (Farrar et al., Doruska and Patterson, Baldwin) rarely differed by more than 20-25% from their central tendency, and in most instances were within 10%. Generally, this low variability should fall within the range expected for biomass estimates, suggesting that very little difference in performance can be detected between these models to 50 cm DBH. According to Rosson (2002), approximately 99% of the estimated 533 million loblolly pine growing in the state of Arkansas were less than 50 cm in DBH, a fraction that will almost certainly have increased as mature trees have continued to be harvested or died and are replaced by small diameter stems. Hence, efforts to predict aboveground carbon storage in a "typical" Arkansas loblolly pine should be adequately satisfied by most if not all of the equations used in this paper.

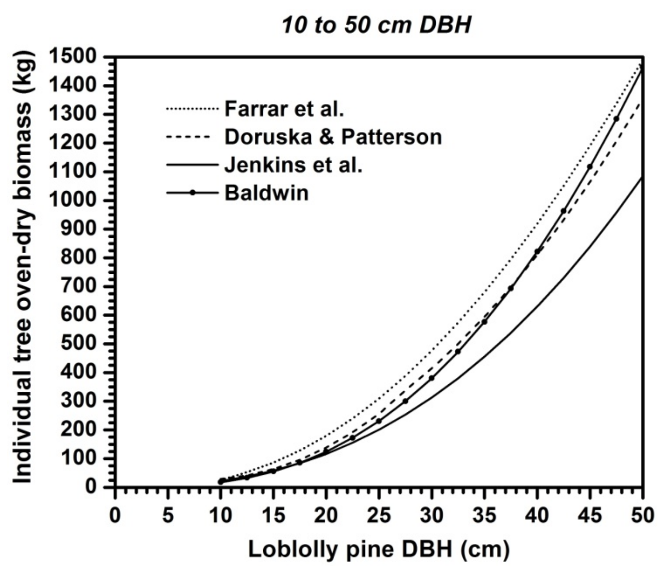

Figure 1. Predicted aboveground live-tree, oven-dry biomass as a function of stem diameter for loblolly pines between 10 and 50 cm DBH using the four different model systems.

However, the biomass equation of Jenkins et al. (2003) produced appreciably different biomass predictions, as much as 24-27% lower than the average of the other models across most of the 10-50 cm DBH range. Presumably, this disparity is largely a function of the generality of the derivation of the Jenkins et al. model, which included *Pinus* of a number of different species, many of which have substantially less dense oven-dry wood than *Pinus taeda* (Miles and Smith 2009).

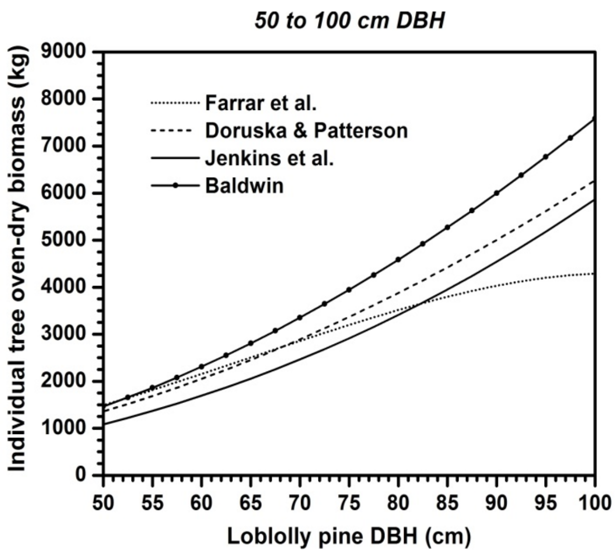

Figure 2. Predicted aboveground live-tree, oven-dry biomass as a function of stem diameter for loblolly pines between 50 and 100 cm DBH using the four different model systems.

Large tree predictions

Loblolly pine aboveground biomass predictions begin departing soon after the stems reach 50 cm DBH, with the differences becoming increasingly pronounced as the pines get larger. Even though the general shape of the Doruska and Patterson, Baldwin, and Jenkins et al. curves are similar (Figure 2), their rates of increase differ and hence their predictions are not proportionally similar. For instance, the Doruska and Patterson and Baldwin predictions for a 50 cm DBH pine differed by only 108 kg (about 8%), compared to an almost 19% mean difference at 100 cm DBH (Table 3). The Jenkins et al. predictions are approximately proportionate for loblolly pines from 50 to 100 cm DBH as they were from 10 to 50 cm DBH, with the exception of the Farrar et al. equation, which has started a prominent departure.

Unlike the others, the Farrar et al. model peaks at about 102 cm DBH, and then begins to rapidly drop until it reaches zero biomass at just under 139 cm DBH (Figure 3, Table 3). Needless to say, it is physically impossible for a loblolly pine of this size to have no biomass. This result arises because the polynomial function used is extrapolated well beyond the range of its original data. Such a disparity was inevitable, given the negative coefficient of the biquadrate of equation (1), which causes a systematic decrease in individual tree biomass as DBH increases. The other models use monotonically increasing power or exponential functions, and thus will never predict such a decline—at just under 139 cm DBH, they yielded estimates between 13,023 and 17,928 kg.

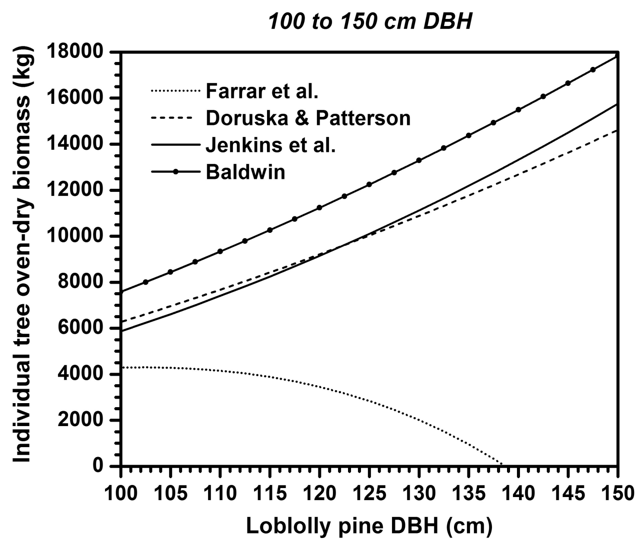

Figure 3. Predicted aboveground live-tree, oven-dry biomass as a function of stem diameter for loblolly pines between 100 and 150 cm DBH using the four different model systems. Note the dramatic departure of the Farrar et al. system from the others.

For the largest of loblolly pines (Figure 3), the three most reasonable models continue to increase in their biomass predictions. The Baldwin equation retains its position as the highest predictor of biomass. At just under 125 cm, the Doruska and Patterson and Jenkins et al. models switch order, but otherwise remain similar. Without destructively sampling very large live trees, it is not possible to say which model system is most appropriate at this extreme in the diameter range for southern Arkansas loblolly. Even though the Baldwin and Doruska and Patterson models were regionally derived from loblolly pine stands, they only included specimens of fairly limited dimensions and were thus not necessarily more reliable across all size classes than the Jenkins et al. model, which used considerably larger trees (but not of loblolly pine). This exemplifies the challenge of this type of effort, when models capable of predicting very large tree biomass are needed but do not currently exist.

Table 3. Aboveground live-tree, oven-dry biomass as a function of individual tree size and model system for loblolly pine growing in southern Arkansas. Italics denote predictions of tree biomass beyond the original model DBH range.

	---------------------------------- Predicted quantity (in kg) ----------------------------------			
DBH (cm)	Farrar et al.	Doruska and Patterson	Baldwin	Jenkins et al.
10	25	29	18	22
25	309	256	231	201
50	1491	1356	1464	1085
75	3196	3365	*3946*	*2913*
100	*4292*	*6271*	*7586*	*5870*
125	*2839*	*10031*	*12247*	*10106*
137.5	*330*	*12222*	*14930*	*12746*
150	*-3908*	*14617*	*17835*	*15753*

Implications for larger scale modeling

The appropriateness of model form under all possible size classes is an important issue. For this type of biomass work, it is advisable for researchers to project their models to the very upper end of the species potential to ensure that irrational results do not occur. The allometric behavior of trees across the range of potential sizes should be one of several criteria used to determine the utility of a modeling system. After all, models developed with limited sample size, restricted geographic distributions, or abbreviated portions of the possible dimensional range are susceptible to influence by outliers or the central tendency of only a portion of the possible conditions. For instance, even though the Farrar et al. model was derived with pines up to 83 cm in DBH, only a few large specimens were used, thus allowing the bulk of the data (smaller trees) to determine the response curve. Hence, when coupled with the polynomial function, irrational large tree predictions were inevitable.

This particular example serves as a cautionary tale for researchers projecting live tree biomass over long time spans, especially as the trees age and approach their upper dimensional limits. Those wishing to project beyond the range of the functions may experience unexpected outcomes. However, such extrapolation may be unavoidable—even though only a fraction of loblolly pines today exceed 100 cm in DBH, it can grow to this size. For instance, a former national champion loblolly near Warren, Arkansas, had a DBH of 152 cm, and historical records from the region exceed even this, with pines from Ashley County, Arkansas, reportedly greater than 180 cm in diameter (Bragg 2002).

Table 4. Stand-level loblolly pine-only aboveground live-tree, oven-dry biomass for Hyatt's Woods predicted by the different modeling approaches. Italics denote predictions of tree biomass beyond the original model DBH range.

DBH class midpoint (cm)	Live pine stocking (stems/ha)	Farrar et al. (1984) (kg/ha)	Doruska and Patterson (kg/ha)	Baldwin (1987) (kg/ha)	Jenkins et al. (2003) (kg/ha)
5	0	0	0	0	0
15	1	72	53	46	48
25	1	257	213	192	167
35	1	565	493	479	378
45	10	11814	10563	11086	8331
55	15	27008	25060	27696	20371
65	19	47637	46607	*53350*	*39088*
75	6	18506	19486	*22847*	*16868*
85	2	9419	*10968*	*13072*	*9799*
TOTALS:	55	115278	113442	128768	95051

The simulation of the loblolly pine component at Hyatt's Woods further demonstrates the sensitivity of the biomass predictions to the model used. In this mature pine-dominated unmanaged stand, few small diameter loblolly are present, and the big pines (those 65 cm DBH or greater) dominate the biomass contributions (Table 4). The Farrar et al. model system predicted the loblolly pine component of this stand to have just over 115,000 kg/ha of biomass, compared to 113,442 kg/ha using the Doruska and Patterson models, 128,768 kg/ha from the Baldwin model, and 95,051 kg/ha according to Jenkins et al.

Thus, stand-level disparities of almost 34,000 kg/ha appear in this one limited example, suggesting that considerable variation in aboveground biomass due solely to model choice can be expected. While these equations are used beyond their range of original data, it is commonplace for biomass estimation to use extrapolated models without consideration of the reliability of these estimates. This is particularly true when simulations are expanded regionally or over long time frames (e.g., Birdsey et al. 2006), and calls into question large-scale carbon storage estimates based on equations that have not been properly evaluated.

Conclusions

A test of a handful of different biomass prediction systems shows that model choice definitely influences estimates of aboveground biomass in loblolly pine. This comparison strongly suggests that researchers examine the full range of potential tree size when evaluating which model system to apply given a number of alternatives. As suggested by a real-world example from Hyatt's Woods, aboveground biomass estimates can arise that may differ by as much as one-third in mature stands of loblolly pine-dominated forest solely based on the model used. In an era of increasing environmental and economic interest in carbon sequestration, the question of appropriate model selection has yet to be adequately addressed.

Acknowledgments

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Effects of Annealing on the Electronic Transitions of ZnS Thin Films

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Abstract

Thin films of zinc sulphide were prepared using a flash evaporation technique. The obtained thin films were subjected to heat treatment to investigate the effect of annealing on the transmittance spectrum and the electronic transitions. It has been found that annealing affected the transmission spectrum and caused an increase in the direct optical band gap. The optical parameters, oscillator energy E_0 and dispersion energy E_d were determined using the Wemple DiDomenico single oscillator model. The optical energy gap obtained from the Wemple and DiDomenico model was in good agreement with the optical energy gap proposed by the Tauc theory.

Introduction

Zinc sulphide (ZnS) has attracted much attention from the viewpoint of fabrication of many devices. ZnS is highly suitable as a window layer in heterojunction photovoltaic solar cells because the wide band gap decreases the window absorption losses and improves the short-circuit current of the cell (Fathy et al. 2004). Thin films of ZnS doped with transition metal elements or rare earth elements have also been used as effective phosphor materials (Takata et al. 1990). In the area of optics, ZnS can be used as a reflector because of its high refractive index (Antony et al. 2005 and Ruffiner et al. 1989), as a dielectric filter because of high transmittance in the visible region (Roy et al. 2006), and as a light emitting diode in the blue to ultraviolet spectral region due to its wide band gap (Lopez et al. 2005).

Thin films of ZnS are produced by different techniques such as chemical vapor deposition (Tran et al. 1999), atomic layer epitaxy (Oikkonen et al. 1988), direct current (DC) electrodeposition (Lokhande et al. 1988), radio-frequency (RF) reactive sputtering (Shaoi et al. 2003), chemical bath deposition (Ben et al. 2008), and spray pyrolysis (Oztas and Yazici 2004).

In the present work, we report the effect of annealing on the optical transition of ZnS using a flash evaporation technique.

Methods

Thin films of ZnS were deposited on glass substrate utilizing a flash evaporation technique. High-purity ZnS powder (99.99%) from Aldrich company was ground. This powder was evaporated using a molybdenum boat filament in a high-vacuum chamber $> 10^{-5}$ torr.

The optimum conditions for obtaining uniform films were at a substrate temperature of 100 ^oC, and deposition rate 0.8 nm/s. The distance between filament and substrate was kept at 10 cm. The thickness of the as-deposited films was about 0.5 μm determined by optical interferometer method.

Optical and transition spectra were recorded in the wavelength range 300 - 900 nm using a double beam UV/Vis Shimadzu Corporation (Japan).

A computer program was used to calculate the absorption coefficients and the electronic transitions.

Results and Discussion

Typical transmission spectra for ZnS samples as a function of annealing temperature (200 ^oC for 2 hours) are presented in Fig. 1. The transmission peaks are shifted toward lower wavelengths after

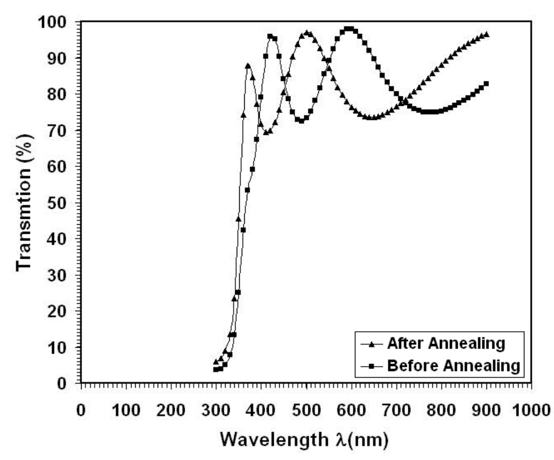

Fig. 1 Transmission of ZnS thin film versus wavelength before and after annealing.

annealing compared to the transmission peaks of deposited films. The average transmission in the visible spectrum was 72-97%. The absorption coefficient (α) was calculated with the help of the following relation (Shamala et al. 2004):

$$T = (1-R)\, e^{-\alpha d} \ldots (1)$$

where (d) is the thickness of the film. (T) and (R) are the transmittance and reflectance, respectively. Fig. 2 shows the calculated absorption coefficient $\alpha(h\upsilon)$, as a function of photon energy. It is clearly seen that α is greater than 10^4 cm^{-1} when ($h\upsilon$) is greater than 3.2 eV before annealing and 3.45 eV after annealing.

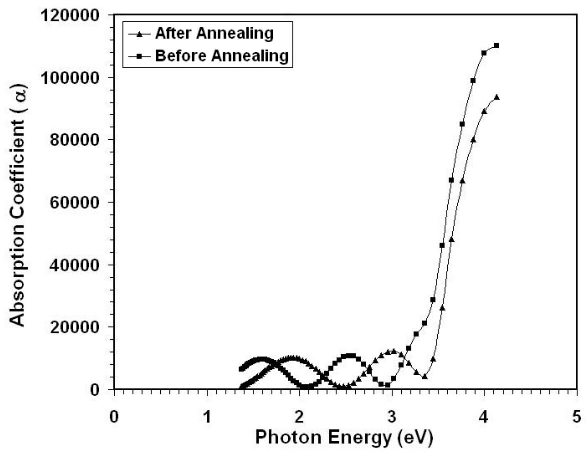

Fig. 2. Absorption of ZnS thin film versus photon energy

The band gap energies of these films were calculated with the help of an absorption spectrum. In general, the absorption coefficient and photon energy ($h\upsilon$) are related by the Tauc plot (Tauc and Meneth 1972):

$$\alpha = \frac{A}{h\nu}(h\nu - E_g)^n \ldots (2)$$

where (A) is a constant and (n) assumes values of (1/2, 2, 3/2 and 3), for allowed direct, allowed indirect and forbidden direct and indirect transitions, respectively. Fig. 3 and Fig. 4 show the curves of $(\alpha h\upsilon)^2$ versus photon energy before and after annealing.

The curve has a good straight-line fit over the higher-energy range above the absorption edge indicative of a direct optical transition near the absorption edge. Based on Fig. 3 and Fig. 4 the direct energy gap was calculated to be 3.6 eV and increases to 3.65 eV after annealing. These values are in good agreement with the reported data obtained using other techniques (Sehhar et al. 1999, Thangaraju and Kalionnan 2000, and Tanusevski and Poelman 2003). This increment could be attributed to the increase in

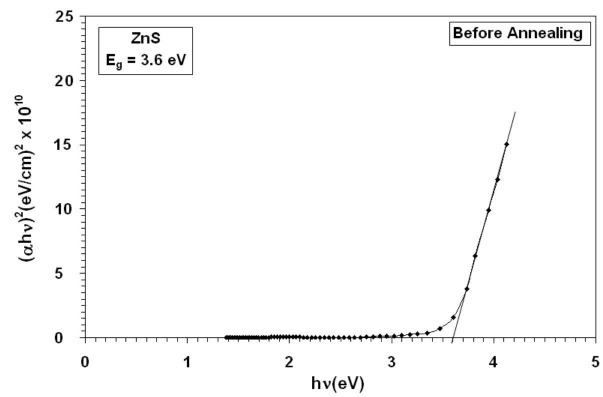

Fig. 3. $(\alpha h\upsilon)^2$ for ZnS thin film versus photon energy before annealing.

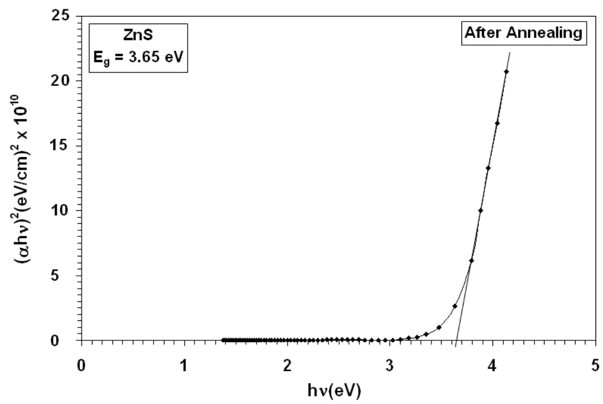

Fig. 4. $(\alpha h\upsilon)^2$ for ZnS thin film versus photon energy after annealing

crystallite size, which induced a decrease in dislocation density. We used a linear curve fitting to obtain the Urbach tail, which is defined as the width of the localized states available in the optical band gap that affects the optical band gap structure and optical transitions. The Urbach tail is determined by the following relation (Urbach 1953):

$$\alpha = \alpha_o \exp\left(\frac{E}{E_o}\right) \ldots (3)$$

where E is the photon energy, (α_o) is constant and E_v is the Urbach energy, which refers to the width of the exponential absorption edge.

Fig. 5 shows the variation of $\ln(\alpha)$ versus photon energy, for ZnS thin films before and after annealing. The value of E_o were calculated from the slope, and the obtained values are given in Table 1, which indicates that Urbach energy values of ZnS film decrease after annealing . It can be clearly seen that the width of the band tail, i.e. the Urbach energy, decreases slightly with increasing annealing temperature, indicating an improvement of the quality of the film due to the

Table 1 Optical parameters of Zn thin films

Sample	E_g^{opt} (eV) by Tauc	E_d (eV)	E_o (eV)	E_g (eV) by W. D.	E_U (eV)
Before annealing	3.6	2.84	7.28	3.64	1.38
After annealing	3.65	3.70	7.42	3.71	1.10

annealing process. The $E_{U,}$ values change inversely with optical band gaps of the films. This decrease leads to a redistribution of states from band to tail, thus allowing for a greater number of possible band to tail and tail transitions (Oleary et al. 1997).

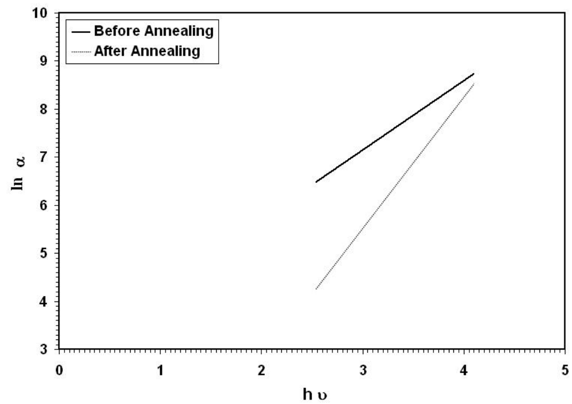

Fig. 5. ln α as a function of hυ.

The dispersion in refractive index can be determined by the single-oscillator model proposed by Wemple and Didomenico. The spectral dependence of the refractive index (n) according to this model is then defined by the equation (Wemple and DiDomenico 1971):

$$n^2 - 1 = \frac{E_o E_d}{E_o^2 - h\upsilon^2} \ldots (4)$$

where E_o is the single-oscillator energy parameter and E_d is the dispersion energy, which is a measure of the strength of the interband transitions.

A plot of $(n^2-1)^{-1}$ versus E^2 would be linearly fitted and would give the values of E_o and E_d from the slope $(1/E_oE_d)$ and the intercept of the y-axis (E_o/E_d). Typical curves for ZnS before and after annealing are plotted in Fig. 6. The oscillator energy E_o is an average energy gap and could be related to the optical band gap, E_g by the approximation $E_o \approx 2E_g$ (Tigau 2005). The obtained values of E_o, E_d, E_g, are listed on Table 1.

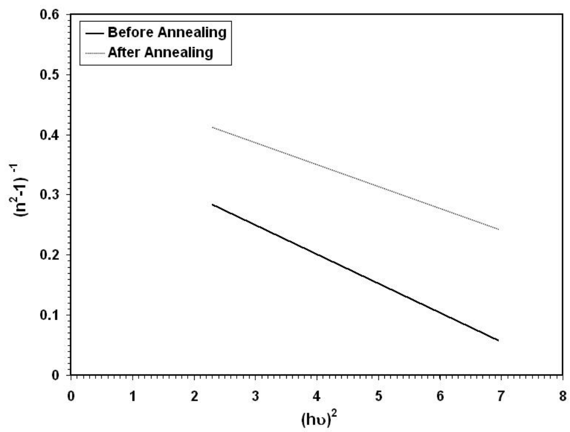

Fig. 6. $(n^2 -1)^{-1}$ as a function of (h

Conclusions

From these results, we conclude that annealing of zinc sulphide films grown by flash evaporation reduces lattice strain, producing a more perfect crystallite and decreasing the number of micro voids. The values of the optical energy gap proposed by the Wemple-DiDominco model were in good agreement with a Tauc plot.

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Raman Spectroscopy of Titania (TiO_2) Nanotubular Water-Splitting Catalysts

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Abstract

The phase composition of nanotubular TiO_2 films was correlated with photoelectrochemical activity as a function of O_2-annealing temperature. TiO_2 nanotubes have been shown to be more efficient than polycrystalline TiO_2 for the photocatalytic splitting of water. Raman spectroscopy was used to identify and quantify the amorphous and crystalline TiO_2 phases. The amorphous TiO_2 nanotubular array was found to consist of TiO_6^{8-} octahedra having the same average structure as those present in the anatase and rutile phases of TiO_2. Results show that the anatase-to-rutile transformation on Ti metal initiates at much lower temperatures compared to polycrystalline TiO_2 and this is attributed to oxygen vacancies located at the metal/oxide interface and is likely responsible for increasing the photocurrent density.

Introduction

Titanium dioxide, TiO_2, has been one of the most widely studied photocatalytic semiconducting materials since the early 1970s when Fujishima and Honda (1972) demonstrated the splitting water into H_2 and O_2 using a simple photoelectrochemical cell and illuminating a single-crystal TiO_2 photoanode (anatase) with UV light of wavelength less than 350 nm.

TiO_2 is a promising semiconducting photoanode material for water splitting using solar radiation. In addition to its low cost and availability, TiO_2 is chemically and photochemically stable, and its band edges match the redox level of water (Burda 2003). The most important requirement of a photocatalyst is its ability to generate electron–hole pairs near the catalyst surface by harvesting a significant portion of the solar spectrum. Unfortunately, the use of TiO_2 is hindered by its large band gap which allows photoconversion of only UV radiation – the band gap must be decreased if TiO_2 is to be used for visible-light applications. Much of the research to date on TiO_2-based water-splitting catalysts has focused on narrowing the band gap by incorporating dopants into the lattice structure (Sharma 2009, Ishihara 2010). In this study, we focus on the actual phase composition of the TiO_2 which has a significant impact on its performance as a photoactive catalyst.

The two most common crystalline phases of TiO_2 suitable for photochemical applications are anatase (tetragonal) and rutile (tetragonal). Amorphous TiO_2 displays little or no photoactivity. Although rutile is more thermodynamically stable and exhibits a lower band gap than anatase (3.0 eV for rutile; 3.2 eV for anatase) (Bendavid 1999), anatase is preferred for photocatalysis. Thus, the photoactivity of the TiO_2 film should be significantly improved by taking advantage of the high surface area of anatase, present as a nanotubular array, and the lower band gap energy of rutile, and the increased efficiency of electron transport of TiO_2 nanotubes (Liu 2009).

The transformation of amorphous TiO_2 to either anatase or rutile, and the temperature at which anatase is converted to rutile, depend on many variables including the method of synthesis and the presence of foreign ions (Heald 1972) which increase the number of oxygen vacancies thereby increasing the rate of rutile formation. In this study, nanotubular TiO_2 films were characterized by Raman spectroscopy. The structural information was correlated with reported photocurrent-density measurements.

Materials and Methods

Synthesis of TiO_2 Nanotubular Arrays

The TiO_2 (titania) nanotubular films were synthesized by the UALR Nanotechnology Center, UALR (Hidetaka Ishihara, Dr. Rajesh Sharma, and Dr. Alexandru S. Biris). The films were synthesized on titanium metal foil (99.9% pure, 0.5 mm thick) using a conventional anodization process (95wt% ethylene glycol + 5wt% NH_4F; 20V). A two-electrode configuration was used for anodization. Anodization was carried out at a constant potential of 20 V using a DC voltage supply (Agilent, E3640A). The anodization current was monitored continuously using a digital multimeter (METEX, MXD 4600 A). The anodized samples were washed with distilled water to remove the occluded ions from the anodized solutions and dried in an air-oven. The Ti foil samples were annealed in an oxygen atmosphere at 400-600 °C for 6 h in a tube furnace to convert the amorphous titania to the crystalline anatase and/or rutile forms of TiO_2.

Raman Spectroscopy

Raman spectra of all TiO_2 films were collected using a LabRam Micro-Raman Spectrometer (Horiba Jobin-Yvon HR800 UV) equipped with an optical microscope and 100x objective lens for a total magnification of 1000x. An argon-ion laser (514.5 nm) or helium-neon (632.8 nm) was used for laser excitation of the Raman signal with appropriate holographic notch filters for eliminating the laser line after excitation. The laser power at the sample ranged from 1 to 3 mW, and the 1/e laser spot size was about 2 μm at the sample. The slit width of the spectrometer was typically set at 700 μm. A holographic grating having 1800 grooves/mm was used for the collection of all Raman spectra and resulted in a spectral resolution of about 1.5 cm^{-1}. Spectral analysis and curve fitting was performed with GRAMS/AI 8.00 Spectroscopy software.

Results and Discussion

The Raman spectra for bulk TiO_2 reference compounds are presented in Figure 1. The thermodynamically stable rutile phase exhibits major peaks at 610, 446, and 242 cm^{-1} and minor peaks at 818, 707, and 319 cm^{-1}. Based on the space group D_{4h}^{14} for rutile and assumed site symmetries for the Ti and O atoms within the unit cell, group-theoretical analysis shows four Raman-active "lattice vibrations" assigned as follows: A_{1g} (610 cm^{-1}) + B_{1g} (144 cm^{-1}) + B_{2g} (827 cm^{-1}) + E_g (446 cm^{-1}) (Balachandran 1982). In the present study, we use bond length / Raman frequency / covalency correlations that have proven quite useful and accurate for many chemical systems (Hardcastle 1990, Hardcastle 1991). Recent application of this approach to the titanates (Hardcastle, work in preparation) reveals the following relationship between Ti-O bond lengths, R, and Raman frequency shifts:

$$\nu_{Ti-O} = 722e^{-1.54946(R-1.809)} \qquad (1)$$

The reported Ti-O bond lengths of *4x* 1.946 Å and *2x* 1.984 Å for rutile (Cromer 1955) are consistent with observed Ti-O bands at 610, 571 (weak), 446, and 407 (weak) cm^{-1} which yield calculated Ti-O bond lengths of *3x* 1.92, 1.96, 2.12, and 2.18 Å. The O-O interactions, based on residual valence, are calculated to occur in the 252-394-cm^{-1} region. The broad band observed near 160-240 cm^{-1} is assigned to O-O interactions involving three- and four-coordinate oxygen. The sharp feature at 143 cm^{-1} is consistent with Ti-Ti covalent interactions (2.96 Å; 0.29 valence units).

The peaks of crystalline rutile are initially observed for an amorphous sample after annealing at 400 °C and become sharper and more intense as the annealing temperature is increased, indicating increased crystallinity of the rutile phase. An unheated Ti foil shows amorphous titania (native oxide) and exhibits broad bands near 680, 580, and 450 cm^{-1} assigned to Ti-O bonds (≈ 1.85, 1.95, and 2.11 Å); broad bands at 350 and 250 cm^{-1} are assigned to O-O interactions consistent with TiO_6^{8-} octahedra that are slightly more distorted than those present in the rutile phase of TiO_2.

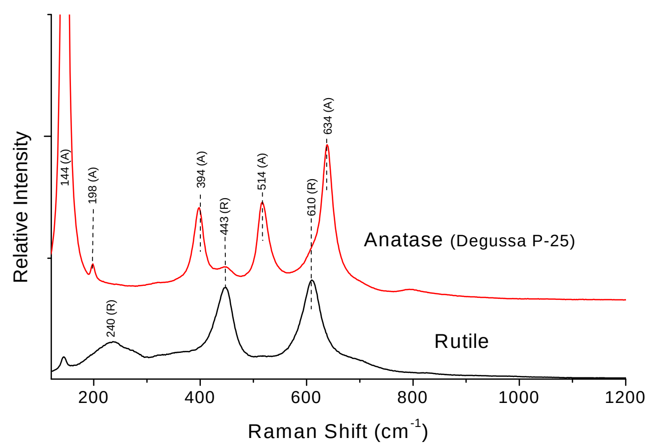

Figure 1. Raman spectra of TiO_2 bulk reference compounds: anatase (Degussa P-25) and rutile.

The Raman spectra for the Ti foil samples that were anodized to produce TiO_2 nanotubular arrays are presented in Figures 2 and 3 as a function of O_2-annealing temperature. The sample dried at room temperature, Figure 2, shows broad peaks near 612 and 467 cm^{-1} due to amorphous titania. Using length / frequency / valence relationships for titanium-oxygen bonds, Eq. (1), these broad bands are found to be consistent with TiO_6^{8-} octahedra having the same average structure as those present in both anatase and rutile phases of TiO_2 with average calculated bond lengths of *5x* 1.93 and 2.12 Å.

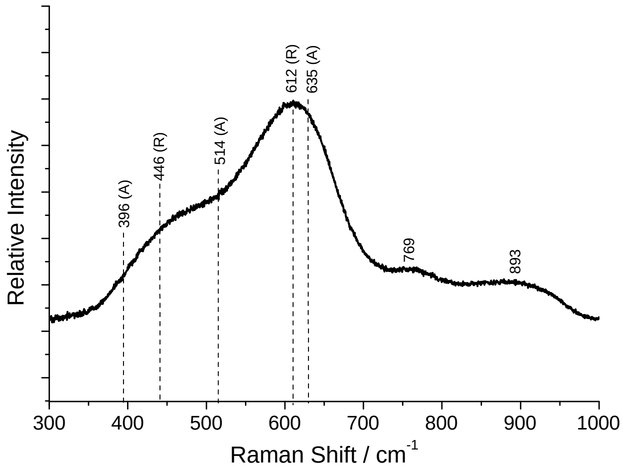

Figure 2. Raman spectra of TiO_2 nanotubes after room-temperature drying.

In addition to TiO_2 phases, Raman spectroscopy is also used to detect and identify carbon species. For the untreated TiO_2 films, amorphous carbon is present in all the films as indicated by the characteristic bands near 1342 and 1601 cm^{-1} assigned to sp^3- and sp^2-hybridized carbon, respectively (Dennison 1996); these bands are similar to those observed for carbon black. Amorphous carbonate, CO_3^{2-}, is also present in all untreated TiO_2 films as indicated by the broad but characteristic peak near 1100 cm^{-1}.

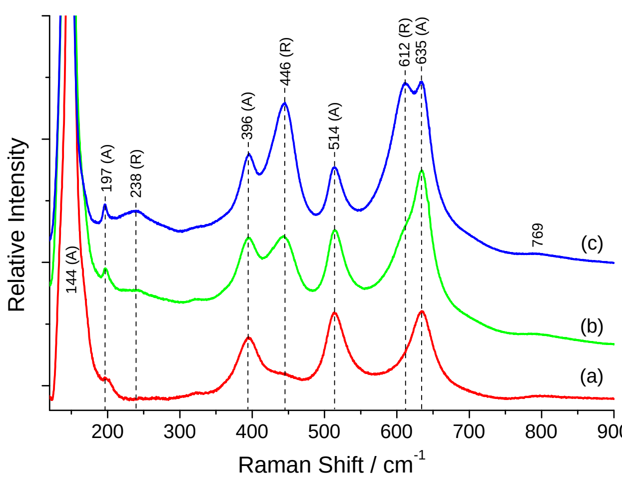

Figure 3. Raman spectra of TiO_2 nanotubular arrays after O_2-annealing at (a) 400°C, (b) 500°C, and (c) 600°C.

Annealing in oxygen at 400 °C for 6 h, Figure 3(a), results in the formation of anatase as the dominant phase in addition to a small amount of rutile. Anatase exhibits Raman bands at 635, 514, 396, and 197 cm^{-1}, as well as a very sharp and intense peak at 144 cm^{-1}. Based on the space group D_{4h}^{19} for anatase and assumed site symmetries for the Ti and O atoms within the unit cell (D_{2d} for Ti; C_{2v} for O), group-theoretical analysis shows six Raman-active "lattice vibrations" assigned as follows: A_{1g} (517 cm^{-1}) + B_{1g} (640 cm^{-1}) + B_{1g} (397 cm^{-1}) + E_g (640 cm^{-1}) + E_g (147 cm^{-1}) + E_g (197 cm^{-1}) (Balachandran 1982); the weak band at 796 cm^{-1} was assigned as the first overtone of the B_{1g} mode. The reported crystallographic Ti-O bond lengths for bulk anatase are *4x* 1.9338 Å and *2x* 1.9797 Å (Horn 1972). Covalence / length / frequency relations show that the observed Raman bands at 640, 517, and 397 cm^{-1} are consistent with the moderately distorted TiO_6^{8-} octahedron in anatase (calculated Ti-O bond lengths: *2x* 1.89, *3x* 2.02 and 2.14 Å). The O-O covalent interactions are calculated near 246-351 cm^{-1}. The sharp peaks at 197 and 144 cm^{-1} are consistent with Ti-Ti bonding present in the octahedral chains with reported Ti-Ti bond length 2.96 Å (calculated: 2.89 and 2.96 Å, respectively). As the oxygen annealing temperature is increased from 400 to 600 °C, Figure 3(a-c), the relative amount of rutile increases as evidenced by the relative intensity increase of the Raman bands at 612, 446, and 238 cm^{-1}. For the anodized sample O_2-annealed at 600 °C, Figure 3(c), both anatase and rutile are present, with rutile being the dominant phase.

The ratio of the integrated Raman peak intensity of rutile at 446 cm^{-1} to that of anatase at 396 cm^{-1} may be used as a semi-quantitative measure of the weight ratio of rutile to anatase. The results of a recent Raman study (Zhang 2006) investigating physical mixtures of crystalline anatase and rutile revealed the following approximate and linear relationship for the weight ratio of rutile to anatase: $W_{R/A} = 3.64 \times (I_{446}/I_{396})$. We utilize this relationship in the present study of TiO_2 nanotubular films, but with the reservation that this relationship is at best semi-quantitative because the Raman scattering cross-sections of anatase and rutile change as the degree of crystallinity changes.

The Raman data and curve fitting show that the room-temperature dried film shows amorphous TiO_2, carbonate (CO_3^{2-}), and decomposition products of the ethylene-glycol electrolyte. The amorphous phase is converted to a mixture of about 3 times as much anatase as rutile 400 °C ($W_{R/A}$ = 0.4), but the relative concentration of rutile increases as the O_2-annealing temperature is increased to 500 °C, where about 5 times more rutile is present ($W_{R/A}$ = 5), and at 600 °C, where about 11 times more rutile is present than anatase ($W_{R/A}$ = 11). The photocurrent density increases from 20 μA cm^{-2} for the dried amorphous film to 379 µA cm^{-2} for the samples O_2-annealed at 500 ^{o}C, where highly crystalline rutile is the dominant phase. It has been suggested that upon annealing, the increased crystallinity results in enhanced charge transfer and photocatalytic activity (Porter 1999). O_2-annealing at 600 ^{o}C, however, results in a decreased photocurrent density of 349 µA cm^{-2} in spite of the increased rutile content and crystallinity in the TiO_2 nanotubular film.

Figure 4 shows a plot of the ratio of the integrated Raman peaks, I_{446}/I_{396}, as a function of measured photocurrent density (shown as squares, axis on the left) for the anodized TiO_2 films. Also shown is the measured photocurrent density as a function of O_2-annealing temperature (circles, axis on the right). For TiO_2 nanotubular films dried at room temperature, only baseline photocurrent densities of 20 µA cm^{-2} were observed for the amorphous TiO_2 film (not shown on the graph). After O_2-annealing at 400 ^{o}C, the photocurrent density increased to 58 µA cm^{-2} with the appearance of mostly crystalline anatase (72 % anatase; $W_{R/A}$ = 0.4). At 500 ^{o}C, the nanotubular film is predominantly rutile (83% rutile; $W_{R/A}$ = 5), and the photocurrent density increases significantly to 379 µA cm^{-2}, which represents the highest photocurrent density observed in this study. O_2-annealing at 600 ^{o}C, however, was detrimental to the PEC activity as the photocurrent density decreased slightly to 349 µA cm^{-2} where ~8% of the TiO_2 is anatase ($W_{R/A}$ = 11).

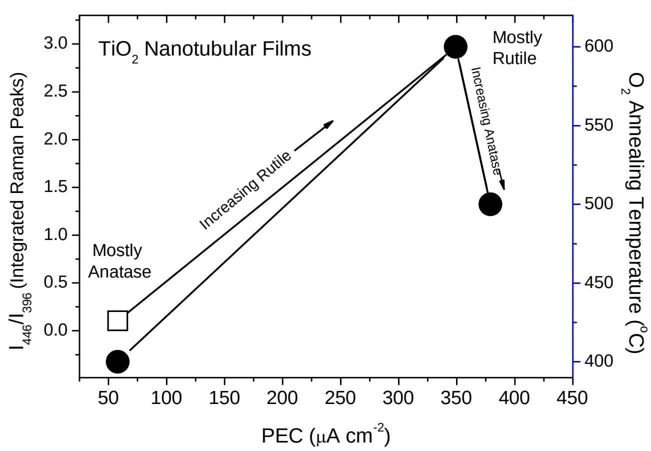

Figure 4. Plot for anodized TiO_2 films showing the photocurrent density (PEC) versus TiO_2-rutile / TiO_2-anatase relative concentration and O_2-annealing temperature. The circles correspond to the annealing temperature axis (right), and the squares correspond to the ratio of integrated Raman peaks (scale on left).

Figure 5 shows a schematic diagram of Raman-identified phases in untreated and TiO_2 nanotubular films as a function of O_2-annealing temperature and measured photocurrent density (PEC measurements: Hardcastle 2011). The anatase-to-rutile transformation occurs at much lower temperatures (~400 ^{o}C) compared to those reported for bulk samples. Previous Raman spectroscopy and X-ray diffraction studies show that the anatase-to-rutile transformation for bulk TiO_2 powders starts at 500 ^{o}C and is completed at about 700 ^{o}C; and for single-crystal anatase, this transformation does not occur until 900 ^{o}C (Shannon 1964).

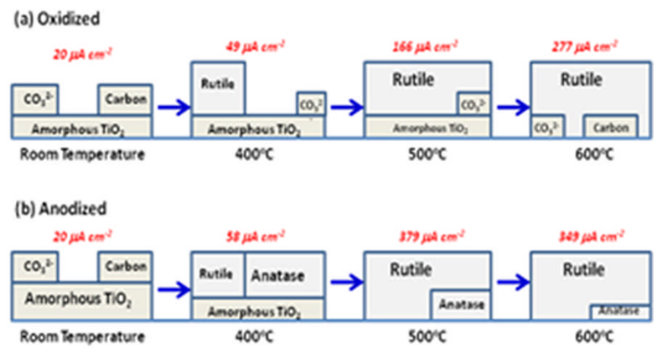

Figure 5. Scheme showing Raman-identified phases in (a) oxidized and (b) anodized films as a function of O_2-annealing temperature and measured photocurrent density (PEC measurements from Hardcastle, 2011).

The kinetics of the anatase-to-rutile transformation depends on many variables, including the nature and amount of Ti impurity interstitials in the TiO_2 lattice in addition to oxygen vacancies. These impurity ions, in this case being titanium cations having a valence less than that of Ti^{4+}, locally increase the number of oxygen vacancies in order to maintain charge neutrality. The oxygen vacancies facilitate cleavage of the Ti-O bonds in the anatase structure, which reduces the lattice volume and results in the formation of the denser rutile phase at lower annealing temperatures.

Whereas oxidized titanium foil forms only rutile, TiO_2 nanotubes are considerably thicker, and more “bulk-like” TiO_2 behavior is expected. Similar to the untreated sample, the low-crystalline rutile phase forms at 400 ^{o}C and is likely located near the oxide/metal interface, but the amorphous TiO_2 nanotubes located outside the oxide/metal interfacial region transform to anatase. At this temperature, about three times more anatase is present than rutile in the anodized nanotubular film. At 500 ^{o}C, there is ~5 times more rutile than anatase because the rutile formed at the oxide/metal interface “seeded” or catalyzed the accelerated formation of rutile throughout the film. At 600 ^oC, the nanotubular film is mostly rutile with ~8% anatase; the anatase is presumably located at the outer edges of the film, furthest from the Ti-metal substrate. By comparison, bulk polycrystalline TiO_2 that has been O_2-annealed at 600 ^oC consists of 60% anatase.

The observed degradation of the nanotubular morphology by SEM (Hardcastle 2011) is expected with rutile formation because of the higher density and decreased surface area characteristic of the rutile phase of TiO_2. For a TiO_2 film on Ti metal, rutile formation initiates at the oxide/titanium interfacial region where oxygen vacancies are present. Collapse of the nanotubular film near the oxide/metal interfacial region is consistent with the morphological changes observed in the SEM images, where buckling of the film begins at 500 ^oC. As the annealing temperature is increased, rutile spreads out into the nanotubular layer (away from the metal surface). At 600 ^oC, where <10% anatase remains, the topical region of the nanotubular array is cracked and fragmented as the remaining anatase begins to transform to the more dense rutile phase at a temperature consistent with that of polycrystalline, unsupported anatase (500 - 700 ^oC).

We have shown using photocurrent-density measurements and Raman spectroscopy that the photoactivity of TiO_2 nanotubular arrays increases with rutile content, but reaches a maximum value at 500 ^oC, then decreases as the nanotubular morphology degrades at 600 ^oC. The increased photoactivity is attributed to the increased amount of rutile combined with the high surface area morphology. The maximun photocurrent density measured for oxidized films is 277 $\mu A\ cm^{-2}$ compared to 379 $\mu A\ cm^{-2}$ for the nanotubular films (O_2-annealed at 500 ^oC). This difference is attributed to the increase in rutile surface area provided by the TiO_2 nanotubular array architecture resulting in increased rutile photoactive sites and increased efficiency of electron transport.

Conclusions

TiO_2 is one of the most widely studied photocatalytic materials for splitting water, but the photoelectrochemical activity strongly depends on the phase composition of the material or film. The more ordered arrangement of the nanotubular TiO_2 arrays shows promise over polycrystalline TiO_2 because of observed increased efficiency of electron transport.

In this study, the photocurrent density of nanotubular TiO_2 films was correlated with the phase composition of the film as a function of oxygen annealing temperature. Raman spectroscopy was used to identify the amorphous and crystalline TiO_2 phases present in the films.

It was found that amorphous TiO_2 is converted to predominantly anatase (~72% anatase) at 400 ^oC, where the photocurrent density is comparable to that of the oxidized (untreated) film. The highest photocurrent density (2.3x that of the oxidized film) is achieved for the nanotubular film at 500 ^oC, where ~83% of the TiO_2 is rutile. At this temperature, there is enough anatase within the nanotubes to sustain its architecture and act as a support for the rutile that forms at the surface. The dramatic increase in photocurrent density is attributed to the increase in rutile surface area and corresponding photoactive sites.

At 600 ^oC, more rutile is formed (92% rutile) in the TiO_2 nanotubular film, but this is countered by the significant loss of rutile surface area due to degradation of the nanotubular array architecture. SEM images show significant degradation (from 500 to 600 ^oC) and cracking of the film as sintering occurs to accommodate the formation of the denser rutile structure. In spite of the increased rutile content, the photocurrent density decreases slightly from its value at 500 ^oC.

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Accuracy and User Variation Associated with Slope Measurement Using a Laser Hypsometer

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Abstract

Slope measurements are often necessary for assessing features and processes within the natural environment. Land managers often use handheld equipment rather than more complicated surveying equipment in order to measure slopes and to conduct field work efficiently. One type of handheld device used to measure slope is a laser clinometer. In order to determine the accuracy and user error associated with this type of clinometer, slope measurements were taken at multiple locations using two types of equipment: 1) a Haglof Sweden Vertex III Hypsometer with a laser clinometer function and 2) a Topcon GTS-603/AF electronic survey total station which can measure elevations and distances to an accuracy of ± 2mm. Slope measurements were compared among the four Vertex III clinometer users in order to determine the variation associated with each user. Also slopes determined by the clinometer were compared to those determined by Topcon GTS-603/AF in order to assess the accuracy of the clinometer. Slopes measured by the laser clinometer users were not significantly different (α=0.05) than those measured using the total station, and the differences on average between the laser clinometer and the total station slopes were less than one percent slope for all clinometer observers.

Introduction

Slope measurements are often necessary for assessing features and processes within the natural environment (Weih and Mattson 2004). Slope of the landscape can be used to help characterize landforms, assess stream type, and fish habitat (Isaak et al. 1999). Additionally slope can contribute to forest harvest planning (Wing and Kellogg 2001) and aid in the quantification of soil erosion (Liu et al. 1994). In many disciplines of land management visual assessment of slope is "the pragmatic approach" but can be very subjective (Milner et al. 1985). Very accurate slope measurements can be obtained using a survey total station, but use of this instrument requires training and can be time consuming to operate, often requiring multiple people to obtain measurements (Wing and Kellogg 2004).

An alternative to using a survey total station is to use a device such as a digital or laser range finder. Wing et al. (2004) stated that digital range finders are capable of measuring many landscape variables including angular measurements. Additionally Wing and Kellogg (2001) found that digital range finders are fast, easy to use, and comparable in terms of accuracy to more traditional measurements techniques.

Several studies have been conducted comparing digital range finders to other slope measurement techniques such as a total station or a Geographic Information System (Isaak et al. 1999; Wing and Kellogg 2004). Božić et al. (2005) compared tree height measurements made using the clinometer function of several types of range finders to the Vertex III and found the Vertex III to be the most accurate and precise piece of equipment. Wing et al. (2004) compared several digital range finders, including the Vertex III, with distance measurements taken using a total station and found that the Vertex III was the third most accurate of five range finders compared. However, it is unknown if there have been studies comparing slope measurements made with a Vertex III laser hypsometer equipped with a clinometer function to those using a Topcon GTS-603/AF electronic survey total station.

The purpose of this study is to determine if using the Vertex III clinometer function is an accurate method for slope measurement and if measurements taken with this devise are highly susceptible to user error or subjectivity. The Vertex III is reported to provide slope measurements that are accurate to ± 0.1˚ by the manufacture. Measurements using this device will be compared to those found using a Topcon GTS-603/AF electronic survey total station which can measure elevations and distances to an accuracy of ± 2mm (Topcon 2002); the survey total station is considered "control" for this study given its high degree of accuracy.

Methods

The sampling site for this study was located on the campus of the University of Arkansas at Monticello (UAM) in Southeast Arkansas. Four observers participated in the study; a brief training session ensured that everyone knew how to properly operate the laser clinometer. The total station was manned by three individuals, including a licensed surveyor. The total station was set up at four locations; measurements were taken in relation to a prism fixed on top of a rod which moved radially around the total station (Figure 1). At each rod location the distance between the total station and the rod as well as the vertical angle between the total station and the rod was measured. Concurrently each of four observers stood next to the total station and sighting the rod prism determined their own slope measurement with the Vertex III laser clinometer. The control slope was calculated using the total station measurements as well as the above ground height of the prism and the above ground height of the total station at each individual rod location. A total of 32 sets of slope measurements were taken with horizontal distances ranging from 13 to 90 m.

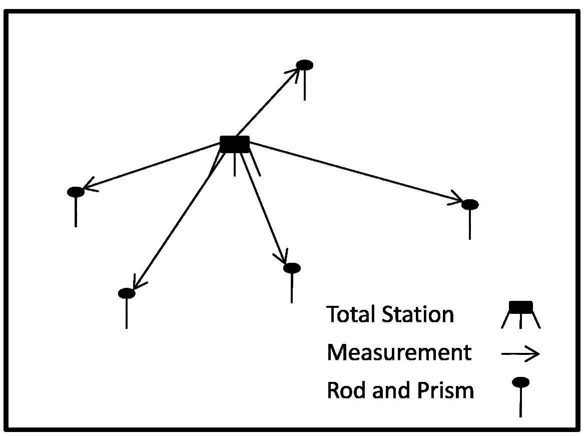

Figure 1. Slope measurements were taken radially from the total station

Slope measurements were recorded by each observer in percent; the measurements of each observer were not disclosed to any other observer. Since the observers targeted the prism, which was at a consistent height of 1.57 m above the ground, rather than a distance identical to the distance between the ground and their individual eye height, it was impossible to directly compare their measurements to that of the total station. Instead the slope measurement of each observer was corrected for the rod height; this corrected slope will be referred to as the observed slope in this study.

All statistical analyses were performed using the statistical program SAS® with the criteria $\alpha = 0.05$. An Analysis of Variance (ANOVA) was used to determine if the observed corrected slopes calculated from each observer were significantly different from one another. A two tailed paired t-test was conducted using an average of the four observers' slopes and the total station slope for each slope location in order to determine if there was a significant difference between the slopes calculated from the total station and those found using the laser clinometer. A 95% confidence interval of the mean difference was also calculated. Additionally, a two tailed paired t-test was performed between each of the four individual observed corrected slopes and the total station slope in order to determine if one observer had more error associated with his or her measurement than another.

Results

The distance from the ground elevation to the eye of each observer varied from 1.51 m to 1.71 m. The distance from the ground to the total station sights varied from 1.58 m to 1.68 m. The prism and rod height was constant at 1.57 m. Of the 32 slope measurements taken 31 were used in statistical analysis due to electronic recording error of one observer. The slopes measured by the total station ranged from 0.30 % to 11.65 %. Figure 2 shows the distribution of slope measurements.

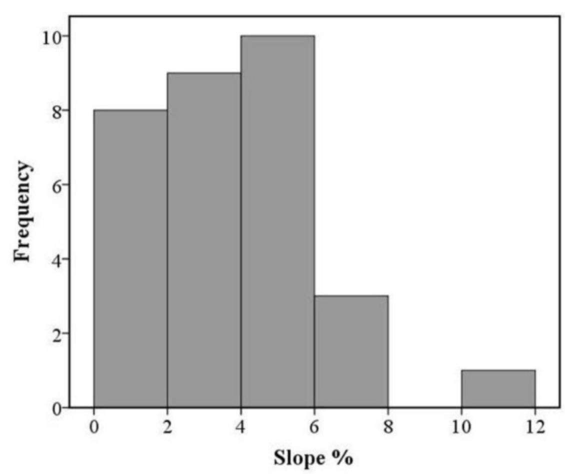

Figure 2. The distribution of slope measurements, in percent, obtained using the total station.

Table 1. Mean, variance, standard deviation and range attributes in percent for the different slope measurements

Slope Measurement Technique	Number of samples	Mean	Variance	Maximum	Minimum
Total Station (control)	31	3.80	6.19	11.65	0.30
Average of Observers	31	3.73	5.99	11.50	0.26
Observer 1	31	3.39	5.77	10.59	0.02
Observer 2	31	3.96	6.32	12.12	0.42
Observer 3	31	3.87	6.22	11.89	0.36
Observer 4	31	3.71	5.82	11.41	0.24

Slopes observed from the laser Hypsometer were similar to control slopes. Table 1 shows the attributes for the different measurements made by the two instruments and the individual observers. The mean slope of each observer was within a ½ percent of the control.

The average of the observer slope values did not significantly differ from those values taken by the total station (Table 2). After determining that there was no significant difference between the observer's average and the total station, an analysis of variance (ANOVA) was conducted using the four observed slopes. The ANOVA procedure revealed that there were no significant differences between the observers at the α=0.05 level (p= 0.81).

The final tests performed were two tailed paired t-tests comparing each individual observed slope to the total station slope (Table 2). These tests revealed that two of the observer's slopes (observer's 1 and 2) were in fact significantly different from the total station slopes while the other two were not. Additionally two of the four observers (observer's 2 and 3) overestimated slope in comparison to the total station.

Table 2. Comparison of measurement techniques in percent

Slope Measurement Method Paired t-tests	Mean difference ∗	P value
Average observed measured slopes vs. total station slopes	0.07	0.094
Observer 1 measured slope vs. total station slope	0.41	<0.001
Observer 2 measured slope vs. total station slope	-0.16	<0.001
Observer 3 measured slope vs. total station slope	-0.07	0.064
Observer 4 measured slope vs. total station slope	0.09	0.187

∗ Mean difference is the (mean total station- observed measurement)

There was no statistical difference between each individual observer or between the averages of the observers compared to the control. Although there were differences between individual observers the differences were small; all differences were less than one half of one percent slope. Variance among observers appeared to slightly decrease as horizontal distance increased (Figure 3).

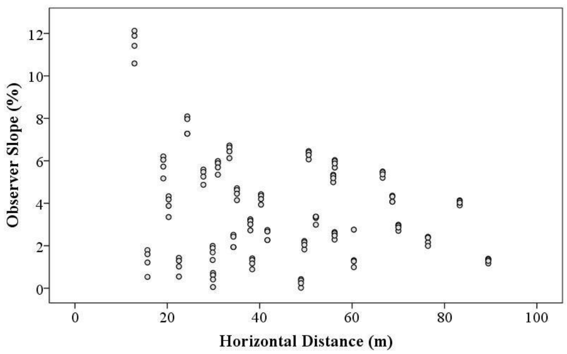

Figure 3. The slope observed by the four clinometer users versus the horizontal distance between the total station and the rod

Discussion and Conclusions

The purpose of this study was to determine if the Vertex III laser hypsometer with a clinometer function is an acceptable substitute to more complex and time consuming surveying instruments for obtaining field slope measurements and if individual slope measurements can be objective. In order to determine this, the error associated with the instrument (the averaged observed slopes) as well as the individual user error was important to consider.

An important consideration when considering the results of this study is context. This study was conducted where slopes are typically small as indicated by our maximum slope found using the total station of 11.65 %. Therefore, it is unknown how this clinometer would perform in a location where slopes tend to be steeper or more varied. Additionally it appeared that the Vertex III performed better, i.e. with more precision at longer distances. Given that the greatest distance used in this study was about 90 m, it is unknown if the trend of decreased variance among observers extends past 90 m.

Wing and Kellogg (2001) found that use of a laser rangefinder similar to the one used in this study in a forest setting made data collection difficult due to thick vegetation. Kiser et al. (2005) found that when obstructions to sight such as brush and tree limbs are present laser rangefinder operators commonly shift or bend to gain sight of a target which can introduce error to measurements. The landscape observed in this study was an open field during winter; there was no vegetation present to obstruct the view of the prism from either the total station or the clinometer.

The results found in this particular study suggest that the Vertex III laser clinometer is able to take fairly accurate slope measurements regardless of the error introduced by individual observers. Discrepancies between the observers and the total station were not only small but were not biased in one direction, as half of the observers measured greater slope measurements than the total station and the other half had lesser slope measurements.

As was found in other studies by Wing et al. (2004) and Božić et al. (2005), the Vertex III clinometer function was fast and easy to use without compromising accuracy. Based on this study, the expected error compared to the survey total station was $0.140^\circ \pm 0.027^\circ$ for the 95% confidence interval which is slightly greater than the reported error provided by the manufacturer of the Vertex III hypsometer. Although the total station is considered to be both precise and accurate, the measurements taken with the clinometer have similar attributes and can be a low cost substitute for making slope measurements for land management decisions.

Acknowledgements

This study would not be possible without the participation of the three other observers: Andrea Long, Dave General, and Nick Weil. We would like to thank Bracy Young and Hunter McCain for their help in taking the surveying measurements.

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Boundary Condition on Electron Temperature for Antiforce Current Bearing Waves

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Abstract

In our investigation of breakdown waves, we apply a one-dimensional, three-component, steady-state fluid model. The wave is considered to be shock fronted and the electrons are assumed to be the main element in propagation of the wave. In our fluid model, the electron gas temperature is assumed to be large enough to sustain the wave motion. Our set of fluid equations is composed of the equations of conservation of mass, momentum and energy plus the Poisson's equation.

This investigation involves breakdown waves for which a large current exist in the vicinity of the wave front. Existence of current behind the wave front alters the equation of conservation of energy and also the Poisson's equation. Therefore, the boundary conditions at the shock front will change as well. For current bearing breakdown waves we will derive the appropriate boundary condition for electron temperature, and using the new boundary condition, we will integrate the fluid dynamical equations through the dynamical transition region of the wave.

Introduction

Paxton and Fowler (1962) considered the luminous pulses to be of fluid-dynamical nature and at the same time as Haberstich (1964) from the University of Maryland proposed a fluid model to describe luminous pulse propagation. Paxton and Fowler (1962) assumed the electrical breakdown wave front to be an electron shock wave and proposed a three-fluid, quasi-steady, hydro-dynamical model. They considered the electron gas partial pressure behind the shock front to be the main cause of the wave propagation. They derived a set of steady-state equations of conservation of mass, momentum, and energy transfer for a continuous medium.

Shelton and Fowler (1968) expanded Paxton's (1962) equations by introducing additional terms to the equations of conservation of momentum and energy. Also, they derived equations for momentum and energy loss terms during the electrons' collisions with heavy particles. Considering waves propagation into a neutral media (no magnetic field), and no time variation in the wave frame, the Maxwell's equations reduce to Poisson's equation alone. Therefore, they formulated a set of one-dimensional, steady-state, constant velocity electron fluid dynamical equations describing breakdown waves propagating into a non-ionized medium. Shelton and Fowler (1968) proposed the existence of two distinct regions. Following the shock front, they proposed existence of a thin dynamical region in which the electrons come to rest relative to heavy particles and the net electric field rapidly falls to a negligible value. They described this region as the sheath region. The sheath region is followed by a thicker region in which the ionization continues and the electron gas cools down to room temperature. Shelton (1968) referred to this region as the quasi-neutral region. Using an approximation method, Shelton and Fowler (1968) solved their set of electron fluid-dynamical equations for breakdown waves propagating into a neutral medium.

In 1984, Fowler et al. (1984) made significant contributions in completing Shelton's (1968) set of electron-fluid dynamical equations. They introduced three additional terms to the equation of conservation of energy in which the heat conduction term proved to be the most important one. In their attempt for numerical solution of the set of equations, they allowed for a discontinuity in the electron temperature derivative at the shock front, which significantly altered the conditions at the shock front. For breakdown waves propagating into a neutral medium, using the new set of boundary conditions, they successfully integrated the set of electron fluid-dynamical equations through the sheath region of the wave.

Model

Breakdown waves for which the electric field force on electrons causes the average drift velocity of the electrons to be away from the wave front are referred to as antiforce waves. In the case of antiforce waves, the electron fluid pressure is considered to be large enough to provide the driving force and cause the propagation of the wave down the tube with observed velocities.

To analyze breakdown waves, the equations that were developed by Fowler et al. (1984) and represent a one-dimensional, steady-state, electron fluid-dynamical wave propagating into a neutral medium at constant velocity will be used. These electron fluid-dynamical equations are the equations of conservation of mass, momentum, and energy coupled with Poisson's equation:

$$\frac{d(n\upsilon)}{dx} = n\beta, \qquad [1]$$

$$\frac{d}{dx}[mn\upsilon(\upsilon - V) + nkT_e] = -enE - Kmn(\upsilon - V), \qquad [2]$$

$$\frac{d}{dx}[mn\upsilon(\upsilon - V)^2 + nkT_e(5\upsilon - 2V) + 2en\upsilon\Phi$$

$$-\frac{5nk^2T_e}{mK}\frac{dT_e}{dx}] =$$

$$-3(\frac{m}{M})nkKT_e - (\frac{m}{M})Kmn(\upsilon - V)^2, \qquad [3]$$

$$\frac{dE}{dx} = \frac{e}{\varepsilon_0}n(\frac{v}{V} - 1). \qquad [4]$$

where n, v, T_e, e and m represent the electron number density, velocity, temperature, charge, and mass, respectively, and $M, E, E_0, V, k, K, x, \beta,$ and ϕ represent the neutral particle mass, electric field within the sheath region, electric field at the wave front, wave velocity, Boltzmann's constant, elastic collision frequency, position within the sheath region, ionization frequency and ionization potential of the gas.

Reducing the set of electron fluid dynamical equations to a non-dimensional form requires introduction of the following dimensionless variables:

$$\eta = \frac{E}{E_o}, \nu = (\frac{2e\phi}{\varepsilon_o E_o^2})n, \psi = \frac{v}{V}, \theta = \frac{T_e k}{2e\phi}, \xi = \frac{eE_o x}{mV^2},$$

$$\alpha = \frac{2e\phi}{mV^2}, \kappa = \frac{mV}{eE_o}K, \mu = \frac{\beta}{K}, \omega = \frac{2m}{M},$$

in which $\eta, \nu, \psi, \theta, \mu,$ and ξ represent the dimensionless net electric field of the applied field plus the space charge field, electron number density, electron velocity, electron gas temperature, ionization rate, and position within the sheath region, while α and κ represent wave parameters. These dimensionless variables are then substituted into equations 1, 2, 3 and 4, yielding

$$\frac{d(\nu\psi)}{d\xi} = \kappa\mu\nu, \qquad [5]$$

$$\frac{d}{d\xi}[\nu\psi(\psi - 1) + \alpha\nu\theta] = -\nu\eta - \kappa\nu(\psi - 1), \qquad [6]$$

$$\frac{d}{d\xi}[\nu\psi(\psi - 1)^2 + \alpha\nu\theta(5\psi - 2) + \alpha\nu\psi + \alpha\eta^2 -$$

$$\frac{5\alpha^2\nu\theta}{\kappa}\frac{d\theta}{d\xi}] = -\omega\kappa\nu[3\alpha\theta + (\psi - 1)^2], \qquad [7]$$

$$\frac{d\eta}{d\xi} = \frac{\nu}{\alpha}(\psi - 1). \qquad [8]$$

In solving the antiforce case problem, in which all quantities including κ are positive and ξ is positive backward, we will use the set of non-dimensional variables introduced by Hemmati (1999).

$$\eta = \frac{E}{E_o}, \nu = (\frac{2e\phi}{\varepsilon_o E_o^2})n, \psi = \frac{v}{V}, \theta = \frac{T_e k}{2e\phi}, \xi = -\frac{eE_o x}{mV^2},$$

$$\alpha = \frac{2e\phi}{mV^2}, \kappa = -\frac{mV}{eE_o}K, \mu = \frac{\beta}{K}, \omega = \frac{2m}{M}.$$

Also, for antiforce problems for which a large current exists in the vicinity of the shock front, Hemmati's et al. (2011) modified set of fluid-dynamical equations need to be used. The set of electron fluid-dynamical equations describing antiforce waves in non-dimensional form are given as follows:

$$\frac{d}{d\xi}[\nu\psi] = \kappa\mu\nu, \qquad [9]$$

$$\frac{d}{d\xi}[\nu\psi(\psi - 1) + \alpha\nu\theta] = \nu\eta - \kappa\nu(\psi - 1), \qquad [10]$$

$$\frac{d}{d\xi}[\nu\psi(\psi - 1)^2 + \alpha\nu\theta(5\psi - 2) + \alpha\nu\psi - \frac{5\alpha^2\nu\theta}{\kappa}\frac{d\theta}{d\xi}$$

$$+\alpha\eta^2] = 2\eta\kappa\iota\alpha - \omega\kappa\nu[3\alpha\theta + (\psi - 1)^2], \qquad [11]$$

$$\frac{d\eta}{d\xi} = \kappa\iota - \frac{\nu}{\alpha}(\psi - 1). \qquad [12]$$

Where, ι, is the dimensionless current and is related to the current behind the wave front, I_1, by the equation, $\iota = I_1 / \varepsilon_0 K E_0$.

Early on in the study of breakdown waves, the ionization rate was considered to be constant throughout the region in which an electric field is present. Later, some investigators considered it to be a function of temperature only. However, in 1983 Fowler (1983) showed that the assumption of a constant ionization rate was incorrect and therefore replaced it by a computation that was based on free trajectory theory. Fowler's (1983) computation included ionization from both random and directed electron motions within the wave. For ionization in a strong electric field with independent electron drift velocity, Fowler derived an equation for ionization rate. In non-dimensional form Fowler's (1983) expression for the ionization rate is given by

$$\mu = \mu_o \int_{1/\sqrt{2\theta}}^{\infty} \sigma_i z^2 dz \int_B^{\infty} \frac{e^{-(z-u)^2} - e^{-(z+u)^2}}{u} du\, e^{-2Cu}, \quad [13]$$

where $B = (1-\psi)/\sqrt{2\alpha\theta}$ and $C = \kappa\sqrt{2\alpha\theta}/\eta$. This function, which changes from accelerational ionization at the front of the wave to directed velocity ionization in the intermediate stages of the wave, to thermal ionization at the end of the wave, in the case of breakdown waves moving with a slow speed, does remain considerably constant at the beginning of the sheath.

Boundary Conditions

Considering the ion number density and velocity behind the wave front to be N_i and V_i, behind the wave front the current is

$$eN_iV_i - env = I_{1.} \quad [14]$$

Absence of an experimentally observed Doppler shift indicates lack of appreciable ion and neutral particle motion in the laboratory frame. Therefore, considering the ion and neutral particle velocities to be almost equal $(V_i \cong V)$, substituting V for V_i and solving equation [14] for N_i results in

$$N_i = \frac{I_1}{eV} + \frac{nv}{V}. \quad [15]$$

For antiforce waves, to find the electron temperature at the shock front, we use the all particle (global) momentum equation, which at the wave front it becomes

$$mnv^2 + nkT_e + MNV^2 + M_iN_iV_i^2 + NkT + N_ikT_i$$

$$+\frac{\varepsilon_0}{2}(E_0^2 - E^2) = MN_0V_0^2 + N_0kT_0.$$

Where, M and N represent the neutral particle mass and number density, T and T_i represent neutral particle and ion temperatures within the sheath region, N_0, T_0 and V_0 represent the neutral particle number density, temperature and velocity in front of the wave. Considering that at the wave front $V \approx V_i \approx V_0, T \approx T_i = T_0, E \approx E_0$, and also substituting for the variable values at the shock front, the above equation becomes

$$mn_1v_1^2 + n_1kT_{e1} + (MN + M_iN_i - MN_0)V^2 +$$

$$(N + N_i)kT = N_0kT_0.$$

Substituting N_0 for $N + N_i$ and m for $M - M_i$ in the above equation, it reduces to

$$mn_1v_1^2 + n_1kT_{e1} - mN_{i1}V^2 = 0.$$

Where, N_{i1} is the ion number density at the wave front and n_1, T_{e1} and v_1 represent the electron number density, temperature and velocity at the wave front. Substituting for N_{i1} from equation [15] in the above equation reduces it to

$$mn_1v_1(v_1 - V) + n_1kT_{e1} - \frac{mI_1V}{e} = 0.$$

Substituting ι for $\dfrac{I_1}{\varepsilon_0 K E_0}$ and the dimensionless variables for antiforce waves in the above equation, gives the electron temperature at the shock front

$$\theta_1 = \frac{\psi_1(1-\psi_1)}{\alpha} - \frac{\kappa\iota}{v_1}. \quad [16]$$

Results and Discussion

Uman and Mclain (1970) derived expressions relating the stepped leader radiation (electric field intensity or magnetic field flux density) to the leader current. By measuring the radiation field from a distance, they were able to calculate the current by using the derived expression for the stepped leader (proforce wave). Their calculated current values were in the range of 800 to 5000 amperes. However, measuring currents at the lightning channel base and with optical observations, Rakov et al. (1998) report a stepped leader current of 5 kA and a return stroke (antiforce wave) peak current of 10 kA.

Determining K from experimental curves (McDaniel 1964) gives $K/P = 3x10^8$ for helium and $K/P = 4.8x10^7$ for nitrogen at 273 K. At a temperature of 10^5, K will be $2.4x10^9$ for helium and $9x10^9$ for nitrogen and applied fields are usually of the order of $10^5 V/m$. Considering that E_0, K, β in our formulas are scaled with P (the electron gas pressure) and using the values of $I_1, \varepsilon_0, E_0, K$ one can estimate the value of ι, which is of the order of one.

In their study of lightning attachment process, Wang et al. (1999) provided evidence of the occurrence of upward discharge making contact with descending leader. They reported that the upward connecting discharge appears to be much weaker in light intensity than its associated downward dart leader. In addition to data on current, Wang et al. (1999) also provided data for upward connecting discharge wave speed, discharge length and leader electric field changes. For upward return stroke, they reported speeds of approximately $2.5x10^8 m/s$.

Using helium-filled screened discharge tubes with different diameters, Asinovsky et al. (1994) performed experimental studies and conducted theoretical analysis of breakdown waves. The theoretical and experimental dependences they obtained, for both positive and negative polarity waves, were in good agreement, indicating the applicability of the ionization drift model to breakdown waves. They reported breakdown wave velocities ranging from 10^7 m/s to $6x10^7$ m/s.

A trial and error method was utilized to integrate equations 9 through 12. For a given wave speed, α, a set of values for wave constant, κ, electron velocity, ψ, and electron number density, ν_1, at the wave front were chosen. The values of κ, ψ, and ν_1 were repeatedly changed in integrating equations 9 through 12 until the process lead to a conclusion in agreement with the expected conditions at the end of the dynamical transition region of the wave.

For several current values, we were able to integrate the electron fluid-dynamical equations [Equations 9-12] for α value as low as 0.01. $\alpha = 0.01$ represents a wave speed of $0.3x10^8 m/s$ and conforms with the lower experimental speed range for return stroke lightning. The successful solutions required the following boundary values

$$\iota = 0.0, \kappa = 1.3, \psi_1 = 0.645, \nu_1 = 0.886$$

$$\iota = 0.25, \kappa = 1.3, \psi_1 = 0.648, \nu_1 = 0.88$$

$$\iota = 0.7, \kappa = 1.3, \psi_1 = 0.6564, \nu_1 = 0.88$$

$$\iota = 1.5, \kappa = 1.3, \psi_1 = 0.674, \nu_1 = 0.847$$

$$\iota = 2.6, \kappa = 1.3, \psi_1 = 0.68, \nu_1 = 0.83$$

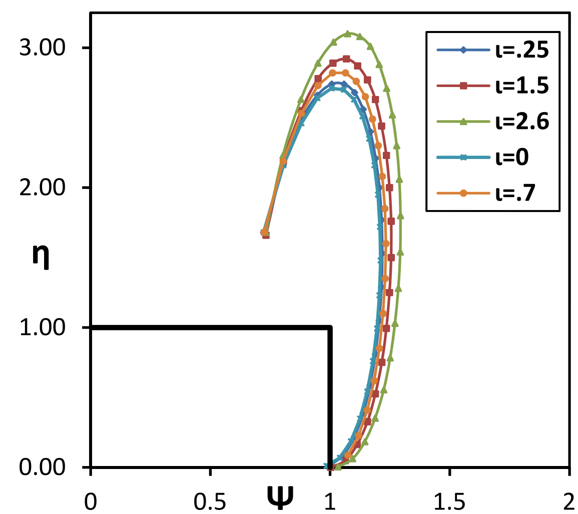

Figure 1. Electric field as a function of electron velocity within the sheath region of current bearing antiforce waves for current values of 0, 0.25, .7, 1.5, and 2.6.

Figure 1 represents the dimensionless electric field, η, as a function of dimensionless electron velocity, ψ, within the sheath region of the wave. As the graph confirms, for all current values, the electric field starting from an initial value at the shock front, initially increases within the sheath region; however, as expected by the required boundary conditions, it reduces to a negligible value at the trailing edge of the wave. As the current increases, integration of the set of equations through the sheath region becomes more difficult and time consuming.

Figure 2 shows the dimensionless electric field, η, as a function of dimensionless position, ξ, within the sheath region of the wave for current bearing antiforce waves.

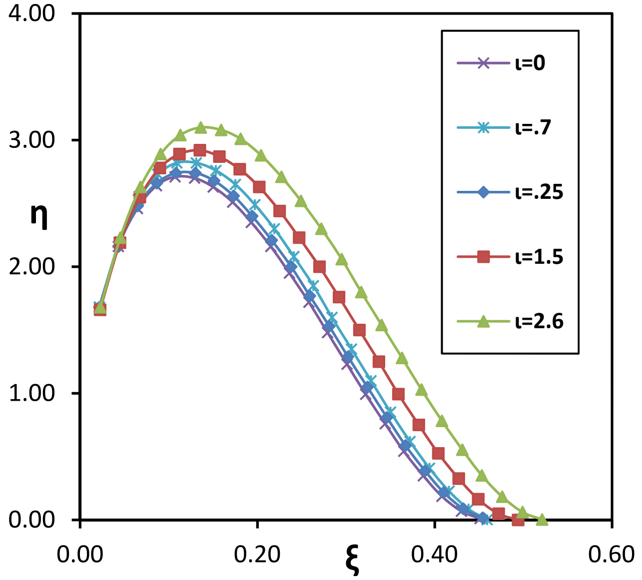

Figure 2. Electric field as a function of position with the sheath region of current bearing antiforce waves for current values of 0, 0.25, 0.7, 1.5, and 2.6.

Applying fluid dynamical techniques to the passage of ionizing wave counter to strong electric fields, for wave speed of 10 m/s, Sanmann and Fowler's (1975) electric field peaked at a distance of 0.04 m behind the wave front and their total sheath thickness was $0.07m$. As our graphs show, for the wave speed of $3x10^{7} m/s$, our dimensionless sheath thickness is 0.5 which represents an actual sheath thickness of $2.5x10^{-2} m$. Measuring electron density behind shock waves, Fujita et al. (2003) report a wave thickness of approximately 5 cm.

Figure 3 depicts the dimensionless electron velocity, ψ, as a function of dimensionless position, ξ, within the sheath region of the wave for antifoce current bearing waves. The graph shows that for all current values, the electron velocity starting from an initial value of less than 1, initially increases; however, for all current values, as expected by the required boundary conditions, reduces to 1 at the end of the sheath region.

Figure 4 represents the dimensionless electron temperature, θ, as a function of dimensionless position, ξ, within the sheath region for antiforce current bearing waves. For all current values, starting from an initial value of approximately 20, the dimensionless electron temperature increases to approximately 67 at the end of the sheath region.

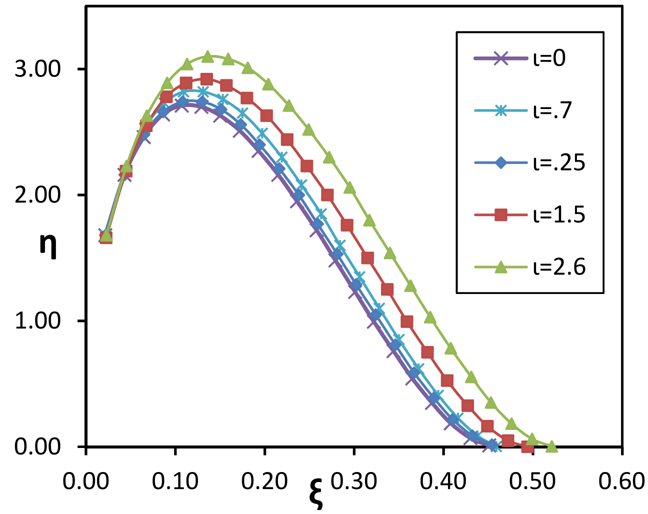

Figure 3. Electric field as a function of position with the sheath region of current bearing antiforce waves for current values of 0, 0.25, 0.7, .1.5, and 2.6.

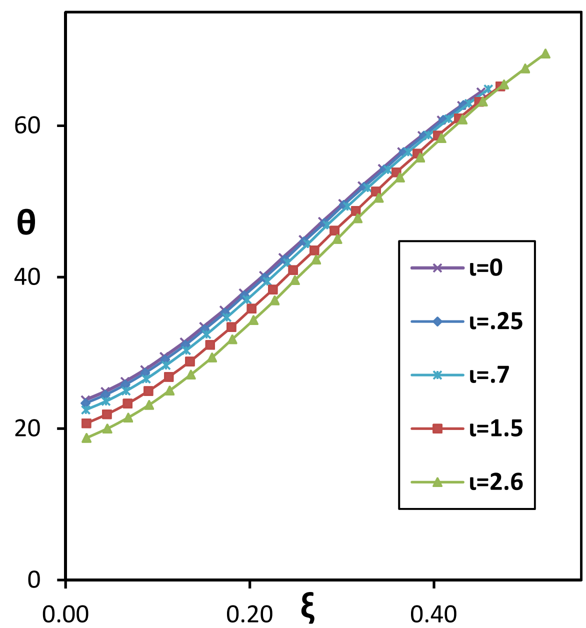

Figure 4. Electron temperature as a function of position within the sheath region of current bearing antiforce waves for current values of 0, 0.25, 0.7, 1.5, and 2.6.

For ionizing waves propagating counter to strong electric fields, Sanmann and Fowler (1975) reported that the electron temperature increases rapidly away from the wave front until it reaches a peak value of around $3.17x10^7 K$ at a distance of $5.4x10^{-2} m$ behind the wave front. Our results show that the temperature increases behind the shock front and it reaches its maximum dimensionless value of $\theta = 67$ at the trailing edge of the wave. $\theta = 67$ represents electron gas temperature of $3.88x10^7$ K.

Figure 5 shows the changes in dimensionless electron number density as a function of dimensionless position within the sheath region of the wave. For all current values, starting from an initial value of less than one, the electron number density initially decreases within the sheath; however, it increases as it approaches the trailing edge of the wave.

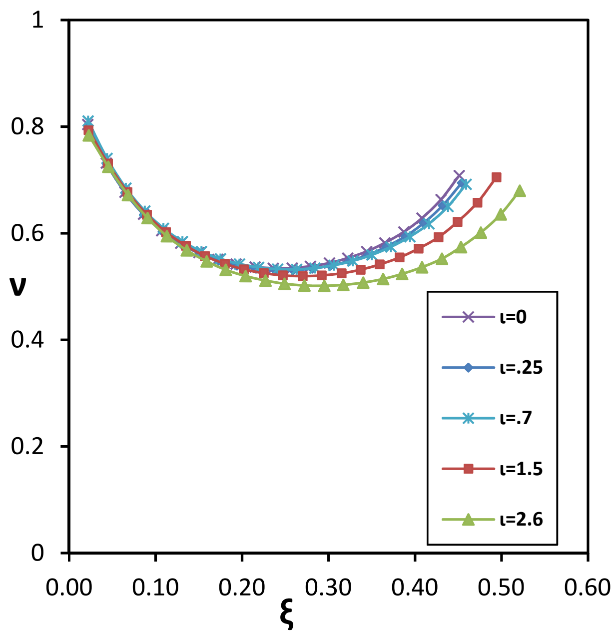

Figure 5. Electron number density as a function of position within the sheath region of current bearing antiforce waves for current values of 0, 0.25, 0.7, 1.5, and 2.6.

Using a fluid model, Brok et al. (2003) study the mechanisms responsible for the propagation of the first anode directed ionization wave that occurs in a straight discharge tube during breakdown. Brok et al. (2003) reported peak electron number density of $6x10^{16} / m^3$, and an average electron number density of $4x10^{15} / m^3$. Our average non-dimensional electron number density of 0.7 represents an actual electron number density of $7.7x10^{15} / m^3$ within the sheath region of the wave.

Conclusions

For a range of dimensionless current values that conform with the experimentally measured current values, using our modified boundary condition on electron temperature, we have been successful in integrating our modified set of electron fluid dynamical equations through the sheath region for antiforce current bearing breakdown waves. For all current values, our solutions meet the expected conditions at the trailing edge of the wave. This is a confirmation of validity of our modified set of electron fluid dynamical equations for antiforce current bearing waves and the set of electron fluid dynamical equations in general.

Providing an accurate mode and an accurate set of equations for breakdown waves is essential for a better understanding of lightning. However, there are many recent applications of breakdown waves in industry and medical sciences which will benefit immensely. An accurate model of breakdown waves, a proper set of equations and solution of the set of equations will be vital for advances in the new applications.

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Occurrence of *Blarina brevicauda* in Arkansas and Notes on the Distribution of *Blarina carolinensis* and *Cryptotis parva*

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Abstract

We provide an update on the species and distribution of shrews occurring in Arkansas. Shrews were collected within Arkansas Game and Fish Commission Wildlife Management Areas and along the Buffalo National River. We also searched mammal collections at several institutional museums to provide additional locality records for *Cryptotis parva*. Specimens of *Blarina* were identified to species by DNA sequencing of the mitochondrial cytochrome *b* gene. Previously, *Blarina hylophaga* was believed to occur in the northwest corner of Arkansas and *B. carolinensis* throughout the rest of the state. However, our genetic analysis revealed that it is *B. brevicauda* that occupies the northwestern portion of the state. We also document several new county records for *B. carolinensis* and *C. parva* in Arkansas.

Introduction

According to George et al. (1981, 1982), Garland and Heidt (1989), and Sealander and Heidt (1990), *Blarina hylophaga* (Elliot's short-tailed shrew) occurs in the northwestern corner of Arkansas and *B. carolinensis* (southern short-tailed shrew) occupies the remainder of the state. Initially, 2 of us (IFG and MBC) collected *Blarina* along the Buffalo National River, Newton County, as part of a larger ecological study. Because Newton County is along the probable contact zone between the 2 species, and because species of *Blarina* are difficult to distinguish based on morphology, we performed genetic analyses to determine whether the *Blarina* were *B. hylophaga* or *B. carolinensis*. Surprisingly, the initial specimens genetically matched *B. brevicauda* (northern short-tailed shrew). We then examined additional specimens of shrews from across the state of Arkansas to determine whether these initial specimens represented an isolated population or were part of a broader distribution.

The purpose of this study was: 1) to determine the specific identity of *Blarina* spp. within Arkansas and 2) to provide additional records of distribution for shrews (*Blarina* spp. and *Cryptotis parva*) from previous small mammal surveys and unpublished museum records.

Materials and Methods

Shrews (*Blarina* spp. and *Cryptotis parva*) were collected from the Buffalo National River and several Arkansas Game and Fish Commission (AGFC) Wildlife Management Areas (WMAs). To provide a more complete distributional record of shrews in Arkansas, we augmented our sample by investigation of unpublished shrew records from mammal collections at institutional museums.

Shrews were trapped along the Buffalo National River (Newton County) during 2 3-night sessions in April and October 2010 using a combination of a trapping web and pitfall traps in each field trapped. The trapping web consisted of a 128-m diameter web with 8 trap lines originating from the center. Sherman-live traps (7.6 x 8.9 x 22.9 cm) were placed 8 m apart with 2 additional traps located in the center for a total of 66 traps per web. Two drift fences (15 m length) were placed along the periphery of the field with a 19-liter bucket on each side of the fence at 7.5 meters and another at either end for a total of 4 buckets per fence.

Shrews were trapped, using Victor© mouse traps, from the WMAs during 3 4-night sessions from July-September in 2002 and 3 3-night sessions from July-September in 2003 and 2004. Five 150-m transects were placed in different habitat types on each WMA with 2 traps placed at each of 15 stations, spaced 10 m apart along each transect. Voucher specimens (including tissues) collected from WMAs have been deposited in the Natural Science Research Laboratory, Texas Tech University.

Shrews were examined and identified as either *Blarina* or *Cryptotis* based on dentition (Sealander and Heidt, 1990). For the 52 specimens identified as *Blarina*, the entire mitochondrial cytochrome *b* (*cytb)* gene was amplified by polymerase chain reaction (PCR) using the primers LGL765 (GAA AAA CCA YCG TTG TWA TTC AAC T) and LGL766 (GTT TAA TTA GAA TYT YAG CTT TGG G; Bickham et al. 1995, 2004) and sequenced (with primer LGL 765 only) using a Beckman-Coulter CEQ8000 Genetic Analysis System (Beckman-Coulter, Inc., Fullerton, California). Specimens were initially identified to species using BLAST searches at the NCBI website (http://blast.ncbi.nlm.nih.gov/Blast.cgi). To verify BLAST identifications, a neighbor-joining tree was constructed from Jukes-Cantor distances of selected specimens using PAUP*4.0b10 (Swofford 2000) with the PaupUp interface (Calendini and Martin 2005). Reference sequences were included in the phylogenetic analysis, including *B. hylophaga* and *B. brevicauda* (from Kansas and Iowa, respectively; Thompson et al. 2011) and *B. hylophaga*, *B. brevicauda*, and *B. carolinensis* from GenBank (AF395480, AB175134, and AF395457). Selected *cytb* sequences obtained in this study were deposited in GenBank.

In order to rule out the possibility of mitochondrial introgression between species of *Blarina* (and thus confounding identification based on *cytb*), we performed amplified fragment length polymorphism (AFLP) analysis on 2 Newton County specimens identified as *B. brevicauda* (based on *cytb*) and compared them with reference specimens of *B. hylophaga* and *B. brevicauda* (from Kansas and Iowa respectively; Thompson et al. 2011) using principal coordinate analysis (PCoA) implemented in the software GenAlEx 6.4.1 (Peakall and Smouse 2006). AFLP analysis was conducted following Thompson et al. (2011).

Specimens from WMAs are referred to by the specimen (TTU) and tissue (TK) numbers (Natural Science Research Laboratory, Texas Tech University). A specimen housed at the University of Central Oklahoma is referred to by the individual collector number (GMW).

Results

Identification of Blarina *specimens*

All specimens of *Blarina* were identified as either *B. carolinensis* or *B. brevicauda* based on 452 base pairs of the *cytb* gene (GenBank accession numbers JF912160-JF912178). Based on phylogenetic analysis of selected specimens (Fig. 1), BLAST searches identified specimens correctly. The 2 specimens of *B. brevicauda* included in the AFLP analysis grouped with reference specimens of *B. brevicauda* in the PCoA (Fig. 2). No specimen was identified as *B. hylophaga* based on *cytb*.

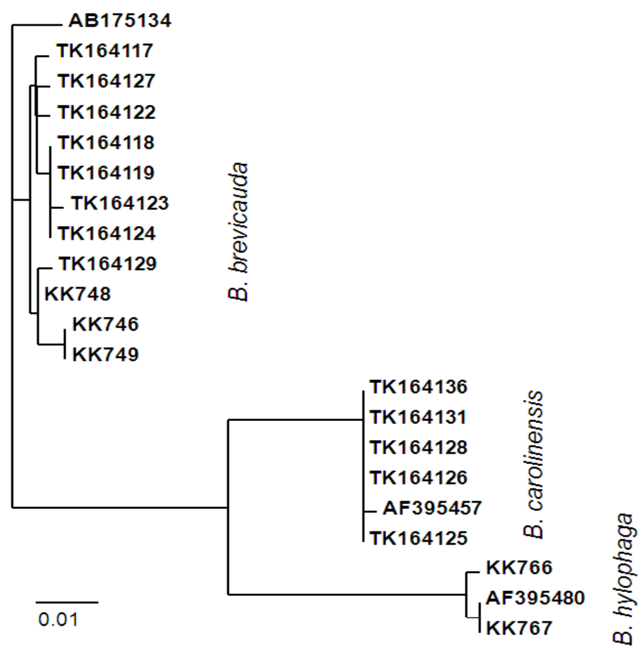

Figure 1. Unrooted neighbor-joining tree based on Jukes-Cantor distances for the cytochrome *b* gene from selected *Blarina* specimens obtained for this study (TK numbers), reference specimens from Thompson et al. 2011 (KK numbers), and GenBank (AB and AF numbers).

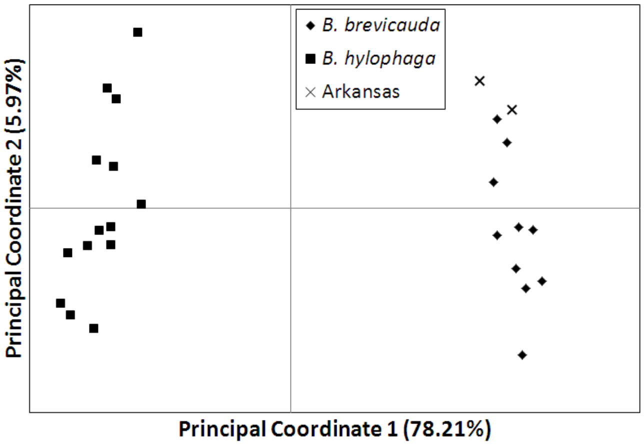

Figure 2. Plots of the first 2 coordinates of principal coordinate analysis based on AFLPs of 2 Arkansas specimens and references specimens of *B. hylophaga* and *B. brevicauda*.

County records of **Blarina brevicauda** *(Say) – Northern short-tailed shrew*

Twelve of the specimens were identified as *B. brevicauda* based on *cytb* sequences. County records are listed below and shown in Fig. 3.

Madison County: Madison County WMA (UTM 15S 435254E 4009705N), 21 July – 19 August 2004, 3 specimens (TTU115289, TK 164118; TTU115290, TK 164119; TTU115288, TK 164123). **Newton County**: Gene Rush WMA (UTM 15S 498268E 3979340N), 13 August 2003, 2 specimens (TTU115291, TK 164116; TTU115292, TK 164117); (15S 501985E 3980908N), 14 August 2003, (TTU115293, TK 164122); Buffalo National River (UTM 15S 485148.30E 3990400.19N), 11 April 2010, 2 specimens (no vouchers). **Pope County**: Piney Creeks WMA, 6 January 2006, (GMW 2666). **Sharp County**: Harold Alexander WMA (UTM 15S 642854E 4010935N), 23 July 2002, (TTU115294, TK 164127); (UTM 15S 639840E 4011859N), 12 August 2002, (TTU115295, TK 164129). **Van Buren County**: Gulf Mountain WMA (UTM 15S 530679E 3936347N), 31 August 2004, (TTU115296, TK 164124).

New county record of **Blarina carolinensis** *(Bachman) – Southern short-tailed shrew*

Forty-one of the specimens were identified as *B. carolinensis* based on *cytb* sequences. A single new county record is listed below and shown in Fig. 3 (additional specimens examined that are not new county records are listed in the Appendix).

Yell County: Petit Jean River WMA (UTM 15S 477499E 3882712N), 27 July 2003 (TTU115336); (UTM 15S 476497E 3882996N), 11 September 2002 (TTU115337, TK 164125).

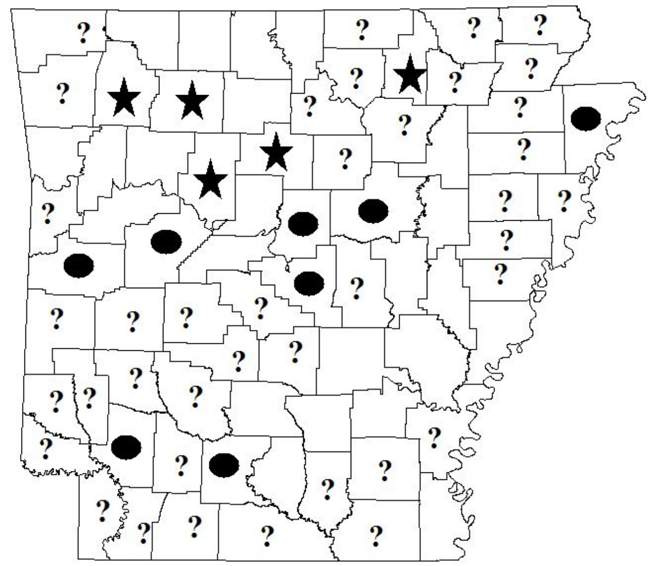

Figure 3. Distribution of *Blarina* in Arkansas. Stars represent *Blarina brevicauda* (confirmed by *cytb*), dots represent *Blarina carolinensis* (confirmed by *cytb*), and question marks represent historical records of genetically unidentified *Blarina* spp.). Historical records are from Connior et al. (2008), Garland and Heidt (1989), Sealander and Heidt (1990), Tumlison et al. (1992), and Tumlison and Robison (2010).

New county records of **Cryptotis parva** *(Say) – Least shrew*

New county records for *C. parva* (including unpublished county records from institutional museums) are listed below and shown in Fig. 4.

Benton County: 14.5 km (9 mi) N of Benton, 28 October 1962, University of Kansas Museum of Natural History (KUM 92635). **Calhoun County:** 0.6 km (0.4 mi) E Locust Bayou, 03 January 1992, Arkansas State University Museum of Zoology Mammal Collection (ASUMZ 26159)**. Clay County:** Piggot, 03 July 1982, (ASUMZ 27222)**. Cleveland County:** 14.5 km (9 mi) N of Warren on AR St. Hwy 8, 26 March 1973, Museum of Texas Tech University (TTU 22461). **Logan County:** 17.1 km (11 mi) W New Blaine, jct. SR 197 & SR 22, 20 March 1990, Cornell University Museum of Vertebrates (CU 14774). **Madison County:** Madison County WMA (UTM 15S 435254E; 4009705N), 18 August 2004

(TTU115369). **Mississippi County:** Big Lake WMA (UTM 15S 763134E; 3975196N), 26 September 2002, (TTU115374). **Nevada County:** 6.4 km (4 mi) W Laneburg near Hwy 299, 11 February 1985, (ASUMZ 12948). **Ouachita County:** 3.2 km (2 mi) N Harmony Grove, 24 April 1992, (ASUMZ 26273). **Sharp County:** Harold Alexander WMA (UTM 15S 643140E; 4012969N); 23 July 2002, (TTU115395). **White County:** Russell, 15 November 1994, (ASUMZ 27524).

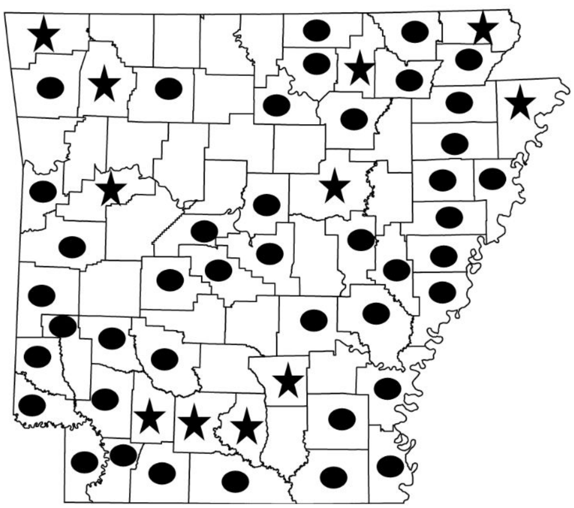

Figure 4. Distribution of *Cryptotis parva* in Arkansas. Stars represent new county records and dots represent historical records. Historical records are from Connior (2010), Garland and Heidt (1989), Sealander and Heidt (1990), Steward et al. (1988), Tumlison and Robison (2010), and Whitsett and Tappe (2009).

Discussion

Identification and distribution of Blarina *ssp.*

Based on DNA sequences, we report herein the occurrence of *B. brevicauda* in Arkansas in areas formerly thought to be occupied by *B. hylophaga*. Because the potential exists for historical introgression of the mitochondrial genome between species (and other limitations of using mtDNA to identify species; Moritz and Cicero, 2004), AFLP analysis was conducted on 2 specimens from Newton County to verify the *cytb*-based identifications. AFLPs reveal variation in the nuclear genome, allowing us to independently confirm the identification of specimens identified as *B. brevicauda* based on *cytb*. When compared with AFLP data for *B. hylophaga* and *B. brevicauda* reference specimens (Thompson et. al 2011), the 2 specimens clearly grouped with the *B. brevicauda* reference specimens in a PCoA (Fig. 2), confirming the status of these specimens as *B. brevicauda* and ruling out the possibility of mitochondrial introgression (or other factors) confounding the identifications based on *cytb*.

Because all specimens of *Blarina* were identified as either *B. carolinensis* or *B. brevicauda* in our study (Fig. 1), and no specimen was identified as *B. hylophaga*, it is possible that *B. hylophaga* may not occur in Arkansas. Rather, all specimens historically recognized by previous researchers as *B. hylophaga* within Arkansas are likely *B. brevicauda* (or *B. carolinensis*), but were assumed to be *B. hylophaga* based on George et al. (1981, 1982).

The question remains why George et al. (1981, 1982) concluded that *Blarina* in northwestern Arkansas were *B. hylophaga*. Their conclusions regarding the distributional limits of *Blarina* spp. were based only on morphometric analysis of the skull and mandible, thus it is likely that clinal size variation, in combination with an absence of *B. brevicauda* reference specimens in their study, resulted in erroneous identifications.

Given the distribution of *B. brevicauda* and *B. carolinensis* based on our results (Fig. 3), we hypothesize that, in Arkansas, *B. brevicauda* is restricted to the Ozark Plateau and Boston Mountains, with *B. carolinensis* occupying the remainder of the state. However, the possibility still exists of *B. hylophaga* occurring in portions of western Arkansas as the precise distributional limits of this species remain unknown.

Our results put into question the published distribution of *Blarina* in adjacent states. Thompson et al. (2011) documented *B. brevicauda* as far south as the Missouri river in northeastern Missouri (the southern-most extent of their study). Given that specimens have not been examined genetically from the southern three-fourths of Missouri, it is possible that most of Missouri is occupied by *B. brevicauda* and not *B. hylophaga*, as is currently thought (George et al., 1981; 1982). In Oklahoma, it is thought that *B. hylophaga* occupies the eastern half of the state, with *B. brevicauda* being absent (Claire et al. 1989). However, our results suggest that *B. brevicauda* could occur in eastern Oklahoma.

Distribution of Cryptotis parva

Cryptotis parva occurs throughout the central and eastern United States and southward into Central America (Whitaker 1974). This shrew commonly inhabits grassy and brushy areas (Whitaker 1974; Sealander and Heidt 1990) but may go undetected, unless specifically targeted, because it is often difficult to trap. We provide several new distributional records confirming that this shrew is widely distributed in Arkansas and may be very abundant locally. For instance, Connior et al. (2008) captured 89 least shrews during 1 trapping season in a drift fence array consisting of 2 33-m drift fences with 8 19 liter pitfall buckets each.

Conclusions

The distribution of *B. brevicauda*, formerly treated as *B. hylophaga* in Arkansas (Garland and Heidt 1989), is larger than previously thought. Our results suggest that *B. brevicauda* occurs throughout the Ozarks and is replaced by *B. carolinensis* to the south and east of the Ozark Plateau and Boston Mountains. However, further sampling throughout the Ozark Uplift, Crowley's Ridge (where isolated populations of *B. brevicauda* may occur), the Arkansas River Valley, and the Mississippi Alluvial Plain is needed to determine the present contact zone between *B. carolinensis* and *B. brevicauda*. Our results also show that *Cryptotis parva* is common throughout Arkansas, agreeing with Sealander and Heidt (1990).

Acknowledgments

We thank the many AGFC wildlife biologists and technicians responsible for data collection on Wildlife Management Areas and Gary Heidt for assistance in providing training to AGFC personnel in small mammal identification. Verification of museum records was assisted by Charles Dardia (Cornell University Museum of Vertebrates), Heath Garner (Museum of Texas Tech University), Tracy Klotz (Arkansas State University Museum of Zoology), and Robert Timm (University of Kansas Museum of Natural History). We also thank G. M. Wilson (University of Central Oklahoma) for providing tissue from a specimen.

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Appendix

Specimens of *B. carolinensis* for which *cytb* sequences were obtained, but that were not new county records. Specimen (TTU) and tissue (TK) numbers (Natural Science Research Laboratory, Texas Tech University) are in parentheses.

Faulkner County: Bell Slough WMA, 2 specimens (TTU115297, TK164126; TTU115298, TK164128). **Hempstead County:** Hope Upland WMA, 8 specimens (TTU115299-115306). **Ouachita County:** Two Bayou WMA, 9 specimens (TTU115307-115314, TTU115315). **Pulaski County:** Holland Bottoms WMA, 9 specimens (TTU115316, TK164131; TTU115317, TK164136; TTU115318, TK164134; TTU115319, TK164133, TTU115320; TTU115321-115323; TTU115324, TK164138). **Scott County:** Cedar Creek WMA, 3 specimens (TTU115325, 115326, 115327). **White County:** Henry Gray WMA, 8 specimens (TTU115328-115334, TTU115335).

Flux Variation of Cosmic Muons

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Abstract

In the current paper, we analyzed the variation of cosmic radiation flux with elevation, time of the year and ambient temperature with the help of a portable cosmic muon detector, the construction of which was completed by a team from Southern Arkansas University (SAU) at Lawrence Berkeley National Laboratory (LBNL). Cosmic muons and gamma rays traverse two synchronized scintillators connected to two photomultiplier tubes (PMT) via light guides, and generate electronic pulses which we counted using a Data Acquisition Board (DAQ). Because muons are the product of collisions between high-energy cosmic rays and atmospheric nuclei, and therefore shower onto earth, the scintillators were arranged horizontally for detection. The elevation measurements were recorded at different locations, starting from 60 feet below sea-level at the Underground Radiation Counting Laboratory at Johnson Space Center, TX, to 4200 feet at Mt. Hamilton, CA. Intermediate locations included sea-level Galveston Bay, TX, and Mt. Magazine, AR (2800 feet). The data points showed a noticeable increase in flux as elevation increases, independent of latitude. Measurements investigating the dependence of cosmic rays on temperature and time of the year took place locally in Magnolia, AR. We found that cosmic muon flux is uniform, appears to be independent of conditions on earth, and is anti-correlative with temperature. We are convinced that the sun has minimal to zero effect on cosmic-ray flux; it cannot be a major contributing source of this background radiation. The source of cosmic radiation remains one of the biggest unanswered questions in physics today.

Introduction

Cosmic rays (CR) are energetic particles that constantly rain through the Earth's atmosphere, a fraction of which penetrates the Earth's surface at high relativistic velocities. CR are the source of a uniform background ionizing radiation, they shower on the Earth's atmosphere at a rate of about 1000 collisions per square meter per second. The source of these particles varies from the sun to yet unidentified astronomical events in the extremities of the universe, such as supernovae and black holes. CR have not only revolutionized astronomy and particle physics; they may have also played a vital role in human life. Since it is evident that ionizing radiation is indeed mutagenic, it is of significant interest to scientists that cosmic radiation had some responsibility in the evolution of life on our planet; that is cells may have developed an adaptive reaction to these showering particles (Rachen et al. 1993). In addition, gamma rays (GR), the uncharged component of CR, continue to have an integral role in evolution in our planet by inducing double-strand DNA breaks in human cells (Francis et al. 2006). Although the growth in the research today concerning these particles is continuing, the origin of CR and the mechanism by which they are accelerated in the universe is still somewhat of a mystery.

Most of the CR energy arrives to the Earth's surface in the form of kinetic energy of muons. The muon (μ^- and μ^+) is a particle belonging to the lepton family, and as such, it has the same charge as that of an electron. It is the second-heaviest lepton with mass 105.6 MeV, which makes it 207 times the mass of an electron. Muons are secondary products of interactions between highly energetic CR and the nuclei of atmospheric particles. They are the result of decay of pions (π^- and π^+). Because of their ultra-relativistic nature, the muons created in the atmosphere can permeate the Earth's surface for hundreds of meters. The flux of these particles can be sufficiently distinguished with a scintillator detector system.

A scintillator is a material that becomes luminescent when ionizing radiation is present. In other words, it releases photons due to interaction with a penetrating radiation. These photons are steered, via a plastic light guide, toward the photocathode surface of a photomultiplier, causing the release of electrons by the photoelectric effect. Each electron is multiplied to many more via an amplification process within the PMT achieved by a series of dynodes kept at high voltages. Therefore, a PMT converts light signals into electrical pulses. A circuit board processes the signals from the PMTs, translating them into counts (or data), which are subsequently collected and read through a USB interface. The detector was synchronized with a data acquisition board (DAQ) to enhance the collection of data at various control voltages. The detector is proficient and sensitive enough to collect both GR and CR muon flux information. To ensure the overall consistency and functionality of the machine, we previously (Bachri et al. 2011) investigated the radiation of gamma rays from an active cobalt-60 sealed source, and showed that radiation falls as $1/r^2$, where r is distance from radioactive source, consistent with the inverse square law.

The current study, however, focuses on cosmic muon flux variation with elevation, in addition to temperature and time of the year. Data acquisition spanned over a period of one year, and was taken in different locations. Locations reported here include (with elevations): Galveston, TX (10ft), Magnolia, AR (338ft), Mt. Magazine, AR (2753ft), Mt. Hamilton, CA (4200ft) and inside the Radiation Counting Laboratory (RCL) at NASA Lyndon B. Johnson Space Center (elevation 60ft below sea-level). Measurement clearly showed a dramatic increase in muon flux (counts/min) as the elevation was increased, that is, the closer one gets to the atmosphere, the higher is the count. The data taken at RCL were especially interesting. RCL at Johnson Space Center is a lab 60 feet underground that was especially and originally constructed for low-level counting of returned lunar samples (Keith 1979). The walls of the room are made of three-eighths-inch mild steel plate that was selected for its low radioactivity. The plates are welded together to form an air-tight wall. Three feet of crushed, washed gravel (with very low radioactive content) perfectly encloses the room, shielding it from the natural radioactivity in the outside concrete and soil. Even so, muons were detected inside RCL, clear evidence that they penetrate large amounts of material due to their large energy before finally decaying, or losing their energy due to their ionizing ability. Their lifetime of 2.2 μs, which is relatively large, also allows them to decay relatively slowly and reach the Earth's surface, even penetrating materials they encounter. The trip of muons through the Earth's atmosphere can only be sufficiently understood within the framework of Special Relativity. Indeed, muons are often described as the penetrating component of CR (Gaisser 1990).

Based on time and temperature measurements at different times of the year, it is clear to us that most of the muon-producing cosmic rays come from outside the solar system, or at least are not generated by the sun. Results clearly show a uniform background of cosmic muons anti-correlated with solar activity. Whether data was collected on a cold winter day or a very hot summer afternoon, the count of muons remains fairly constant and around 500 per minute per unit area.

Materials and Methods

Detector and Detection Mechanism

The major components of the detector apparatus are the scintillator paddles and photomultiplier tubes. Both major components must be tested and calibrated for optimum performance. In a scintillator detector, a scintillating paddle is connected to a PMT via a light guide, and the entire apparatus is made light proof by way of photo-tape and photo-paper wrapping placed carefully over an aluminum foil layer. The absence of light leaks is tantamount to the reliability of scintillator-PMT detectors.

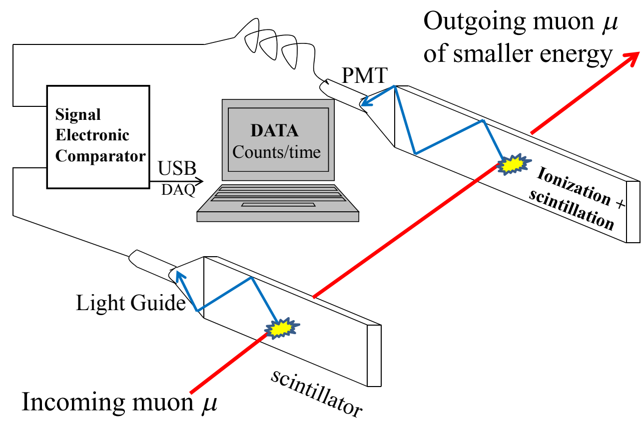

Figure 1: Components and Principle of detection. Mechanism: The detector is a set of two individual self-counting modules (PMT, scintillator and light guide) feeding data to an electronic comparator to isolate background noise from real muons, and to a USB data acquisition card.

The scintillator-PMT detectors will be used in pairs to detect muons. The setup uses two scintillators, mainly, to eliminate counting random events from electronic noise, in addition to giving the detector directionality. The detector operates under the assumption that an energetic muon travels near the speed of light, passing through two parallel scintillator paddles nearly simultaneously. This results in simultaneous generation of signals, which reach the electronic counter in nearly the same time. Those two signals are interpreted as a single coincident count.

Using coincidence counting greatly reduces the chance that a large signal can be caused by an event other than the passage of an energetic muon.

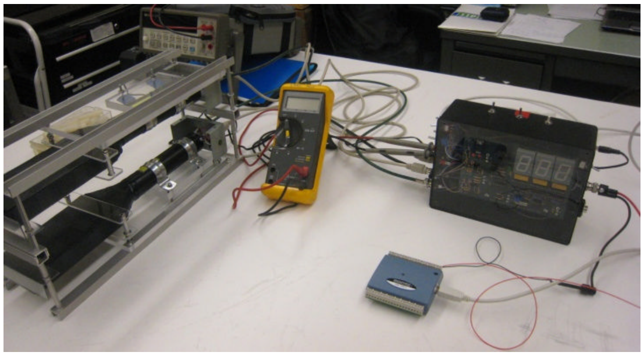

Figure 2: Cosmic muon detector. Two modules stacked on top of each other to detect muons travelling vertically downward. The count is displayed on a computer interface (not shown here) via a DAQ; the count is further duplicated by a standalone digital display of an electronic signal comparator.

Scintillators can be categorized into organic and inorganic types (Syed 2007). In organic materials, scintillation is due to excitation of electrons in a ground singlet state to a higher singlet or triplet level. This excitation is caused by an incident particle or wave imparting energy to the material via one of several modes of collision. An electron promoted to a higher energy level will decay to either the ground singlet state directly, emitting a photon quickly (fluorescence) or to an adjacent triplet level, which then decays to the ground triplet state. This process takes longer to complete and is called delayed fluorescence. When traversed by ionizing radiation, the scintillator's organic material emits electromagnetic radiation of such a wavelength that it absorbs the same emitted photons very efficiently. Thus, to ensure that scintillation light can be utilized for detection, organic scintillators are doped with a substance that will re-emit photons of a lower wavelength, often in the visible spectrum, so that the scintillating material is transparent to the new photons. Doping the scintillator material is a process that involves mixing a wavelength-shifting agent into the plastic solution, creating a homogenous mixture of different scintillating molecules, allowing for a uniform wavelength shifting.

A light guide connects the scintillator paddles with the PMTs and transmits light between them via total internal reflection (Collier and Wolfley 2006). PMTs are devices which convert incoming photons into electric signals with magnitude proportional to the incident photon flux. Upon striking the cathode of the PMT, a photon displaces an electron, via photoelectric effect; the electron is then accelerated through a series of dynodes through a strong electric potential. At each dynode, the electron is absorbed, and an increased number of electrons are emitted towards the next dynode due to the increasing electric potential at each dynode. This avalanche effect can create a signal at the anode with a magnitude of tens of millions of electrons. At the anode, the current signal is converted to a pulse of measurable voltage signal, which can be read on an oscilloscope. In our case, we connect the PMT-scintillator pair to an electronics module that can count the total number of pulses in a predefined time.

The electronics of the apparatus consist of a pulse counter and an optional DAQ module. The counter is responsible for providing power to the PMT and reading signals from the PMTs as counts. A gain voltage knob at the counter changes the power input of the PMT, thereby changing the sensitivity of the PMT. The plateauing of the PMTs, which indicates the optimal operating voltage, allows for greater sensitivity with little interference of background radiation. The collection of resistors, capacitors, diodes and integrated circuits compares PMT output pulses against a given voltage; this voltage difference can be as small as 7 mV can still make a detection event. Then the electronic circuit determines, through a series of logic gates, if the pulses from each PMT are close enough in time to call the pulses coincidences. To qualify as a count, the electronics require that hits in each module occur within a predetermined time of few milliseconds; only then will the electronic circuits advance the counter. The pulse counter can be connected to two detectors at the same time. A three-point toggle switch in the counter enables connection to either one of the counters separately or to both, in which case coincident counts are measured. The counter, however, is limited to making one-minute counts only. If counting for a longer period of time is desired, the DAQ module must be used. It connects the counter to a computer, and with necessary software, allows for counts ranging to any amount of time.

Result

Flux Dependence on Elevation

It has previously been determined that the flux of cosmic muons is proportional to altitude within a certain elevation range (Gaisser 1990). Thus, the feasibility of our radiation detection unit as a reliable portable muon-tagging device is dependent on its ability to confirm the accepted model for atmospheric muon flux. Because of the Lorentz length contraction, cosmic muons can travel farther than classically limited by their 2.2 μs lifetime. However, it stands to reason that the probability of a muon decaying increases the longer it travels. Thus, we expect a decrease in muon flux as distance increases downwards from the cosmic-shower atmospheric boundary.

To test the flux dependence on elevation, the standardized detector modules were placed at several locations at different elevations, keeping the parameters of the detector units constant for all data collections. The data was taken at each elevation to determine muon flux per unit area per unit time. Our findings were checked for correlation against accepted flux vs. elevation trends. The coincidence counts for a detection unit pair at each location is given in Fig. 3.

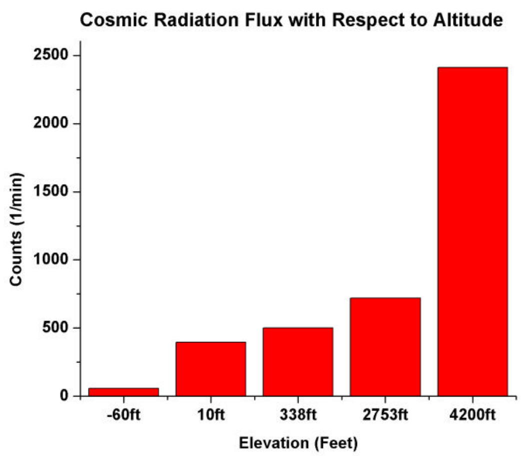

Figure 3: Flux as function of elevation. Locations tested included: Magnolia, AR (338ft), Galveston, TX (10ft), Mt. Magazine, AR (2753ft), Mt. Hamilton, CA (4200ft) and inside the Radiation Counting Laboratory (RCL) in the NASA Lyndon B. Johnson Space Center (- 60ft).

Flux Dependence on Different Date of the Year

The prevalent idea is that the flux of cosmic muons is unaffected by the temperature, solar activity and other climatic conditions on the earth. Cosmic muons are believed to be the result of the interaction of CR with the Earth's atmosphere. The precise origin of those CR is still unknown. Solar activity does not actually fall out of suspicion, and hence we have tried to determine if solar activity has any impact on the creation of cosmic muons. For this purpose, we took several one- minute coincidence-count measurements during different times of the year. The solar flux, sky conditions, and the temperature were noted. If the assumption that the solar activity is ineffective in the creation of cosmic muons is correct, there would not be any significant difference in the muon counts measured at different time of the year when the climatic conditions on Earth are different. In Fig. 4, we can clearly see that the counts measured per minute of the muons are not significantly different, and comparable. The small amount of difference can be attributed to the uncertainty in the measurements. Ten simultaneous measurements were taken, and an average of those measurements was taken on each date (Fig. 4, Table 1).

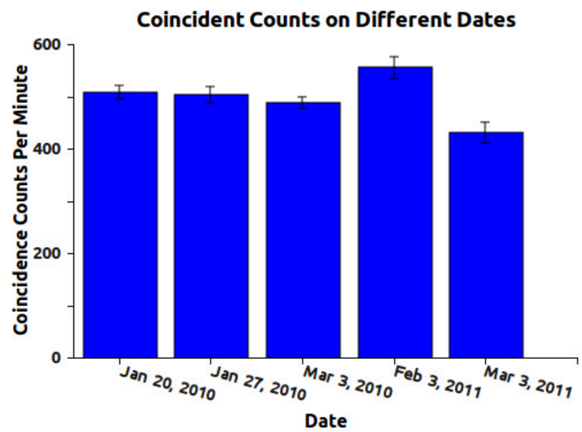

Figure 4: Flux as a function time and temperature. Irrespective of the day of the year or the temperature of the particular day, muon flux remains fairly uniform.

Table 1: Counts per minutes on different dates, over a one year span.

Date	Counts	Uncertainty
Jan 20, 2010	507	23
Jan 27, 2010	503	22
Mar 3, 2010	487	22
Feb 3, 2011	555	24
Mar 3, 2011	458	21

Discussion and Conclusion

Muons are created in the upper atmosphere, approximately 50,000 feet above sea-level. Traveling at close to the speed of light, it takes them no more than 100 μs to reach sea-level. In the current paper, however, we measured a flux of about 1 muon per minute per square-cm at Galveston Bay and a flux of about 100 muons per minute per square-cm at Mt. Hamilton (4200 ft). Clearly not all muons reach sea-level; the larger the elevation, the more muons we registered. As charged particles, muons are subject to Coulomb interactions during their trip from the atmosphere into rocks on the Earth. In accordance with previous findings, this suggests that some of them are slow to start with, so they lose their kinetic energy and decay to an electron, an electron-antineutrino, and a muon-neutrino before reaching the Earth's surface. The highly energetic muons traverse matter and scatter through electromagnetic interactions; nevertheless, we did detect some of them 60 feet under the ground. Our investigation of the flux variation versus elevation shows a strong correlation between the two. The second important question that we addressed concerns the source of CR; can we identify a cosmological origin? Understanding the origin and acceleration mechanism of CR is a fundamental area of astroparticle physics with major unanswered questions. The uniform flux we observed over various times and days of the year clearly rules out the sun as a source. Furthermore, the number of counts did not vary with the time of day due to varying quantities of solar energy interfering with the travel of CR. Therefore, whatever their source, it must reside beyond our solar system or even our galaxy. This fact is not new; it has been long known, but with a fairly simple and portable detector we arrive at the same conclusions. The detector we describe in this manuscript has been a very useful tool in gaining an insight to the interesting world of muons.

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Malaria, Intestinal Parasitic Infection, Anemia, and Malnourishment in Rural Cameroonian Villages with an Assessment of Early Interventions

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Abstract

Malaria, water-borne diarrheal diseases, and geohelminth infections, combined with severe malnutrition ravage entire villages throughout sub-Saharan Africa. The Bawa Health Initiative (BHI) is a 501c(3) non-profit organization with the goal of implementing a comprehensive public health program in an attempt to address these problems in a series of rural villages located in the West Province of Cameroon, Africa. Interventions include the provision of permethrin-treated bed nets to reduce the transmission of malaria, the installation of biosand water filters to reduce the prevalence of water-borne diseases, and a geohelminth control program utilizing mass treatment with albendazole. This study details the results of surveys conducted to monitor the success of the interventions. Since implementation of interventions, the number of clinical cases of malaria, diarrheal disease and typhoid has decreased, the prevalence of water-borne protozoan parasites has decreased, the prevalence and intensities of geohelminth infections has significantly decreased, and the prevalence of anemia has significantly decreased. When viewed in its entirety, these data show that the comprehensive approach to public health challenges in these villages initiated by BHI has been extremely successful. However, much work remains to be done. The primary purpose of this paper is to further inform academicians, students, and the general public about the continuing problems associated with these diseases and to describe and assess the effectiveness of some current interventions being used to combat them.

Introduction

Malaria, water-borne diarrheal diseases, and helminth infections combined with severe malnutrition is the perfect formula for extreme human suffering. More than 2 billion people are infected with worms, more than 500 million suffer from malaria, 884 million people lack access to improved water, and 2.6 billion do not use improved sanitation (Breman et al. 2006, Hotez et al. 2006, World Health Organization (WHO) and United Nations Children's Fund (UNICEF) 2010). Millions die because of intestinal infection in combination with malnutrition. Undernutrition itself is directly or indirectly responsible for at least 35% of global deaths in children less than five years of age. Due to the disastrous effects of malnutrition, approximately 186 million (32%) children under five in developing countries are stunted, and about 55 million (10%) are wasted (WHO 2010a).

Malaria, arguably the most important human disease that has ever existed, is caused by infection of red blood cells with apicomplexan parasites of the genus *Plasmodium*, transmitted to humans through the "bite" of female mosquitoes of the genus *Anopheles*. Approximately 732,000 children under 5 die each year of malaria (Bryce et al. 2005, Breman et al. 2006, Black et al. 2010). Sub-Saharan Africa accounts for 90% of all cases of malaria that occur in the world. Treatment of malaria consumes 40% of sub-Saharan Africa's public health expenditure, and accounts for 30-50% of hospital admissions (Akande and Musa 2005, WHO 2010b). In Africa, a child under five dies of malaria every 45 seconds (WHO 2010b). Additionally, malaria infection during pregnancy causes up to 10,000 maternal deaths each year, 8-14% of low birth-weight babies, and 3-8% of all infant mortality (Steketee et al. 2001, Marchesini and Crawley 2004). Furthermore, malaria inflicts a heavy burden on the economies of Africa and the general well-being of her people by placing a heavy burden on both nutritional and human resources. If malaria had been eradicated as hoped in the early 1960s, it is estimated that Africa's gross domestic product would currently be $100 billion greater than it is now (Brundtland 2005).

A similarly vexing public health challenge in sub-Saharan Africa is that of water-borne diseases. Unsafe drinking water and inadequate sanitation has been implicated as the source of 2.5 billion cases of diarrhea in children under 5 each year, leading to 1.5 million deaths (UNICEF and WHO 2009). Most of these deaths are of children in developing countries, and the majority is in sub-Saharan Africa. Water-borne diarrheal diseases include bacterial diseases such as typhoid and cholera, and diseases such amebiasis and giardiasis caused by the parasitic protozoans *Entamoeba histolytica* and *Giardia lamblia*, respectively. It is estimated that *E. histolytica* and *G. lamblia* infect nearly 500 million and 200 million at any given time, respectively (WHO 1990). Callahan (2010) provided a summary of reports of water-borne protozoal diseases in Africa.

A third party in this "unholy trinity," a phrase coined by Hotez (2008), is infection with geohelminths. These soil-borne nematodes include whipworms (*Trichuris trichiura*), the large human roundworm (*Ascaris lumbricoides*) and hookworms (*Ancylostoma duodenale* and *Necator americanus*). An estimated 300 million people suffer severe morbidity as a result of heavy infection with goehelminths and 150,000 die each year as a result (Crompton 1999, Montresor et al. 2002, Hotez et al. 2006). While, relatively speaking, geohelminth infections cause few deaths, they have profound and insidious effects on the health and nutritional status of millions. Hotez (2008) pointed out that geohelminth infections comprise the most common infections of the world's poorest people, may be the leading cause of growth retardation and stunting, and are "a major cause of economic underdevelopment, as they presently block the escape from poverty." This observation becomes particularly profound when one considers that these infections are often most prevalent alongside malnutrition from a severe lack of food.

The global statistics related to geohelminth infections demonstrate that they have a crippling effect on society. Whipworms infect over 1 billion people worldwide (Crompton 1999). World-wide 21% of preschool-age children (114 million) and 25% of school-age children (233 million) are infected with whipworms (Stephenson 2002). Chronic whipworm infection contributes to stunted growth and anemia in children (Cooper and Bundy 1988, Bundy and Cooper 1989, Despommier et al. 2005). *Ascaris lumbricoides* infects 1 in 4 people worldwide. As of 1990, 158 million (29%) of the world's preschool age children and 320 million (35%) of school-age children were estimated to be infected (Stephenson 2002). Approximately 1.3 billion people are infected with either *A. duodenale* or *N. americanus*, leading directly to 65,000 deaths per year, mostly children. Because of their hematophagous zeal, hookworms are a primary cause of anemia. Despommier et al. (2005) pointed out that children heavily infected with hookworms are likely to develop deficits in both physical and cognitive development and that hookworm infection during pregnancy may lead to low birth weight, premature birth, and increased risk of maternal mortality.

The Bawa Health Initiative (BHI) is a 501(c)3 with the goal of initiating a comprehensive public health care program in the village of Bawa and surrounding areas located in the Menoua Divison, West Province of Cameroon, Africa that lies along a volcanic line in the western Cameroon highlands (Tchuinkam et al. 2010). These Bamiléké villages are a homogenous assemblage of remote rural villages populated almost exclusively by subsistence level farmers. There is no electricity, running water, or improved sanitation in the villages. See Smith (2007), Callahan (2010), and Richardson et al. (2011a) for more complete descriptions of the villages and Tchuinkam et al. (2010) for a more complete geographic characterization of the region. A broader goal of BHI is to educate the general public, particularly young people, in the developed world about the heavy toll taken on humanity by infectious diseases in the developing world.

This study details the results of surveys of intestinal parasites, nutritional status, and prevalence of clinical diseases conducted in Bawa-Nka (a quarter within the village of Nka), Bawa, and Nloh. This facilitates the assessment of the early effectiveness of interventions initiated by BHI.

During the summer of 2006, an oral survey was conducted of each family compound in the village of Bawa to assess knowledge and attitudes concerning infectious diseases and matters of basic hygiene and sanitation. The survey revealed malaria and diarrheal diseases to be among the greatest health problems in the village. Over 50% of parents responding to the survey indicated that at least one of their children had been afflicted with malaria within the preceding two weeks. Records at the nearest government-operated health clinic indicated that more than 80% of all hospitalizations of residents from Bawa were a result of malaria or diarrheal disease.

Tchuinkam et al. (2010) pointed out that although the highland areas of Africa are known to be malaria hypoendemic, because climatic conditions are not ideal for development of *Anopheles* mosquitoes, the probability of transmission of malaria by a single mosquito encounter in these regions is actually higher than in holoendemic areas (Beier et al. 1994, Snow et al. 1997). Tchuinkam et al. (2010) further suggested that the recent increase in the number of malaria epidemics with a spread of endemic malaria into the highland fringes (Adjuik et al. 1998) may be a consequence of global warming (Martens et al. 1995, Jetten et al. 1996), as anophelid vectors extend their normal range or exhibit local increases in abundance in response to changing climate.

The proper use of insecticide-treated bed nets substantially reduces morbidity and mortality associated with malaria (Breman et al. 2006, Lengler 2009). Additionally, the greatest efficacy is being realized in hypoendemic zones (Lengeler 2009) such as in the western Cameroonian highlands (Tchuinkam 2010). Insecticide-treated nets typically provide more than 50% efficacy in preventing episodes of malaria, a 29% reduction in the number of cases of malaria, and they may reduce childhood mortality by 18% (Breman et al. 2006).

Materials and Methods

In June 2007, a survey was conducted in Bawa and Nloh in which the prevalence of intestinal protozoans (*E. histolytica/dispar*, *G. lamblia*, and *C. parvum*) and prevalence and intensity of geohelminths was ascertained. The results of the geohelminth and protozoological surveys conducted in 2007 were reported by Richardson et al. (2011a) and Richardson et al. (2011b), respectively. In addition, morphometric data and hemoglobin concentrations determined in 2007 are reported herein.

In June 2010, a survey was conducted in which the prevalence of intestinal protozoans was determined in Nloh and Bawa-Nka, and the prevalence and intensity of geohelminths along with morphometric data and hemoglobin concentrations were determined for all available residents in Nloh, Bawa, and Bawa-Nka. Bawa-Nka lies directly adjacent to Bawa and is a quarter of the village of Nka. The results of the 2010 survey are reported herein.

Table 1 presents a summary of all surveys conducted and interventions initiated in Bawa, Nloh, and Bawa-Nka between 2006 and 2010.

Table 1. Summary of interventions and surveys conducted by the Bawa Health Initiative, 2006-2010.

	Malaria	
	Bed nets Installed	Assessment
Bawa	2007	Ongoing, Fig. 1 herein
Nloh	2008	--
Bawa-Nka	2010	--

	Waterborne Disease		
	Biosand Filters Installed	Baseline	Follow-up
Bawa	2006	Figs. 2 and 3 herein	Ongoing, Figs. 2 and 3 herein
Nloh	2007	Table 1 in Richardson et al., 2011b	2010, Reported herein
Bawa-Nka	Projected 2012	Reported herein	--

	Helminth Disease		
	Treatment Initiated	Baseline	Follow-up
Bawa*	2008 2x/year	Table 4 in Richardson et al., 2011a	2010, Table 4 herein
Nloh*	2008 3x/year	Table 3 in Richardson et al., 2011a	2010, Table 5, herein
Bawa-Nka	2010 1x/year	Table 3 herein	--

*Prevalence and intensities of geohelminth infections between 2007 and 2010 for Bawa and Nloh combined are given in Figures 5 and 6, herein. In June 2010, treatment frequency in Nloh was changed to 2x/year.

	Nutritional Status (Morphometrics)	
	Baseline	Follow-up
Bawa	2007,Reported herein	2010, Reported herein
Nloh	2007,Reported herein	2010, Reported herein
Bawa-Nka	2010,Reported herein	--

	Hemoglobin Concentration	
	Baseline	Follow-up
Bawa	2007, Table 6 herein	2010, Table 6 herein
Nloh	2007, Table 6 herein	2010, Table 6 herein
Bawa-Nka	2010, Table 6 herein	--

This study protocol was approved by the Human Experimentation Committee, Quinnipiac University, Hamden, Connecticut (HEC/IRB Protocol#5905) and the Cameroonian Ministry of Health. After the study was explained, written consent was obtained from all adult participants and parents or guardians of minors.

Installation of Insecticide-treated Bed Nets

Bed nets treated with permethrin were distributed to all residents of Bawa and Nloh during the summers of 2007 and 2008, respectively. In all, more than 600 bed nets were distributed. Bed nets were installed by members of the Village Health Committee under the direct supervision of the BHI field coordinator. The Village Health Committees and BHI maintain an ongoing program of education stressing the importance of continual proper usage of bed nets, including inspection and replacement of nets as necessary.

Installation of Biosand Water Filters (BSFs)

In order to remediate health-related problems associated with fecally contaminated drinking water, the BHI installed and implemented the use of 100 biosand water filters (BSFs) in each household in the villages of Bawa and Nloh. The BSF is an in-home filtration unit that is a modification of traditional slow-sand filtration that has been used for centuries (Richardson et al. 2011b). When used properly the BSF has been reported to be extremely effective in removing water-borne pathogens and in reducing the probability of diarrheal disease (see Richardson et al. (2011b) and references therein). Biosand water filters were installed in each compound in Bawa during the summer and fall of 2006 and BSFs were installed in each compound in Nloh during the summer and fall of 2007, subsequent to the 2007 survey of waterborne protozoan parasites (Richardson et al. 2011b). In addition to the use of BSFs, the village health committees of Bawa and Nloh conduct on-going education for the villagers concerning the proper use of BSFs and basic matters of hygiene and sanitation.

Universal Helminth Treatment

Anthelmintic drug treatment is aimed at reducing morbidity by decreasing worm burden; however, there is no one-size-fits-all approach to optimizing a deworming program. There are 3 primary considerations that must be taken into account when establishing a helminth control program: 1) who will be treated? 2) what anthelmintic will be used? and 3) what will be the frequency of treatment (Hotez et al. 2006)?

There are 3 primary approaches to treatment: universal, targeted, and selective. These approaches were described by Anderson (1989) and summarized by Richardson et al. (2011a). Many factors, such as the amount of labor required and the cost, contribute to the final choice of treatment strategy to be employed. The merits and disadvantages of these approaches were discussed by Richardson et al. (2011a). A universal treatment strategy was initiated in the villages of Bawa and Nloh beginning in 2008. The drug used for treatment was albendazole because it is a broad spectrum anthelmintic that in a previous study in Cameroon demonstrated high efficacy, excellent tolerance, and considerable reduction of egg output in the case of residual infections (Raccurt et al. 1990).

Beginning January 2008 in Bawa and Nloh, albendazole was administered as a single dose of 400 mg at each treatment cycle to each individual in the community over the age of 2 years, excepting pregnant women. Individuals in Nloh were treated 3 times per year, specifically in February and June 2008, January, May, and September 2009, and January 2010. Individuals in Bawa were treated twice per year, specifically in January and June 2008, January and June 2009, and January 2010. Treatment was suspended following the January 2010 cycle until completion of the helminth survey described herein. All treatment was supervised by Dr. Pierre Tsekeng, Chief Medical Officer of the Bawa Health Initiative.

Assessment of the Prevalence of Malaria, Diarrheal Disease, and Typhoid in Bawa

Medical records were obtained from the government-operated health clinic in the village of Nka documenting all visits of residents from the village of Bawa beginning in 2006. The head nurse at the clinic records each visit of any individual from Bawa and reports directly to the BHI field coordinator. Additionally, detailed mortality records have been kept for the village of Bawa since 2006. Clincal data should be viewed conservatively because records of clinical visits are not a highly effective means of assessing prevalence of disease. Many people who are ill may elect not to seek treatment, seek treatment from traditional healers, or to seek treatment at a clinic in a distant village. Although clinical records do not provide a comprehensive account of the occurrences of clinical diseases in Bawa, they serve as a relative indication in trends of the occurrence of various diseases, particularly considering that the population of Bawa has remained consistent at about 340 individuals.

***Survey of* E. histolytica/dispar, G. lamblia, *and* C. parvum**

During June 2010, 36 stool samples from Nloh and 64 stool samples from Bawa-Nka were tested for the presence of *E. histolytica/dispar*, *G. lamblia,* and *C. parvum* utilizing the Triage Micro Parasite Panel® (Biosite Diagnostics, San Diego, California), a rapid enzyme-linked immunoassay used for the detection of these protozoans in human fecal specimens, as described by Richardson et al. (2011b). Garcia et al. (2000) and Sharp et al. (2001) provided a detailed description and clinical assessment of the assay, respectively. Although the Triage Micro Parasite Panel® does not differentiate between *E. histolytica* and the non-pathogenic congener *E. dispar*, the two are epidemiologically similar. Prevalences between villages were statistically compared using contingency table analyses as described by Zar (1999). Prevalence data from this survey were also compared to those from 2007 (Richardson et al. 2011b) using contingency table analyses. All significant differences assume $P \leq 0.05$.

Individuals testing positive for *E. histolytica/dispar* or *G. lamblia* were treated with metronidazole according to Despommier et al. (2005). Treatment was supervised by Dr. Pierre Tsekeng, Chief Medical Officer of the Bawa Health Initiative.

Geohelminth Survey

The geohelminth survey was conducted according to Richardson et al. (2011a) as follows. Between 10 June and 24 June 2010, 376 stool samples from Nloh, Bawa, and Bawa-Nka were examined for the presence of the geohelminths *A. lumbricoides, T. trichiura,* and hookworms as described by Richardson et al. (2011a), using the Kato-Katz technique and when sample volume permitted, fecal flotation as described by Richardson et al. (2008). All slides examined using the Kato-Katz technique were examined within one hour of preparation. Thirty six, 213, and 127 samples were examined from Nloh, Bawa, and Bawa-Nka, respectively. The data were divided by gender and among age groups as follows: 0-5 years (pre-school children), 6-15 (school-aged children), 16-59 (adults), and ≥ 60 (senior adults). For Nloh, Bawa, and Bawa-Nka, 30, 197, and 94 samples were examined both by Kato-Katz and fecal flotation respectively and 6, 16, and 33 samples were examined only by Kato-Katz, respectively. Prevalences between villages, among demographic groups within villages, and between this survey and that of Richardson et al. (2011a) were compared using contingency table analyses. Intensities of infection determined by egg output recorded as egg per gram of feces (epg) were based on Kato-Katz analyses and compared using either analysis of variance (ANOVA), Student's two-tailed t-tests, or paired two-tailed t-tests as appropriate. Specimens testing negative by Kato-Katz but positive by fecal flotation were recorded as having an intensity of 24 epg, the minimum value detectable by Kato-Katz, as described by Richardson et al. (2011). Infection intensity was categorized as light, moderate or heavy based on Montresor et al. (2002) (Table 2).

Table 2. Classes of intensity given as eggs per gram of feces for geohelminth infections proposed for use by a WHO Expert Committee in 1987 (after Montresor et al. 2002). From Richardson et al. (2011a).

Helminth	Light	Moderate	Heavy
Ascaris lumbricoides	≤ 5,000	5,001-49,999	≥ 50,000
Trichuris trichiura	≤ 1,000	1,001- 9,999	≥ 10,000
Hookworm	≤ 2,000	2,001- 3,999	≥ 4,000

Morphometrics and Hemoglobin Concentration

To assess the general health and nutritional status of individuals in Bawa, Nloh, and Bawa-Nka, morphometric data (height, weight, and body mass index (BMI)) and hemoglobin levels were recorded. As the geohelminth control program proceeds, it is predicted that growth-retardation and stunting will become less pronounced. Additionally, BHI is considering implementation of a program of nutritional supplements and a nutrition education program. The morphometric data presented herein will provide a baseline to assess the effectiveness of such programs.

For each individual included in the survey, height was recorded in cm using a stadiometer and weight was recorded in kg using a Detecto® mechanical weigh-beam scale. Body Mass Index (BMI) was calculated according to WHO (2006) using the formula BMI=mass (kg) ÷ [height (m)]^2. Individuals with a BMI ≤ 2SD from the WHO growth standards were considered malnourished and individuals with a BMI ≤ 3SD were categorized as exhibiting severe acute malnutrition following universal standards calculated by WHO for children ≤ 5 years (WHO 2006; WHO and UNICEF 2009), adolescents 6-19 years (de Onis et al. 2007), and adults (WHO 1995). Children and adolescents ≤ 19 years exhibiting height for age ≤ 2SD and ≤ 3 SD from the WHO standards were considered stunted and severely stunted, respectively (Caulfield et al. 2006). Children exhibiting weight for age ≤ 2SD and ≤ 3SD from the WHO standards were considered underweight and severely underweight, respectively. Children whose weight for height was ≤ 2SD from the WHO standards were considered wasted (Caulfield et al. 2006).

Hemoglobin concentration was recorded in g/dl using a STAT-Site® MHgb hemoglobin test meter from a drop of blood procured by dermal puncture. Individuals were categorized as not anemic, anemic or severely anemic according to standards established by Stoltzfus and Dreyfuss (1998). The hemoglobin concentration (g/dl) cut-off for being considered anemic for children under 5 years and pregnant women was 11.0. For children 5-11 years and pregnant women the cutoff was 11.5, for non-pregnant women the cutoff was 12.0, and for men the cutoff was 13.0. Individuals with a hemoglobin concentration ≤ 7 were considered severely anemic. These represent conservative estimates because the standards were established assuming hemoglobin concentration at sea level (Stoltzfus and Dreyfuss 1998) and the numbers were not adjusted for altitude (Nestle et al. 1999).

Results

Assessment of the Prevalence of Malaria, Diarrheal disease, and Typhoid in Bawa

The number of cases of malaria, diarrheal disease, and typhoid based on visits of residents of Bawa to the government clinic in the neighboring village of Nka are given in Figures 1-3 respectively.

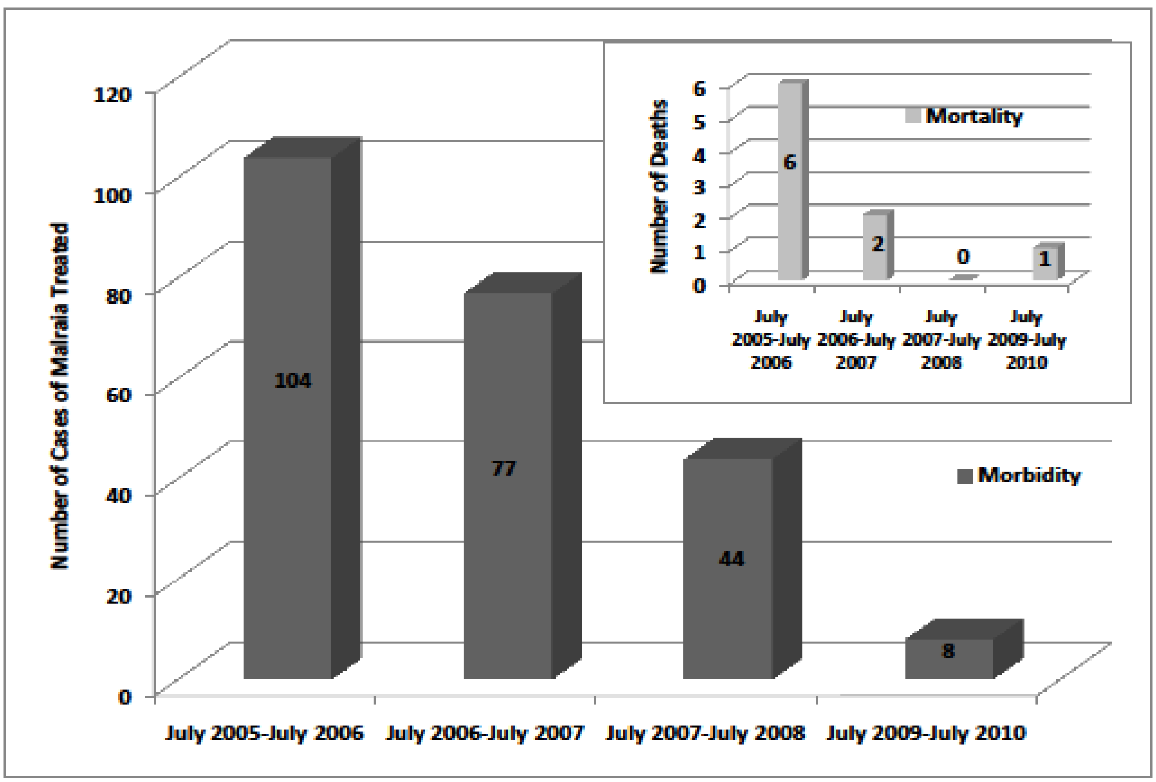

Figure 1. Mortality and morbidity of malaria in the village of Bawa for the various time periods indicated. Data are based on visits made by residents of Bawa to a government operated health clinic, in the village of Nka which lies adjacent to Bawa.

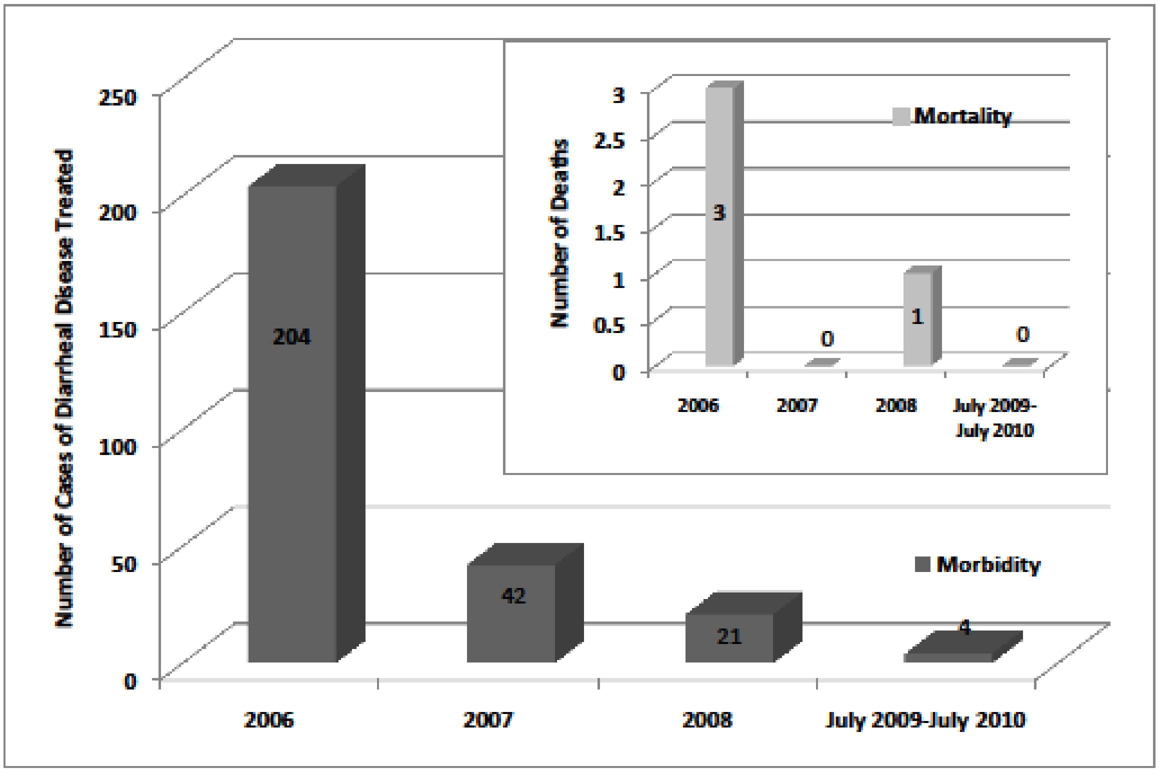

Figure 2. Mortality and morbidity of diarrheal disease in the village of Bawa for the various time periods indicated. Data are based on visits made by residents of Bawa to a government operated health clinic, in the village of Nka which lies adjacent to Bawa.

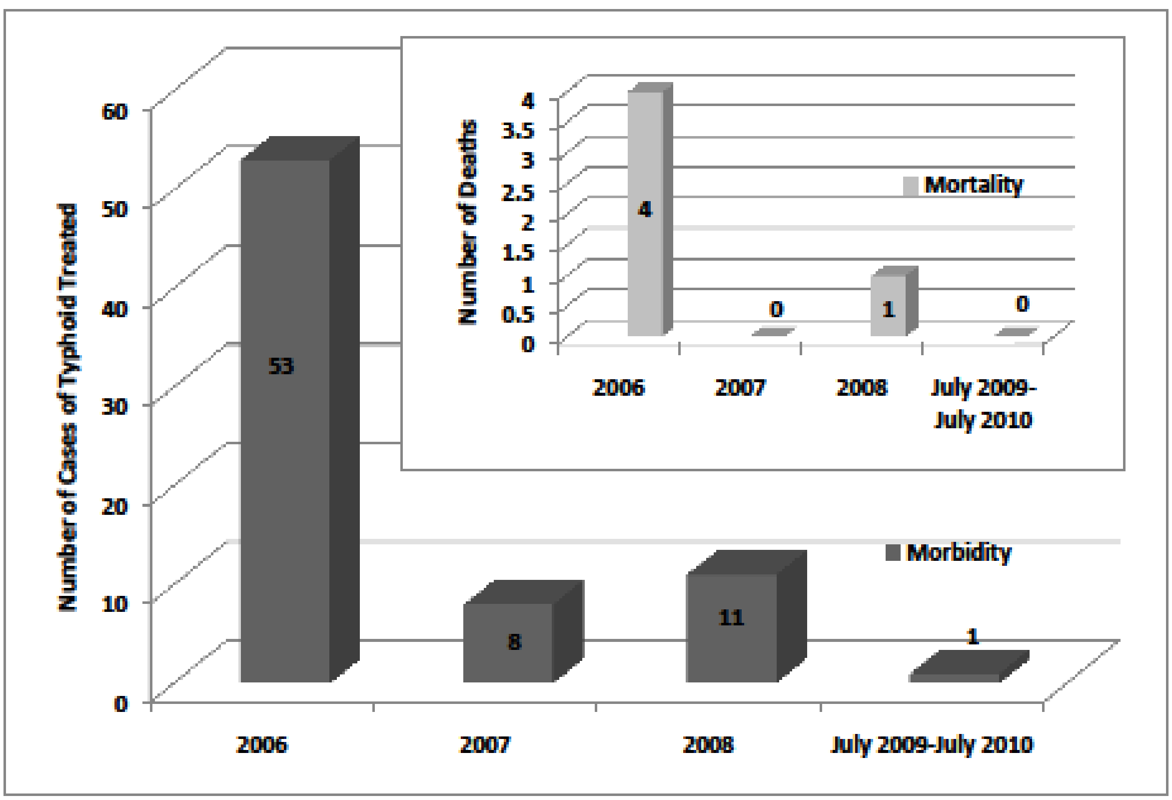

Figure 3. Mortality and morbidity of typhoid in the village of Bawa for the various time periods indicated. Data are based on visits made by residents of Bawa to a government operated health clinic, in the village of Nka which lies adjacent to Bawa.

***Survey of* E. histolytica/dispar, G. lamblia*, and* C. parvum**

In Nloh for 2010, 5 (13.9%) of 36 individuals tested were infected with *E. histolytica/dispar* or *G. lamblia*. Four of 36 (11.1%) individuals were infected with *E. histolytica/dispar*, 1 of 36 (2.8%) with *G. lamblia*, and no infection with *C. parvum* was detected. For 2007, Richardson et al. (2011b) reported that 22 (25.9%) of 85 individuals surveyed from Nloh were infected with *E. histolytica/dispar*, *G. lamblia*, *C. parvum*, or some combination thereof. Thirteen of 83 (15.7%) individuals were infected with *E. histolytica/dispar*, 12 of 83 (14.5%) with *G. lamblia*, and 3 of 83 (3.6%) with *C. parvum*. Contingency table analysis revealed no significant difference in prevalence for protozoan infection in general (X^2=2.083; 1 d.f.; P=0.149), or for *E. histolytica/dispar* (X^2=0.358; 1 d.f.; P=0.550) and *G. lamblia* (X^2=3.385; 1 d.f.; P=0.066), individually between 2007 and 2010.

In the 2010 Bawa-Nka survey, 14 (21.9%) of 64 individuals tested were infected with *E. histolytica/dispar* or *G. lamblia*. Ten (15.6%) individuals were infected with *E. histolytica/dispar*, and 4 (6.3%) were infected with *G. lamblia*. No individual was infected with multiple species and none of the 64 individuals tested for *C. parvum* were infected.

Helminth Survey

Bawa-Nka

In 2010, stool samples from 127 individuals were examined. Sixty-eight (53.5%) individuals were infected with *A. lumbricoides*, *T. trichiura*, hookworms, or some combination thereof. Sixteen (12.6%) were infected with 2 species, and 8 (6.3%) were infected with all 3 helminth species. Twenty-seven (21.3%) individuals were infected with *A. lumbricoides*, 56 (44.1%) individuals were infected with *T. trichiura*, and 17 (13%) individuals were infected with hookworm. The mean intensity ($\pm$SE) of *A. lumbricoides*, *T. trichiura*, and hookworm infection was 10,946 ($\pm$5,895), 182 ($\pm$35), and 134 ($\pm$53) epg respectively. The relative abundance ($\pm$SE) of *A. lumbricoides*, *T. trichiura*, and hookworm infection was 2,327 ($\pm$ 1,298), 79 ($\pm$17), and 18 ($\pm$ 8). Data are summarized in Table 3.

Contingency table analysis revealed no significant differences in prevalence between males and females in Bawa-Nka for any helminth, although females exhibited markedly higher prevalence of infection with all species than did males. T-tests revealed no significant differences in intensity or relative abundance between males and females. Genders were combined for subsequent analyses.

Contingency table analysis did reveal a significant difference in the prevalence of hookworm infection among age groups (X^2=10.29; 3 d.f.; p=0.016). Chi square analyses revealed that adults exhibited a significantly higher prevalence than did school-age children (X^2=5.35; 1 d.f.; p<0.025). Sample sizes were not adequate to make comparisons among other age groups.

The populations of *A. lumbricoides, T. trichiura,* and hookworms were each highly aggregated, exhibiting the characteristic negative binomial distribution (Figure 4). For *A. lumbricoides*, the 2 (1.6%) most heavily infected individuals of the 127 sampled were responsible for 76.7% of the total egg production. The variance to mean ratio was 91,913.0:1. For *T. trichiura*, the 7 (5.5%) most heavily infected individuals of the 127 sampled were responsible for 56.0% of the total egg production and the eighteen (14.2%) most heavily infected individuals were responsible for 77.6% of the total egg output. The variance to mean ratio was 475.7:1. For hookworms, the 2 (1.6%) most heavily infected individuals of the 127 sampled were responsible for 57.9% of the total egg production and the 6 (4.7%) most heavily infected individuals were responsible for 83.2% of the total egg output. The variance to mean ratio was 459.6:1.

For *A. lumbricoides* there were 2 heavy infections (a 3-yr-old female and an adult male) and 4 moderate infections (a school-aged male and female and an adult male and female). For *T. trichiura* there was 1 moderate infection (a 7-yr- old female) and no heavy infections. For hookworms, there were no heavy or moderate infections. Among the 7 moderate to heavy geohelminth infections, no individual was moderately or heavily infected with multiple species.

Bawa

Forty-five (21.1%) of the 213 individuals examined were determined to be infected with *A. lumbricoides, T. trichiura,* hookworms, or some combination thereof. This was significantly lower than the 142 (51.6%) of 275 individuals infected with geohelminths in 2007 (X^2=46.053; 1 d.f.; p=1.15 x 10^{11}) reported by Richardson et al. (2011a). Seven (3.3%) were infected with 2 species, and 2 (0.9%) were infected with all three helminth species. Eleven (5.2%)

Table 3. Prevalence (number infected/number sampled (%), mean intensity (±SE) given in eggs per gram of feces (epg), and range of infection intensity (epg) of *Ascaris lumbricoides*, *Trichuris trichiura*, hookworm, and combined geohelminths in Bawa-Nka, West Province, Cameroon for various demographic cohorts, in 2010.

Cohort		*Ascaris lumbricoides*	*Trichuris trichiura*	Hookworm	Overall Geohelminths
♂ Preschool	# infected/# sampled (%)	1/6 (16.7%)	4/6 (66.7%)	0/6 (0.0%)	4/6 (66.7%)
	Mean intensity (±SE)	476±0	168±71	---	
	Range	---	24-360	---	
♀ Preschool	# infected/# sampled (%)	2/11 (18.2%)	4/11 (47.1%)	0/11 (0.0%)	5/11 (45.5%)
	Mean intensity (±SE)	67,176±67,152	66±28	---	
	Range	24-134,328	24-144	---	
Overall Preschool	# infected/# sampled (%)	3/17 (17.6%)	8/17 (47.1%)	0/17 (0.0%)	9/17 (52.9%)
	Mean intensity (±SE)	44,943±44,693	117±40	---	
	Range	24-134,328	24-360	---	
♂ School-aged	# infected/# sampled (%)	3/17 (17.6%)	10/17 (58.8%)	1/17 (5.9%)	10/17 (58.8%)
	Mean intensity (±SE)	10,328±9,361	156±69	456±0	
	Range	24-29,016	24-600	---	
♀ School-aged	# infected/# sampled (%)	4/25 (16.0%)	12/25 (36.4%)	2/25 (8.0%)	13/25 (52.0%)
	Mean intensity (±SE)	3,384±2,556	348±129	96±0	
	Range	24-10,872	24-1,320	96-96	
Overall School-aged	# infected/# sampled (%)	7/42 (16.7%)	22/42 (52.4%)	3/42 (7.1%)	23/42 (54.8%)
	Mean intensity (±SE)	6,360±4,044	261±78	216±120	
	Range	24-29,016	24-1,320	96-456	
♂ Adult	# infected/# sampled (%)	3/11 (27.3%)	4/11 (36.14%)	1/11 (9.1%)	5/11 (45.5%)
	Mean intensity (±SE)	32,672±29,826	114±34	48±0	
	Range	24-92,232	24-192	---	
♀ Adult	# infected/# sampled (%)	10/36 (27.8%)	13/36 (36.1%)	11/36 (30.6%)	20/36 (55.6%)
	Mean intensity (±SE)	1,598±760	109±22	109±77	
	Range	24-7,368	24-312	24-864	
Overall Adult	# infected/# sampled (%)	13/47 (27.7%)	17/47 (36.2%)	12/47 (25.5%)	25/47 (53.2%)
	Mean intensity (±SE)	8,769±6,988	110±18	126±70	
	Range	24-92,232	24-312	24-864	
♂ Senior	# infected/# sampled (%)	0/7 (0.0%)	5/7 (71.4%)	0/7 (0.0%)	5/7 (71.4%)
	Mean intensity (±SE)	---	226±144	---	
	Range	---	24-792	---	
♀ Senior	# infected/# sampled (%)	4/14 (28.6%)	4/14 (28.6%)	2/14 (14.3%)	6/14 (42.9%)
	Mean intensity (±SE)	552±389	78±32	60±36	
	Range	24-1,680	24-168	24-96	
Overall Senior	# infected/# sampled (%)	4/21 (19.0)	9/21 (42.9%)	2/21 (9.5%)	11/21 (52.4%)
	Mean intensity (±SE)	552±389	160±81	60±36	
	Range	24-1,680	24-792	24-96	
♂ Overall	# infected/# sampled (%)	7/41 (17.1%)	24/41 (58.5%)	2/41 (4.9%)	24/41 (58.5%)
	Mean intensity (±SE)	18,496±12,902	8,304±6,663	252±204	
	Range	24-92,232	24-134,328	48-456	
♀Overall	# infected/# sampled (%)	20/86 (23.3%)	32/86 (37.2%)	15/86 (17.4%)	44/86 (51.2%)
	Mean intensity (±SE)	8,304±6,662	187±51	118±56	
	Range	24-134,328	24-1,320	24-864	
OVERALL	# infected/# sampled (%)	27/127 (21.3%)	56/127 (44.1%)	17/127 (13.4%)	68/127 (53.5%)
	Mean intensity (±SE)	10,946±5,895	182±35	134±53	
	Range	24-134,328	24-1,320	24-864	

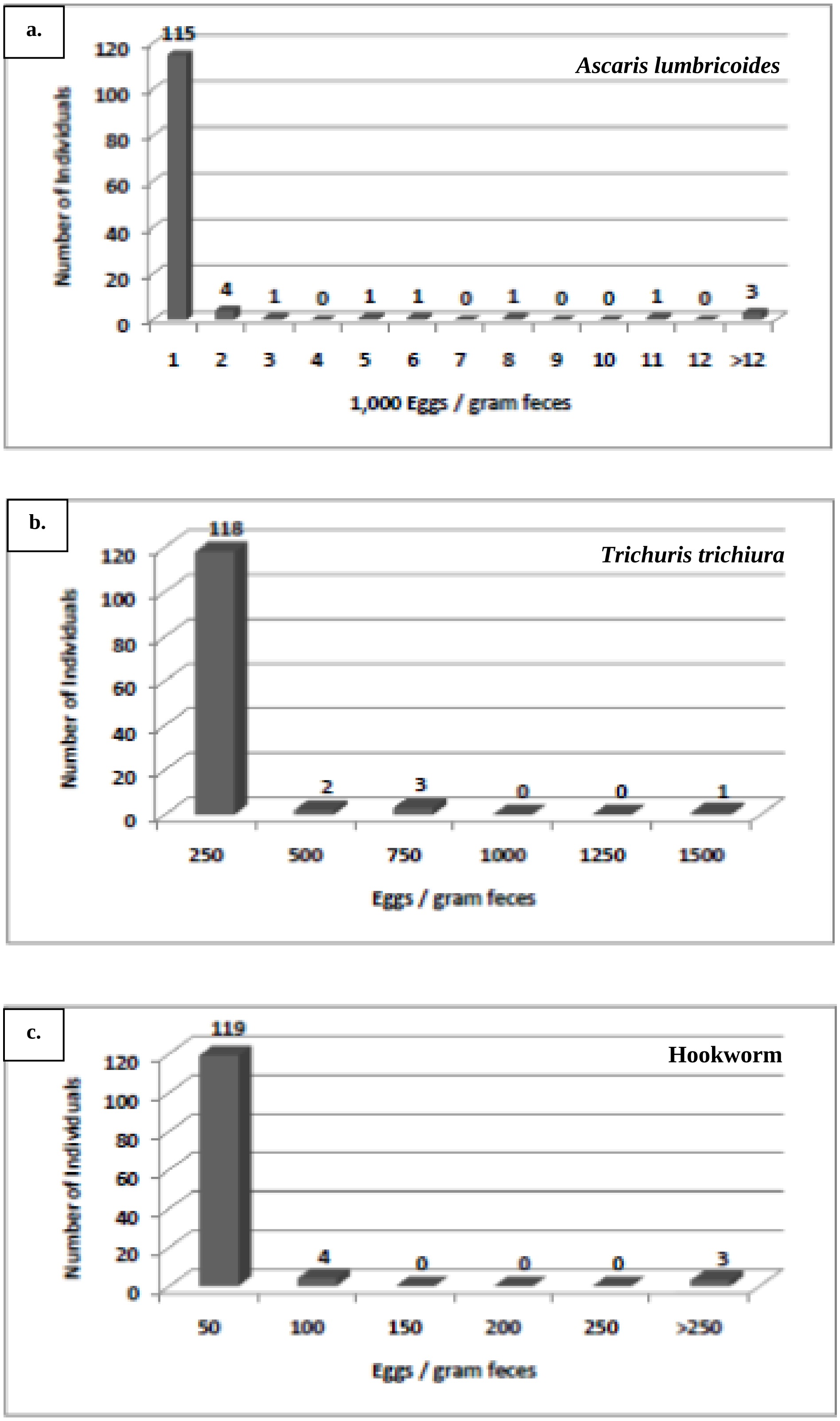

Figure 4. Frequency distributions of geohelminth intensity for Bawa-Nka, West Province, Cameroon. Infection intensities are reported as maximum eggs per gram feces for each class. **a.** *Ascaris lumbricoides*. **b.** *Trichuris trichiura.* **c.** Hookworm.

individuals were infected with *A. lumbricoides*. This was significantly lower than the 42 (15.3%) of 275 individuals infected with *A. lumbricoides* in 2007 (X^2=12.349; 1 d.f.; p=4.41x10^{-4}). Thirty-four (16.0%) individuals were infected with *T. trichiura*. This was significantly lower than the 114 (41.5%) individuals infected in 2007 (X^2=35.514; 1 d.f.; p=2.53 x 10^{-9}). Twelve (5.6%) individuals were infected with hookworm, which was significantly lower than the 39 (18.7%) of 275 individuals infected in 2007 (X^2=14.542; 1 d.f.; p=1.37 x 10^{-4}). The mean intensity (±SE) of *A. lumbricoides, T. trichiura,* and hookworm infection was 1,898 (±935), 68 (±15), and 60 (±22) epg respectively. These values were not significantly different than the mean intensities (±SE) of *A. lumbricoides, T. trichiura,* and hookworm infection of 18,904 (±6,995), 346 (±80), and 57 (±13) epg reported for Bawa in 2007 by Richardson et al. (2011a). The relative abundances (±SE) of *A. lumbricoides, T. trichiura*, and hookworm infection were 98 (± 54), 11 (±3), and 3 (±2). These were each significantly lower than the values of 2,887 (±1,134) (t=2.158; 482 d.f.; p=0.031), 144 (±35) (t=3.219; 482 d.f.; p=0.001), and 10 (±3) (t=1.991; 482 d.f.; p=0.047), respectively, reported for Bawa in 2007 by Richardson et al. (2011a). Data are summarized in Table 4.

Chi square analysis revealed no significant difference in prevalence between males and females in Bawa for any helminth. T-tests revealed no significant difference in intensity or relative abundance between males and females. Genders were combined for subsequent analyses.

Contingency table analyses and ANOVA revealed no significant difference in the prevalence or intensity, respectively of infection among age groups for any helminth species.

The populations of *A. lumbricoides, T. trichiura,* and hookworms were each aggregated. For *A. lumbricoides*, the 2 (0.9%) most heavily infected individuals of the 213 sampled were responsible for 69.1% of the total egg production and the 3 (1.4%) most heavily infected individuals were responsible for 88.7% of the total egg production. The variance to mean ratio was 6,438.2:1. For *T. trichiura*, the 5 (2.3%) most heavily infected individuals of the 213 sampled were responsible for 55.7% of the total egg production and the 14 (6.6%) most heavily infected individuals were responsible for 79.4% of the total egg production. The variance to mean ratio was 171.6:1. For hookworms, the 2 (0.9%) most heavily infected individuals of the 213 sampled were responsible for 53.3% of the total egg production. The variance to mean ratio was 164.7:1.

For *A. lumbricoides* there was 1 moderate infection, a 57-yr-old male, and no heavy infection. For *T. trichiura* there were no heavy or moderate infections. For hookworms, there were no heavy or moderate infections. The single moderate infection representing 0.5% of the population is significantly lower than the 27 moderate to heavy geohelminth infections recorded by Richardson et al. (2011a) for 2007 (X^2=18.663; 1 d.f.; p<0.001).

Nloh

Thirteen (36.1%) of the 36 individuals examined were determined to be infected with *A. lumbricoides, T. trichiura*, hookworms, or some combination thereof. This was significantly lower than the 68 (72.3%) of 94 individuals infected with geohelminths in 2007 (X^2=11.961; 1 d.f.; p=0.001) reported by Richardson et al. (2010a). Three individuals (8.3%) were infected with 2 species. No individual was infected with all 3 species. Six (16.7%) individuals were infected with *A. lumbricoides*. This was significantly lower than the 31 (33.0%) of 94 individuals infected with *A. lumbricoides* in 2007 (X^2=5.99; 1 d.f.; p=0.014). Six (16.7%) individuals were infected with *T. trichiura*. This was significantly lower than the 51 (54.3%) individuals infected in 2007 (X^2=19.097; 1 d.f.; p=1.24 X 10^{-5}). Five (13.9%) individuals were infected with hookworm which was not significantly lower than the 25 (26.6%) of 94 individuals infected in 2007. The mean intensity (±SE) of *A. lumbricoides, T. trichiura*, and hookworm infection was 82 (±27), 28 (±4), and 29 (±5) epg respectively. These values, although lower, were not significantly different than the mean intensities (±SE) of *A. lumbricoides, T. trichiura*, and hookworm infection of 2,490 (±1,216), 246 (±92), and 293 (±172) epg reported for Nloh in 2007 by Richardson et al. (2011a). Likewise, although substantially lower, the relative abundance (±SE) of *A. lumbricoides, T. trichiura,* and hookworm infection of 11 (± 6), 5 (±2), and 4 (± 2) were not significantly lower than the values of 821 (±415), 133 (±51), and 78 (±47), respectively, reported for Nloh in 2007 by Richardson (2011a). Data are summarized in Table 5.

Table 4. Prevalence [number infected/number sampled (%)], mean intensity±SE given in eggs per gram of feces (epg) of *Ascaris lumbricoides*, *Trichuris trichiura*, hookworm, and combined geohelminths in the village of Bawa, West Province, Cameroon for various demographic cohorts in 2010.

Cohort		*Ascaris lumbricoides*	*Trichuris trichiura*	Hookworm	Overall Geohelminths
♂ Preschool	# infected/# sampled (%)	0/11 (0.0%)	2/11 (18.2%)	0/11 (0.0%)	2/11 (18.2%)
	Mean intensity (±SE)	---	24±0	---	
	Range	---	24-24	---	
♀ Preschool	# infected/# sampled (%)	0/9 (0.0%)	1/9 (11.1%)	0/9 (0.0%)	1/9 (11.1%)
	Mean intensity (±SE)	---	48±0	---	
	Range	---	48-48	---	
Overall Preschool	# infected/# sampled (%)	0/20 (0.0%)	3/20 (15.0%)	0/20 (0.0%)	3/20 (15.0%)
	Mean intensity (±SE)	---	32±8	---	
	Range	---	24-48	---	
♂ School-aged	# infected/# sampled (%)	2/48 (4.2%)	9/48 (18.8%)	2/48 (4.2%)	12/48 (25.0%)
	Mean intensity (±SE)	288±264	59±21	60±36	
	Range	24-522	24-216	24-96	
♀ School-aged	# infected/# sampled (%)	3/42 (7.1%)	6/42 (14.3%)	2/42 (4.8%)	8/42 (19.0%)
	Mean intensity (±SE)	360±300	36±8	24±0	
	Range	48-960	24-72	24-24	
Overall School-aged	# infected/# sampled (%)	5/90	15/90 (16.7%)	4/38 (10.5%)	20/90 (22.2%)
	Mean intensity (±SE)	331±185	50±13	42±18	
	Range	24-960	24-216	24-96	
♂ Adult	# infected/# sampled (%)	2/19 (10.5%)	2/19 (10.5%)	3/19 (15.8%)	5/19 (26.3%)
	Mean intensity (±SE)	6,948±240	240±168	24±0	
	Range	4,104-9,792	72-408	24-24	
♀ Adult	# infected/# sampled (%)	3/46 (6.5%)	7/46 (15.2%)	1/46 (2.2%)	7/45 (15.6%)
	Mean intensity (±SE)	1,768±1,442	86±41	24	
	Range	48-4,632	24-312	---	
Overall Adult	# infected/# sampled (%)	5/65 (7.7%)	9/65 (13.8%)	4/38 (10.5%)	12/64 (18.8%)
	Mean intensity (±SE)	3,840±1,744	120±48	24±0	
	Range	48-9,792	24-408	24-24	
♂ Senior	# infected/# sampled (%)	0/14 (0.0%)	5/14 (35.7%)	1/14 (7.1%)	6/14 (42.9%)
	Mean intensity (±SE)	---	72±37	72	
	Range	---	24-216	---	
♀ Senior	# infected/# sampled (%)	1/24 (4.2%)	2/24 (8.3%)	3/24 (12.5%)	4/24 (16.7%)
	Mean intensity (±SE)	24±0	24±0	128±81	
	Range	24-24	24-24	24-288	
Overall senior	# infected/# sampled (%)	1/38 (2.6%)	7/38 (18.4%)	4/38 (10.5%)	10/38 (26.3%)
	Mean intensity (±SE)	24±0	58±27	114±59	
	Range	24-24	24-216	24-288	
♂ Overall	# infected/# sampled (%)	4/92 (4.3%)	18/92(19.6%)	6/92 (6.5%)	20/92 (21.7%)
	Mean intensity (±SE)	18,496±12,902	79±24	44±13	
	Range	24-92,232	24-408	24-96	
♀Overall	# infected/# sampled (%)	7/121 (5.8%)	16/121 (13.2%)	6/121 (5.0%)	25/121 (20.7%)
	Mean intensity (±SE)	915±635	57±19	76±43	
	Range	24-4,632	24-312	24-288	
OVERALL	# infected/# sampled (%)	11/213 (5.2%)	34/213 (16.0%)	12/213 (5.6%)	45/213 (21.1%)
	Mean intensity (±SE)	1,898±935	68±15	60±22	
	Range	24-9,792	24-408	24-288	

Table 5. Prevalence (number infected/number sampled (%)), mean intensity±SE given in eggs per gram of feces (epg), and range of infection intensity (epg) of *Ascaris lumbricoides*, *Trichuris trichiura*, hookworm, and combined geohelminths in the village of Nloh, West Province, Cameroon for various demographic cohorts in 2010.

Cohort		*Ascaris lumbricoides*	*Trichuris trichiura*	Hookworm	Overall Geohelminths
♂ Preschool	# infected/# sampled (%)	0/0	0/0	0/0	0/0
	Mean intensity (±SE)	---	---	---	
	Range	---	---	---	
♀ Preschool	# infected/# sampled (%)	0/1 (0.0%)	0/1 (0.0%)	1/1 (100.0%)	1/1 (100.0%)
	Mean intensity (±SE)	---	---	24	
	Range	---	---	---	
Overall Preschool	# infected/# sampled (%)	0/1 (0.0%)	0/1 (0.0%)	1/1 (100.0%)	1/1 (100.0%)
	Mean intensity (±SE)	---	---	24	
	Range	---	---	---	
♂ School-aged	# infected/# sampled (%)	0/7 (0.0%)	1/7 (14.3%)	1/17 (14.3%)	2/7 (28.6%)
	Mean intensity (±SE)	---	24	48	
	Range	---	---		
♀ School-aged	# infected/# sampled (%)	1/6 (16.7%)	1/6 (16.7%)	1/6 (16.7%)	2/6 (33.3%)
	Mean intensity (±SE)	24	24	24	
	Range	---	---	---	
Overall School-aged	# infected/# sampled (%)	1/13 (7.7%)	2/13 (15.4%)	2/13 (15.4%)	4/13 (30.8%)
	Mean intensity (±SE)	24	24	36±12	
	Range	---	24-24	24-48	
♂ Adult	# infected/# sampled (%)	0/4 (0.0%)	0/4 (0.0%)	0/4 (0.0%)	0/4 (0.0%)
	Mean intensity (±SE)	---	---	---	
	Range	---	---	---	
♀ Adult	# infected/# sampled (%)	2/12 (16.7%)	2/12 (16.7%)	2/12 (16.7%)	5/12 (41.7%)
	Mean intensity (±SE)	72±0	36±12	24±0	
	Range	72-72	24-48	24-24	
Overall Adult	# infected/# sampled (%)	2/16 (12.5%)	2/16(12.5%)	2/16 (12.5%)	5/16 (31.3%)
	Mean intensity (±SE)	72±0	36±12	24±0	
	Range	72-72	24-48	24-24	
♂ Senior	# infected/# sampled (%)	1/2 (50.0%)	1/2 (50.0%)	0/0 (0.0%)	2/2 (100.0%)
	Mean intensity (±SE)	144	24	---	
	Range	---	---	---	
♀ Senior	# infected/# sampled (%)	1/4 (25.0%)	1/4 (25.0%)	0/4 (0.0%)	1/4 (25.0%)
	Mean intensity (±SE)	24	24	---	
	Range	---	---	---	
Overall senior	# infected/# sampled (%)	2/6 (33.3%)	2/6 (33.3%)	0/6 (0.0%)	3/6 (50.0%)
	Mean intensity (±SE)	84±60	24±0	---	
	Range	24-144	24-24	---	
♂ Overall	# infected/# sampled (%)	1/13 (7.7%)	2/13 (15.4%)	1/13 (7.7%)	4/13 (30.8%)
	Mean intensity (±SE)	144	24±0	48	
	Range	---	24-24	---	
♀Overall	# infected/# sampled (%)	5/23 (21.7%)	4/23 (17.4%)	4/23 (17.4%)	9/23(39.1%)
	Mean intensity (±SE)	53±12	30±6	24±0	
	Range	24-72	24-48	24-24	
OVERALL	# infected/# sampled (%)	6/36 (16.7%)	6/36 (16.7%)	5/36 (13.9%)	13/36 (36.1%)
	Mean intensity (±SE)	82±27	28±4	29±5	
	Range	24-144	24-48	24-48	

Chi square analysis revealed no significant difference in prevalence between males and females in Nloh for any helminth. Because of the small sample sizes, prevalence, intensity and relative abundance was not analyzed among age groups in Nloh.

The populations of *A. lumbricoides*, *T. trichiura*, and hookworms were each aggregated. For *A. lumbricoides*, the 2 (5.6%) most heavily infected individuals of the 36 sampled were responsible for 70.6% of the total egg production and the 3 (8.3%) most heavily infected individuals were responsible for 88.2% of the total egg production. The variance to mean ratio was 109.2:1. For *T. trichiura,* the single (2.8%) most heavily infected individual of the 36 sampled was responsible for 28.6% of the total egg production. The variance to mean ratio was 26.8:1. For hookworms, the single (2.8%) most heavily infected individual of the 36 sampled was responsible for 33.3% of the total egg production. The variance to mean ratio was 28.8:1.

In Nloh there were no moderate or heavy infections for any of the 3 geohelminths. Richardson et al. (2011a) reported 9 moderate infections for Nloh in 2007, 4 for *A. lumbricoides*, 3 for *T. trichiura,* and 2 for hookworms.

Comparison of Geohelminth Infections Among Villages

Chi square analysis revealed that the prevalence of 16.7% of *A. lumbricoides* in Nloh was significantly higher than the prevalence of 5.2% in Bawa (X^2=3.90; 1 d.f.; p=0.048). No significant differences in prevalence were detected between villages for *T. trichiura*, hookworms, or geohelminths overall. A comparison of intensities of *A. lumbricoides, T. trichiura*, hookworms, and geohelminths overall by t-tests revealed no significant differences between Bawa and Nloh. Combined data for Bawa and Nloh are summarized in Figures 5 and 6.

Contingency table analysis revealed that prevalences of *A. lumbricoides, T. trichiura,* hookworms, and overall geohelminths in Bawa-Nka were significantly higher than those for Bawa and Nloh combined. T-tests analysis revealed the intensity ($\pm$SE) of 51 ($\pm$ 76) of *T. trichiura* for Bawa and Nloh combined was significantly lower than the intensity ($\pm$SE) of 182 ($\pm$ 265) for Bawa-Nka (t=-3.078; 95 d.f.; p=0.003). No significant differences were detected in the mean intensities of *A. lumbricoides* or hookworm between Bawa and Nloh combined and Bawa-Nka. T-tests analysis did reveal that the relative abundances of all 3 geohelminths were significantly lower in Bawa and Nloh combined than in Bawa-Nka.

Nutrition

Nloh

In 2010, in Nloh, 2 (4.9%) of 41 individuals were categorized as malnourished based on BMI. Both were adult females. No individual was categorized as severely malnourished based on BMI. In 2007, 3 (3.4%) of 87 individuals examined were categorized as malnourished based on BMI, a senior male and 2 adult females. No individual was categorized as severely malnourished based on BMI.

Among children and adolescents in 2010, 4 (26.7%) of 15 individuals were categorized as stunted based on WHO height for age standards. No individual was found to be severely stunted. In 2007, 8 (25.8%) of 31 children were found to be stunted or severely stunted; with 6 being categorized as stunted and 2 being severely stunted. In 2010, among children 2 to 10 years of age, 2 of 10 (20%) were categorized as underweight based on WHO weight for age standards. No child was found to be severely underweight. In 2007, 5 (26.3%) of 19 children were underweight or severely underweight. Two of these, constituting 10.5% of the childhood population were categorized as severely underweight. In 2007, 1 (20.0%) of 5 children under 5 examined, a 3-year-old female, was categorized as wasted based on WHO standards of weight for height. In 2010, none of the 3 children under 5 years of age examined were categorized as wasted.

Bawa

In 2010, in Bawa, overall 11 (5.0%) of the 220 individuals examined were categorized as malnourished based on BMI, 1 adolescent male, 3 adolescent females, 2 adult females, 3 senior males, and 2 senior females. No individual was categorized as severely malnourished based on BMI. In 2007, 23 (8.6%) of 269 individuals examined were categorized as malnourished based on BMI, 3 senior males, 4 senior females, 4 adult females, 2 adolescent males, 4 adolescent females, 4 male children (under 5 years old) and 2 female children. Of these, 4 individuals constituting 1.8% of the population, 3 males under 5 years old and one 14-year-old male, were categorized as severely malnourished. Chi square analysis revealed no significant difference in the relative number of malnourished individuals between 2007 and 2010.

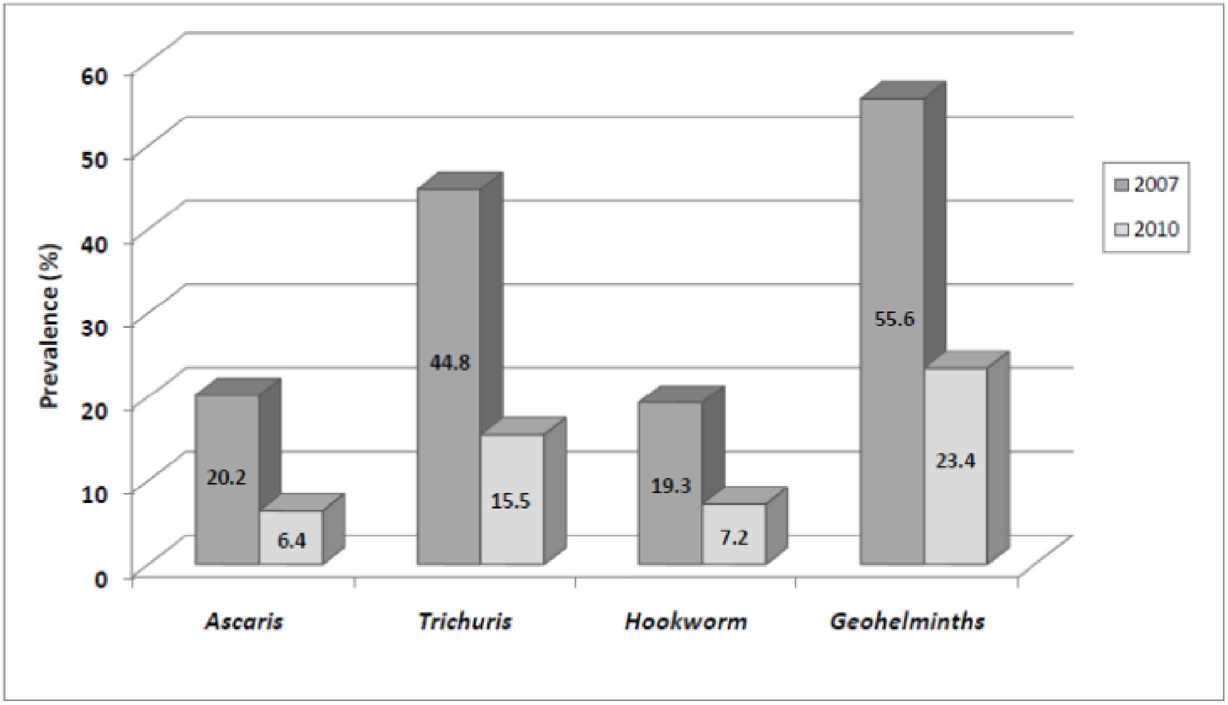

Figure 5. Comparison of prevalences of *Ascaris lumbricoides*, *Trichuris trichiura*, hookworms, and combined geohelminth between 2007 and 2010 for the combined population of the villages of Bawa and Nloh, West Province, Cameroon.

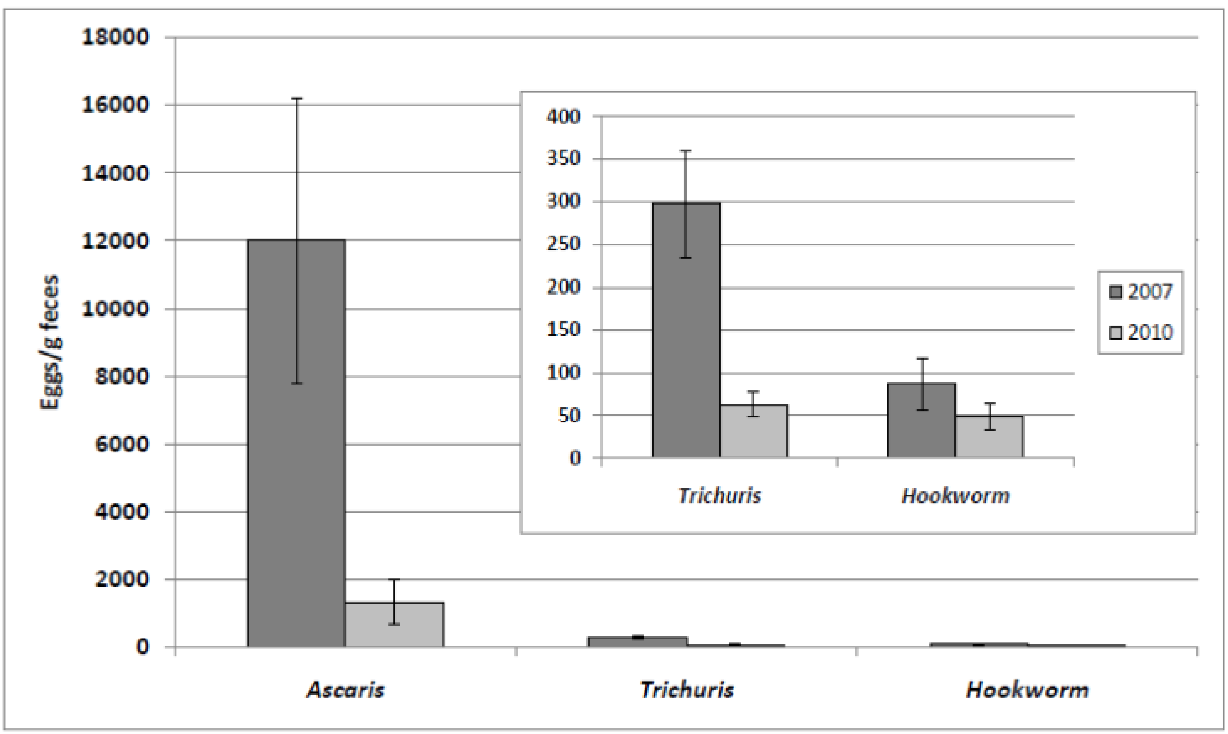

Figure 6. Comparison of mean intensities of *Ascaris lumbricoides*, *Trichuris trichiura*, and hookworms given as eggs per gram feces between 2007 and 2010 for the combined population of the villages of Bawa and Nloh, West Province, Cameroon. Error bars show standard error about the mean.

Among children and adolescents examined from Bawa in 2010, 41 (36.3%) of 113 individuals were categorized as stunted based on WHO height for age standards. Of these, 20 constituting 17.7% of the sample were severely stunted. Chi-square analysis revealed a significant difference in the relative number of stunted individuals between genders (X^2=8.20; 1 d.f.; p=0.004) with 28 (49.1%) of 57 males and 13 (23.2%) of 56 females sampled stunted or severely stunted. In 2007, 52 (43.0%) of 121 children and adolescents were stunted or severely stunted; with 33 categorized as stunted and 20 (16.3%) severely stunted. Chi-square analysis revealed no significant difference in the relative number of stunted children and adolescents between 2007 and 2010. In 2010, among children 2 to 10 years of age, 23 of 56 (41.1%) were underweight or severely underweight based on WHO weight for age standards. Nine of the 23 (39.1%) were severely underweight. Chi-square analysis revealed no significant difference between genders in weight for age indices. In 2007, 31 (35.6%) of 87 children were underweight or severely underweight. Chi-square analysis revealed no significant difference in the relative number of underweight or severely underweight individuals between 2007 and 2010. In 2007, 2 (5.9%) of the 34 children under 5 years of age were categorized as wasted based on WHO standards of weight for height. None of the 13 children under 5 examined in 2010 were categorized as wasted.

Bawa-Nka

In 2010 in Bawa-Nka, overall 10 (6.8%) of the 148 individuals examined were categorized as malnourished or severely malnourished based on BMI, 4 adolescent males, 2 adolescent females, and 4 adult females. Among these, 3 of the adolescent males, constituting 2.0% of the population, were categorized as severely malnourished based on BMI. Among children and adolescents examined from Bawa-Nka in 2010, 27 (42.9%) of 63 individuals were categorized as stunted based on WHO height for age standards. Of these, 15 (23.8%) were severely stunted. Among children 2 to 10 years of age, 19 of 39 (48.7%) were underweight or severely underweight based on WHO weight for age standards. Eight of the 19 (20.5%) were severely underweight. Chi-square analysis revealed no significant difference between genders in weight for age indices. Three (25.0%) of 12 children, ages 2 to 4 years, were categorized as wasted. Chi-square analyses revealed no significant differences between genders in height for age or weight for age.

Chi-square analyses revealed no significant differences in 2010 between Bawa and Bawa-Nka in nutritional status determined by BMI, height for age, and weight for age.

Hemoglobin Concentrations

Nloh

In Nloh for 2010, 25 (69.4%) of 36 individuals tested were anemic with 1 (2.8%) individual, an 81-year-old female, being severely anemic. Chi-square analysis revealed no significant difference in prevalence of anemia measured in Nloh for 2007 when 51 (63.8%) of 80 individuals were determined to be anemic, with 1 (1.3%) individual, a 16-year-old female being severely anemic. Data are summarized in Table 6.

Bawa

In Bawa for 2010, 105 (49.1%) of 214 individuals tested were anemic with 1 (0.5%) severely anemic individual, a 14-year-old female. This was significantly lower than the prevalence of anemia in Bawa for 2007 when 194 (75.8%) of 256 individuals were anemic, with 9 (3.5%) severely anemic individuals (X^2=35.94; 1 d.f.; p=2.03 x 10^{-9}). Chi-square analysis revealed no significant differences in the prevalence of anemia between genders in Bawa for 2007 or 2010. Chi-square analyses did reveal significant differences among age groups in the prevalence of anemia in Bawa for 2007 (X^2=19.46; 3 d.f.; p=2.19 x 10^{-4}). In 2007, the prevalence of anemia among children 5 and under was 86.7% which was significantly higher than that of adults (34.9%) (X^2=7.473; 1 d.f.; p=0.006) and senior adults (61.0%) (X^2=8.12; 1 d.f.; p=0.004). Likewise the prevalence of anemia in school-aged children (86.3%) was significantly higher than that of adults (X^2=11.101; 1 d.f.; p=0.001) and senior adults (X^2=10.962; 1 d.f.; p=0.001). Chi-square analyses in Bawa for 2010 revealed that the prevalence of anemia in children under 5 was 76.2% which remained significantly higher than that of adults (42.4%) (X^2=7.267; 1 d.f.; p=0.007) and of senior adults (46.2%) (X^2=5.015; 1 d.f.; p=0.025). Data are summarized in Table 6.

Bawa-Nka

In Bawa-Nka for 2010, 55 (39.6%) of 139 individuals were anemic with no individual being severely anemic. Chi-square analysis revealed no significant difference in the prevalence of anemia between Bawa-Nka and Bawa in 2010. Chi-square analysis revealed no significant differences in the

Table 6. Incidence (number anemic/number sampled (%)), mean intensity (±SE) given as hemoglobin concentration as g hemoglobin/dl of whole blood, and incidence of severe anemia (≤7 g hemoglobin/dl) in the villages of Bawa and Nloh and in Bawa-Nka, West Province, Cameroon for various demographic cohorts.

Age (years)		*Bawa*		*Nloh*		*Bawa-Nka*
		2007	*2010*	*2007*	*2010*	*2010*
<5	# anemic/# sampled	26/30 (86.7%)	9/13 (69.2%)	3/4 (75.0%)	1/2 (50.0%)	11/17 (64.7%)
	Mean Hbg (±SE)	9.4±0.3	9.5±0.8	9.9±0.5	12.3±2.6	10.3±0.3
	# Severely anemic (%)	3 (10.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
5-11	# anemic/# sampled	60/67 (89.6%)	36/69 (52.2%)	7/15 (46.7%)	6/8 (75.0%)	15/28 (53.6%)
	Mean Hbg (±SE)	9.6±0.2	11.4±0.2	11.9±0.6	10.7±0.5	11.6±0.2
	# Severely anemic (%)	4 (6.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
>11	# anemic/# sampled	108/159 (68.0%)	60/132 (45.5%)	41/61(67.2%)	18/26 (69.2%)	29/94 (30.9%)
	Mean Hbg (±SE)	11.0±0.2	11.4 ±2	11.3±0.3	11.7±0.4	12.9±0.2
	# Severely anemic (%)	2 (1.2%)	1 (0.8%)	1 (1.6%)	1 (3.8%)	0 (0.0%)
Overall	# anemic/# sampled	194/256 (75.8%)	105/214 (49.1%)	51/80(63.8%)	25/36 (69.4%)	55/139 (39.6%)
	Mean Hbg (±SE)	10.5±0.1	11.9±0.1	11.4±0.2	12.3±0.1	12.3±0.1
	# Severely anemic (%)	9 (3.5%)	1 (0.5%)	1 (1.3%)	1 (2.8%)	0 (0.0%)

prevalence of anemia between genders. Contingency table analyses did reveal a significant difference among age groups in Bawa-Nka (X^2=15.81; 3 d.f.; p=0.001). The prevalence of anemia among children 5 and under was 64.7% which was significantly higher than that of adults (22.2%) (X^2=10.669; 1 d.f.; p<0.005) and senior adults (33.3%) (X^2=3.938; 1 d.f.; p<0.05). Likewise, the prevalence of anemia in school-aged children (54.5%) was significantly higher than that of adults (X^2=10.902; 1 d.f.; p<0.001). Data are summarized in Table 6.

Discussion

In the villages of Bawa and Nloh where BHI has implemented intervening modalities, the number of clinical cases of malaria, diarrheal disease, and typhoid has decreased, the prevalence of water-borne protozoan parasites has decreased, the prevalence and intensities of geohelminth infections has significantly decreased, and the prevalence of anemia has significantly decreased. When viewed in its entirety, these data clearly demonstrate that the comprehensive approach of intervention to public health challenges facing Bawa, Cameroon and surrounding villages has been extremely effective. Following is an independent assessment of each modality.

Clinical Data

Clinical data presented were based on visits by residents of Bawa to the government clinic in Nka, which is the nearest available healthcare for residents of Bawa. Although the clinical data are encouraging in that the number of cases of malaria, diarrheal disease, and typhoid treated have dropped substantially over the 4 years subsequent to commencement of implementation of modalities, these data are anecdotal and should be assessed conservatively. Although it is tempting to attribute the decline in clinic visits for these diseases directly to interventions implemented by BHI, many socio-demographic factors could influence such clinical data. For instance, the nursing staff has changed during this time period and periods of time have passed that the clinic was not open for patients. Nevertheless, these data, when viewed in lieu of other data assessing the efficacy of specific modalities, support the assertion that insecticide treated bed-nets have been effective at reducing the burden of malaria and that biosand water filters (BSFs) have been effective in reducing the occurrence of diarrheal disease, including typhoid.

Prevalence of Water-Borne Protozoan Parasites

Although the prevalences of *E. histolytica/dispar*, *G. lamblia.* and *C. parvum* in Nloh were substantially lower in the summer of 2010 than they were in the summer of 2007, no significant differences were detected. In view of the small sample size for the village of Nloh, these data should be viewed as suggestive that the BSF may be effective in reducing the prevalence of water-borne protozoan parasites.

One potential explanation for the small sample size recorded for the village of Nloh was that many of the villagers, particularly the household patriarchs, were away working at their farms in the nearby village of Santchou. In addition to presenting an interference with compliance in follow-up surveys, the water in Santchou is reported by local residents and physicians to be notoriously contaminated. Several villagers from Nloh and Bawa indicated that although they always use their BSFs when at "home" they are unable to do so while they work at their farms, where they may spend several days at a time. This presents the likelihood of individuals becoming infected with water-borne protozoans while traveling. The urgency to *always* consume only filtered water is being stressed in the continuing education concerning proper use and maintenance of BSFs by the Village Health Committees.

The clinical data obtained from the government clinic in Nka support the assertion of the effectiveness of BSFs in reduction of diarrheal disease, as does the observation of a similarly low prevalence of *E. histolytica/dispar* and *G. lamblia* infection observed by Richardson et al. (2011b) in Bawa, 1 year subsequent to installation of BSFs. In addition, both Nloh and Bawa, 3 years and 1 year respectively following implementation of BSF use, exhibited lower prevalences of water-borne protozoans than did Bawa-Nka, where no intervention or education program had been implemented.

In Nloh, the prevalence of *G. lamblia* exhibited a greater reduction (14.5% to 2.8%) from 2007 to 2010 than did *E. histolytica/dispar* (15.7% to 11.1%). Similarly, one year following installation of BSFs in Bawa, the prevalence of *G. lamblia* was 1.8% whereas that of *E. histolytica/dispar* was 7.1%. Comparatively, in Nloh, prior to installation of BSFs, the prevalences of *G. lamblia* and *E. histolytica/dispar* were 14.5% and 15.7% respectively (Richardson et al. 2011b). These data suggest that BSFs may be more effective in reducing the prevalence of *G. lamblia* than that of *E. histolytica*. Both *E. histolytica/dispar* and *G. lamblia* may be transmitted to humans in a variety of ways; however, it has been suggested that *G. lamblia* is primarily a water-borne parasite (Pung 2003); whereas *E. histolytica/dispar*, in addition to being transmitted by fecally contaminated water, is also commonly transmitted by a variety of other pathways (Marquardt et al. 2000). Transmission through contaminated food may be an important source of infection with *E. histolytica*. For instance, identification and treatment of infected food handlers has been shown to result in a 12-fold reduction in the occurrence of infection with *E. histolytica* (Marquardt et al. 2000). Roberts and Janovy (2009) suggested that the manner of human waste disposal is the most important factor in the epidemiology of *E. histolytica*. While BSFs appear to be having an impact on the control of giardiasis, control of amebiasis in Bawa and surrounding areas may depend more heavily upon improved sanitation than water filtration.

Another piece of anecdotal evidence supporting the effectiveness of the BSF at preventing intestinal disease is the significant differences in the prevalences of geohelminths reported by Richardson et al. (2011a) between Nloh prior to implementation of interventions, and Bawa 1 yr subsequent to installation of BSFs alongside the implementation of a sanitation and hygiene education program. Nloh exhibited *A. lumbricoides* and *T. trichiura* prevalences of 33.0% and 54.3%, respectively, while Bawa exhibited prevalences of 15.3% and 41.5%, respectively. Although *A. lumbricoides* and *T. trichiura* are primarily soil-borne, there is a body of evidence supporting the assertion that the provision of "clean" water may have a substantial impact on their prevalence (Esrey et al. 1991, Schliessmann et al. 1958, Henry 1981, Hotez et al. 2006, Jombo et al. 2007, Richardson et al. 2011a).

When used properly, the BSF is remarkably effective in removing water-borne pathogens, including protozoan cysts and helminth eggs (Palmateer et al. 1999, Duke et al. 2006, Stauber et al. 2006, Baumgartner et al. 2007, Center for Affordable Water and Sanitation Technology (CAWST) (2008a,b)). Nevertheless, effectiveness of the BSF in removing water-borne pathogens does not necessarily equate to a reduction in the prevalence of water-borne disease in a community served by BSFs, although anecdotal clinical data are supportive of this assertion (CAWST 2008b, Stauber et al. 2009, present study).

A preponderance of circumstantial data gathered in this study is supportive of the effectiveness of the BSF at reducing water-borne disease. However, we emphasize the point that these are anecdotal data and more robust empirical evidence that demonstrates the effectiveness of BSFs in actually reducing the prevalence of water-borne parasites in a community is urgently needed in view of the phenomenal resources being expended in implementation of BSF projects. Hopefully, the data gathered in Nloh and Bawa-Nka will provide the baseline for more robust definitive tests of the ultimate effectiveness of the BSF at reducing the prevalence of water-borne parasites.

Geohelminth Survey

The universal helminth treatment program implemented by BHI in 2007 has been successful in reducing the prevalence, intensity, and relative abundance of geohelminth infections in Bawa and Nloh. Overall, the prevalence of geohelminth infections in Bawa and Nloh has been reduced from 56.9% in 2007 (Richardson et al. 2011a) to 23.3% in 2010. The finding that there were no significant differences in the prevalences or intensities of geohelminths between the two villages suggests that 2 treatments per year are as effective as 3 treatments per year in the control of geohelminths. Because of the possible development of albendazole resistance by worms, the number of treatments in Nloh is being reduced from 3 per year to 2 per year.

Hotez et al. (1996) pointed out that repeated chemotherapy at regular intervals (periodic deworming) in high-risk groups can ensure that the levels of infection are kept below those associated with morbidity, resulting in rapid improvement in child health and development and may reduce transmission over time. Hotez et al. (1996) also pointed out some disadvantages to periodic deworming including the lower efficacy of a single-dose of anthelmintic (Albonico et al. 1994, Adams et al. 2004), high rates of post-treatment reinfection (Albonico et al. 1995, 2003), and most concerning, the possibility of the appearance of anthelmintic resistance by the worms (Albonico et al. 2003, Hotez et al. 1996).

The ultimate goal of most geohelminth control programs is reduction in the number of moderate and severe infections and thus reduction in morbidity and potential mortality. In Bawa and Nloh collectively, in 2007, 36 (9.8%) of 369 individuals examined exhibited moderate or severe infections (Richardson et al. 2011a). In the present study, only 1 of 249 individuals exhibited a moderate infection in 2010.

The secondary goal of most geohelminth control programs is reduction of the prevalence of helminth infections with the ideal of eradication. Richardson et al. (2011a) postulated that the relative effectiveness of a universal helminth control program was contingent upon disruption of the negative binomial distribution exhibited by worm populations. Universal or mass treatment undermines the infrastructural stability of the helminth metapopulation by attacking the two components of overdispersion that underlie the negative binomial distribution, the many lightly infected individuals to the "left," and the few heavily infected individuals to the "right." Figures 7-9 show the comparative frequency distributions of geohelminths between 2007 and 2010 for the villages of Bawa and Nloh combined. Hilbe (2007) gave a detailed explanation of the negative binomial distribution and its derivation. Bliss and Fisher (1953), Crofton (1971), and Schmid and Robinson (1972) provided detailed explanations and examples of fitting the negative binomial distribution to biological and parasitological data. The degree of overdispersion of all 3 geohelminths, has been reduced in the course of the universal control program carried out in Bawa and Nloh, evidenced by the reduction in variance to mean ratios in all instances. Likewise, the overdispersion parameter *k* (Bliss and Fisher 1953) is expected to increase because the overdispersion parameter varies inversely with the degree of overdispersion, or aggregation, such that as *k* approaches 0 the worms are more highly aggregated and as *k* approaches ≥ 5 the worms are randomly distributed among the hosts (Anderson 1989). Reduction in mean intensity will coincide with reduction in the number of heavily infected individuals, while reduction in prevalence will lead primarily to reduction in the number of lightly infected individuals. As the intervention progresses and intensities are reduced the data will become less heteroskedastic (skewed to the right); therefore, the mean intensity will be expected to decrease. As the mean intensity decreases, the variance is expected to decrease concomitantly. Likewise, as prevalence decreases, the size of classes representing lightly infected individuals to the left will decrease, while the "0 class" representing uninfected individuals will increase. A decrease in the degree of heteroskedasticity along with concomitant decrease of intensity in classes that represent lightly infected individuals will result in a distribution that fits the negative binomial less efficiently as the overdispersion parameter *k* increases and the variance to mean ratio approaches unity. The data must be 0-truncated because an increase in the number of uninfected individuals would give the illusion of overdispersion. The insets in Figures 7-9 show the 0-truncated distributions of *A. lumbricoides*, *T. trichiura*, and hookworm, respectively for Bawa and Nloh combined. Analysis of the truncated distributions reveal that for *A. lumbricoides* between 2007 and 2010 the mean intensity was reduced from 12,344 to 1,281 and that the sample variances decreased from 1.31 x 10^9 to 7,245,130. This results in a decrease of the variance to mean ratio for the 0-truncated distribution of *A. lumbricoides* by 95.7%, from 106,125:1 in 2007 to 5,656:1 in 2010. Analysis of the truncated distributions reveals that for *T. trichiura* between 2007 and 2010 the mean intensity was reduced from 299 to 52 and that the sample variances decreased from 623,557 to 5,925. This results in a decrease of the variance to mean ratio for the 0-truncated distribution

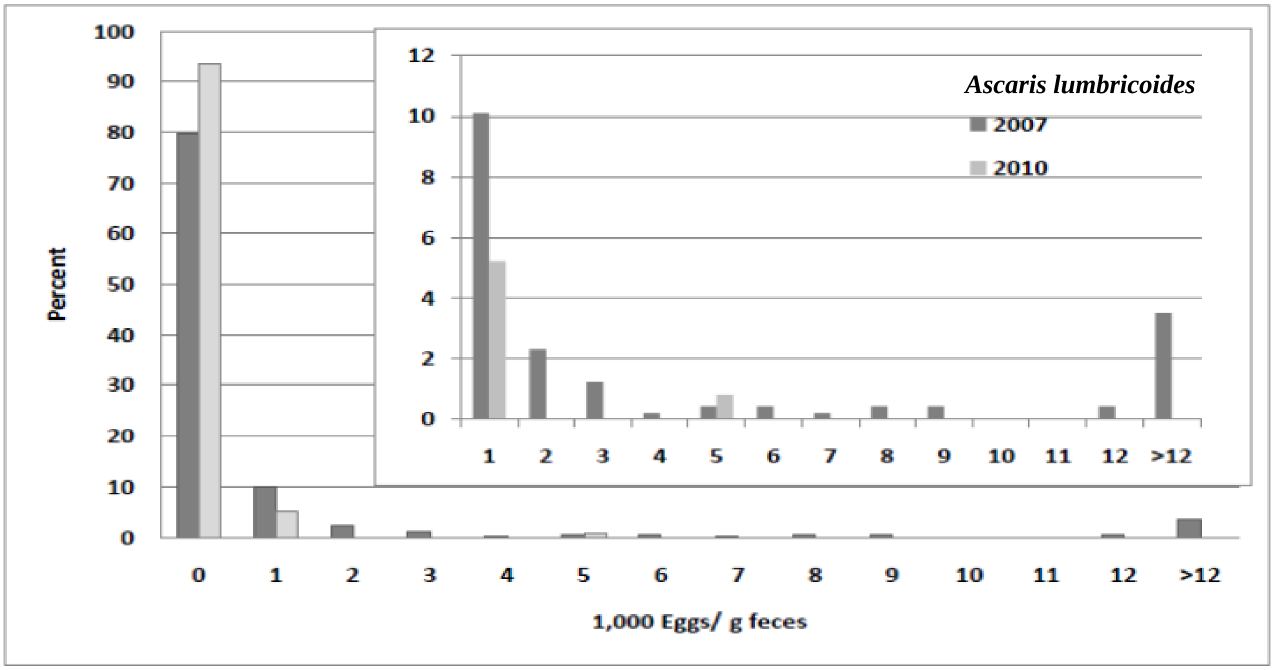

Figure 7. Frequency distribution of intensities of *Ascaris lumbricoides* for the combined populations of Bawa and Nloh, West Province, Cameroon comparing intensities in 2007 and 2010. Infection intensities are reported as maximum eggs per gram feces for each class. Insets show 0-truncated frequency distributions (i.e. exclude the 0 class).

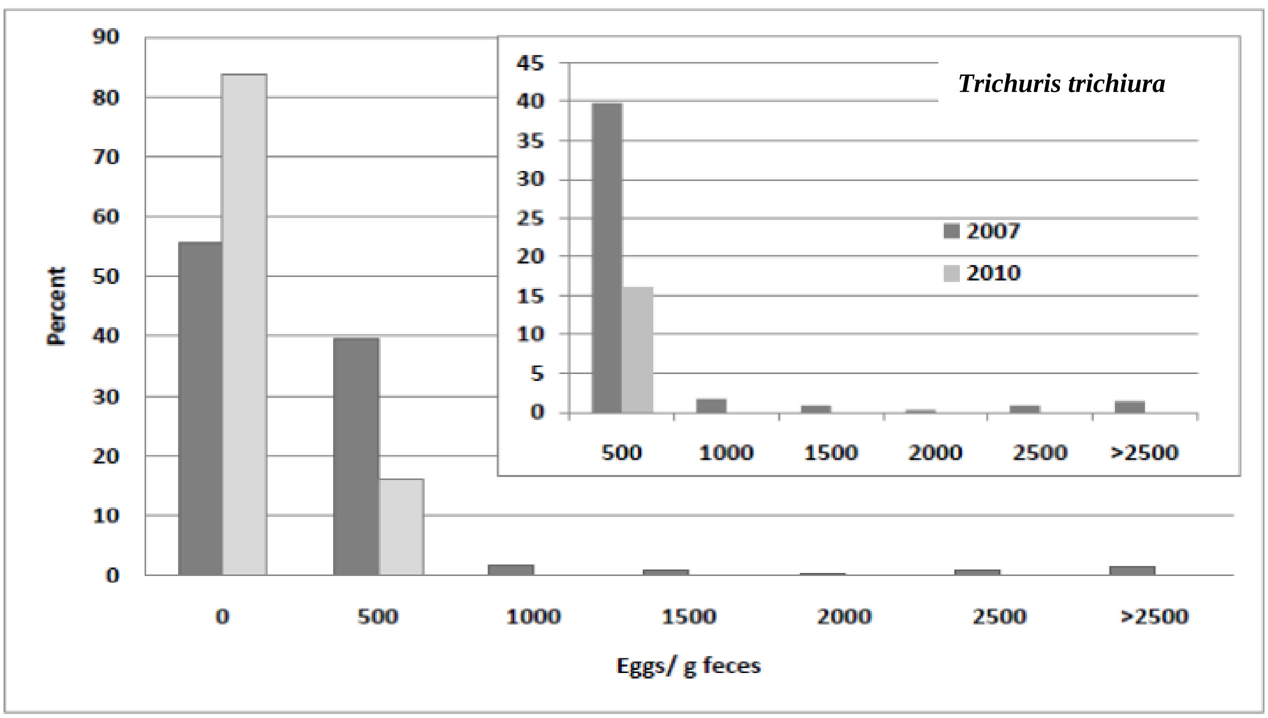

Figure 8. Frequency distributions of intensities of *Trichuris trichiura* for the combined populations of Bawa and Nloh, West Province, Cameroon comparing intensities in 2007 and 2010. Infection intensities are reported as maximum eggs per gram feces for each class. Insets show 0-truncated frequency distributions (i.e. exclude the 0 class).

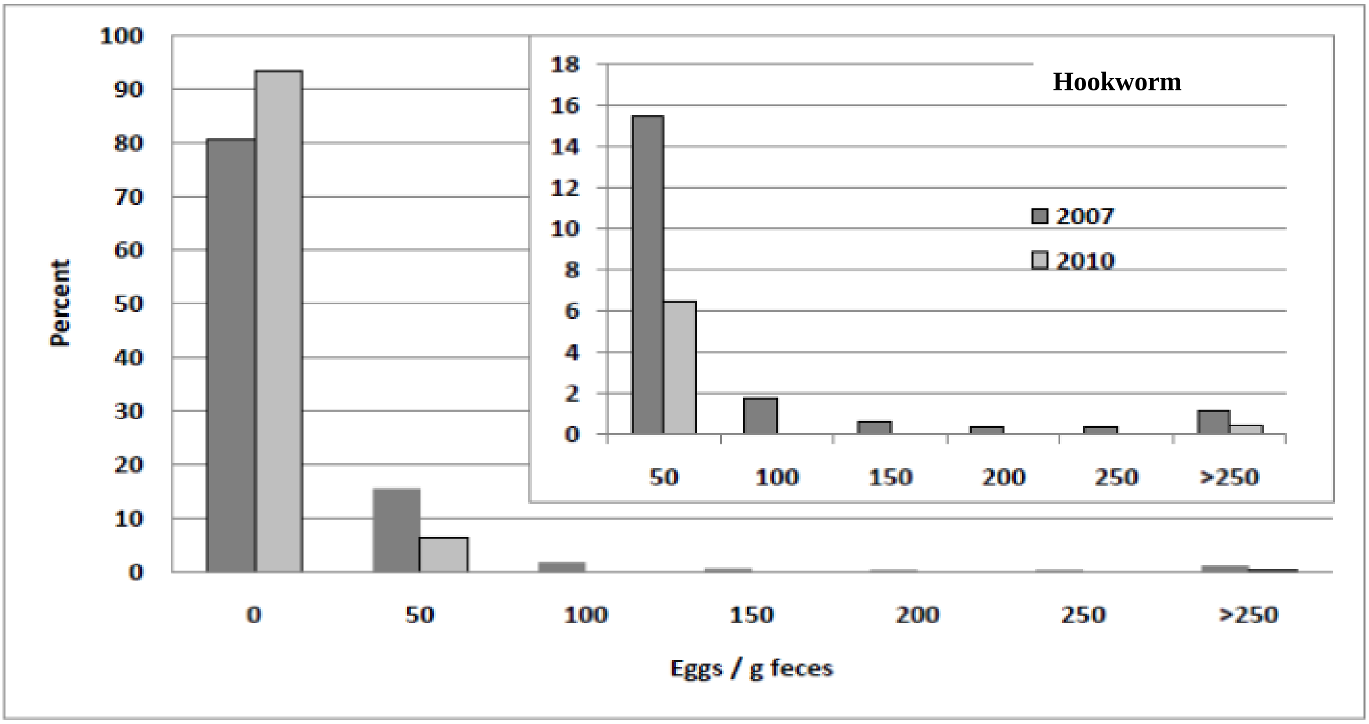

Figure 9. Frequency distributions of intensities of hookworm for the combined populations of Bawa and Nloh, West Province, Cameroon comparing intensities in 2007 and 2010. Infection intensities are reported as maximum eggs per gram feces for each class. Insets show 0-truncated frequency distributions (i.e. exclude the 0 class).

of *T. trichiura* by 94.5%, from 2,088:1 in 2007 to 114:1 in 2010. Analysis of the truncated distributions reveals that for hookworm between 2007 and 2010 the mean intensity was reduced from 86 to 43 and that the sample variances decreased from 60,647 to 4,044. This results in a decrease of the variance to mean ratio for the 0-truncated distribution of hookworm by 98.7%, from 7,487:1 in 2007 to 95:1 in 2010.

Although the geohelminth populations in Bawa and Nloh continued to exhibit overdispersion in 2010, the degree of overdispersion, and thus the negative binomial distribution, has been heavily impacted by chemotherapeutic intervention, evidenced by the profound decreases in variance to mean ratios. The relatively small sample sizes, particularly regarding the heavy infection classes for 2010, preclude robust estimation of the overdispersion parameter k for these populations. Although these preliminary data are compelling, the distribution of infection intensities for large populations comprised of thousands of individuals should be compared before and after treatment to further assess the impact that population-level chemotherapy has on reducing overdispersion. Review of the literature failed to provide data sets reported in such a way as to lend themselves to retrospective analysis. Laboratory models that may be utilized in detailed study of the negative binomial distribution of parasite populations and their response to population-level treatment are being sought.

The general recommendations of the World Health Organization (2002) regarding frequency of treatment are as follows: In areas where the prevalence of geohelminth infection is greater than 70% and more than 10% moderate and heavy infections, 2-3 treatments per year are recommended. When the prevalence is between 40-60% and the incidence of moderate and heavy infections is less than 10%, treatment is recommended once per year.

The prevalence of geohelminth infection in Bawa-Nka is 53.5% and 5.5% of the population exhibits moderate or heavy infections. This offers an ideal scenario with which to assess the efficacy of the single annual treatment approach in comparison with 2 or 3 treatments per year. The treatment strategy of single annual treatments in Bawa-Nka and 2 treatments annually in Bawa and Nloh that has been adopted by BHI will facilitate such comparison.

Over the next 7 years the prevalence and intensity of geohelminth infections will be monitored in all 3 villages to assess effectiveness of the different approaches in periodicity of treatment. Changes in metapopulation structuring as illustrated by the negative negative binomial distribution will be monitored to test the hypothesis of Richardson et al. (2011a), which predicts that disruption of the negative binomial distribution is essential to success of geohelminth control programs.

Although many studies report the prevalence of geohelminths and many report the short-term results of treatment programs, few provide well-controlled long term detailed data concerning the effectiveness of community helminth treatment programs. The goal of BHI is to track the effectiveness of community control over a period of decades. This approach will facilitate long-term assessment of various strategies and provide early detection of possible failure of treatment due to drug resistance.

Nutrition

Three different measures of nutritional status were considered: BMI, height-for-age (stunting), and weight-for-age. It is important, especially in developing countries, to use multiple measures of nutritional status to gain a clear picture of a situation. One of the most commonly used indices for nutritional status is BMI (de Onis et al. 2007). While BMI is generally adequate for assessing nutritional status of adults, it can be misleading when applied to children. Because BMI is based upon weight relative to height, an individual that is concomitantly underweight or severely underweight and stunted or severely stunted may exhibit a BMI within the normal range. For instance, in Bawa and Nloh BMI measurements suggested that 5.0% (13/261) of the overall population was malnourished or undernourished, 9 adults and 4 children. These data suggest that there are no serious widespread nutritional issues in the village. However, height-for-age indices revealed that 35.2% (45/128) of children and adolescents were stunted, 15.6% (20/128) were severely stunted and 37.9% (25/66) of children 2 to 10 years of age exhibited low weight-for age. Thus it is important to collectively consider a variety of indices when assessing the extent of malnutrition and undernutrition in a population. Stunting tends to result from chronic undernutrition (Caulfield et al. 2006) and/or geohelminth infection (Hotez 2008), whereas wasting is more indicative of acute undernutrition or disease (Caulfield et al. 2006). Low weight-for-age encompasses both stunting and wasting (Caulfield et al. 2006).

Growth retardation may result from malnutrition, undernutrition, and/or infection with geohelminths. Hotez (2008) pointed out that geohelminth infections may represent the world's leading cause of growth retardation and stunting. Caulfield et al. (2006) pointed out that childhood malnutrition diminishes adult intellectual ability and work capacity. This further diminishes the socioeconomic integrity of a community thereby creating a vicious cycle by setting the stage for the likelihood of more malnutrition. Furthermore, Caulfield et al. (2006) pointed out that malnourished women are more likely to deliver premature and small birth-weight babies that are likely to exhibit suboptimal growth and development. Caulfield et al. (2006) projects if malnutrition and undernutrition were eliminated, childhood mortality could be reduced by 53% because undernutrition and malnutrition increases the risk that a child will die as a result of a given disease.

Anemia

Hemoglobin concentration is an indicator of anemia which as pointed out by Crawley (2004) is multi-factorial in origin and may result from malaria, geohelminth infections, and/or malnutrition or undernutrition. Thus, the frequency of anemia in a population may be the most important single measure of the overall health status of a population regarding malaria, geohelminth infection and mal- or undernutrition. Between 2007 and 2010, the prevalence of anemia in Bawa was reduced from 75.8% to 49.1% with a concomitant decrease in prevalence of clinical malaria and decrease in the prevalence and intensity of geohelminth infection. Additionally, the frequency of severe anemia in Bawa has significantly decreased from 3.5% to 0.5%. Although the frequency of anemia actually exhibited a slight increase in Nloh between 2007 and 2010, from 63.8% to 69.4% and the frequency of severe anemia increased from 1.3% to 2.8%, these increases were not significant.

Interventions put in place by BHI have alleviated a substantial degree of the burden of disease among these Cameroonian villages including malaria, diarrheal disease, and geohelminth infection. Although cause for cautious optimism, these data also reflect the degree of work that remains to be done.

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Geographic Distribution and Life History Aspects of the Freshwater Shrimps, *Macrobranchium ohione* and *Palaemonetes kadiakensis* (Decapoda: Palaemonidae), in Arkansas

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Abstract

Two species of shrimps occur in Arkansas; they include the Ohio shrimp, *Macrobrachium ohione* (Smith) and the Mississippi grass shrimp, *Palaemonetes kadiakensis* Rathbun. The present survey is based on collections made between 1974 and 2008 with additional supplemental data from museum specimens to document the overall distribution of the 2 species. Our survey found a total of only 42 specimens of *M. ohione* from 6 localities (2 counties) in Arkansas, all taken from the Mississippi River. Specimens were seined over sandy substrates in 0.6-0.9 m of water without vegetation. A 1914 museum collection of 5 individual *M. ohione* is the only known occurrence of *M. ohione* from Phillips County. All other specimens were taken between 1974-1975 near the US 82 bridge (Chicot County). It appears that *M. ohione* is a relatively rare shrimp in Arkansas. Since specimens were documented from a single drainage system (Mississippi River) in only 2 counties, we recommend a "threatened" conservation status of *M. ohione* in Arkansas because of this restricted distributional range. However, *P. kadiakensis* is relatively abundant in Arkansas. This shrimp had previously been reported from 10 counties of the state. Over 3,400 specimens of *P. kadiakensis* were documented during this study from various sites in 49 counties and most were released upon capture. Grass shrimp were commonly found in sluggish backwater regions of streams especially preferring heavily vegetated lentic areas of pool regions. Mississippi grass shrimp have remained abundant and widespread in occurrence for the past 35 years. The Nature Conservancy lists populations of *P. kadiakensis* as secure (G5) in rounded global status. Indeed, Mississippi grass shrimp populations in Arkansas are also secure and in no need of special protection.

Introduction

Freshwater shrimp are conspicuous members of Arkansas' aquatic macroinvertebrate fauna, and yet, have received little attention. Of the few species that are endemic to or range into the north temperate regions of the Western Hemisphere, only 2 species are known from Arkansas (Bouchard and Robison 1980). These 2 freshwater caridean shrimps are represented by 2 genera in the family Palaemonidae of the crustacean Order Decapoda. In North America, the Palaemonidae includes 68 described species in 16 genera (Williams 1989) and is cosmopolitan in distribution. Caridean shrimps are distinguished from crayfish by possessing 2 pairs of chelipeds while crayfish have 3 pairs as well as major differences in body shape (Bauer 2004).

The Ohio shrimp, *Macrobrachium ohione* (Smith), is migratory, the larger (up to 110 mm total length [TL]) of the 2 species of Arkansas shrimps and was the basis of formerly more extensive food and bait fisheries in the Mississippi River drainage (Hedgpeth 1949). The smaller (up to 53 mm TL) shrimp species native to Arkansas is the Mississippi grass shrimp, *Palaemonetes kadiakensis* Rathbun. This shrimp is often used as fish bait and for fish forage in farm ponds. Because of its limited commercial value, the grass shrimp has been little studied across its range (Cheper 1988). Most published information is new distributional records or range extensions of the species (Cheper 1988, 1992, Taylor 1992, Conaway and Hrabik 1997, Pigg and Cheper 1998, Poly and Wetzel 2002, Cooper 2011).

The Ohio shrimp is endemic to coastal rivers in the central and southeastern U.S., and ranges from Alabama to Texas and is on the northern periphery of its range in Illinois and Ohio (Page 1985). It also occurs along the Atlantic Coast from Florida to Virginia (Page 1985, Taylor 1992). The Mississippi grass shrimp ranges from northeastern Mexico, north to the Great Lakes and east to Florida (Page 1985).

Little is known about the distributional limits of these shrimps in Arkansas and even less about their natural history, ecology, reproduction, habitat characteristics, and general biology. Limited previous collecting of these species is primarily responsible for this lack of knowledge. Surveys of aquatic macroinvertebrates of various parts of the state include collections of *P. kadiakensis* reported by Harp and Harp (1980) in Crittenden County, Cargill and Harp (1987) in Clay County, Cochran and Harp (1990) in Craighead, Greene, and Poinsett counties, Chordas et al. (1996) in Arkansas, Desha, Monroe and Phillips counties, and Harp and Robison (2006) in Lawrence County.

Specific objectives of our study were (1) to determine the relative abundance and precise distributional limits of the range of *M. ohione* and *P. kadiakensis*; (2) to gather data on life history aspects of these shrimp species including information on habitat, reproductive period, and any other biological data available; (3) to document data on ecological and habitat characteristics of these shrimp species; and (4) to assess the current conservation status of *M. ohione* and *P. kadiakensis* based on the collected distributional data.

Materials and Methods

This survey of the shrimps of Arkansas is based on collections that we made between 1974-2008. Collecting methods included the use of conventional seines (3.1 × 1.8 m with 3.2 mm mesh or 6.1 × 1.8 m with 3.2 mm mesh) and standard aquatic dipnets. Most individuals were released unharmed at the collection site; however, representative voucher specimens were preserved in 70% isopropanol and deposited in the invertebrate collection at Southern Arkansas University (SAU), Magnolia. The number of specimens (Appendix) is the number of specimens preserved or the total number found at an individual site.

In addition to our collections, supplemental museum specimens housed at the United States National Museum of Natural History (USNM 2009), Washington, D.C., Illinois Natural History Survey, Champaign, Illinois (INHS 2010), and the G. L. Harp Aquatic Macroinvertebrate Collection, Arkansas State University, Jonesboro, Arkansas (ASUMZ) were used to document the overall distribution of the 2 species in the state. Previous literature dealing with these shrimp species was also consulted. Both our survey data and historical county collection locales were plotted on maps (see Figs. 1-2).

Results and Discussion

Our survey found a total of only 42 specimens of *M. ohione* from 6 localities in 2 counties (Table 1) whereas 3,418 specimens of *P. kadiakensis* from 238 localities in 49 counties (Table 2; Appendix) were documented.

Macrobrachium ohione (Smith, 1874)

Taxonomic Remarks

Holthius (1952) revised the subfamily Palaemoninae from the Americas including all known U.S. species of *Macrobrachium*. There are 6 species of *Macrobrachium* in the U.S. (Bowles et al. 2000); however, only *M. ohione* inhabits the Mississippi River drainage in Arkansas. It is characterized by having the first pairs of legs chelate, the second pair of chelipeds (pereopods 2) longer and more robust than first chelipeds (pereopods 1), the carpus of the second leg not subdivided, a hepatic spine present, and the upper edge of the rostrum curved with 9-13 teeth and a toothless dagger-like tip.

Table 1. Records of 42 *M. ohione* from Arkansas.

County	Locality	Date	Number	Collector	Museum Collection
Chicot	Mississippi River at US 82 bridge	17 Aug. 1974	3	HWR	SAU
	Mississippi River at US 82 bridge near boat landing	9 Jul. 1975	2	HWR	SAU
	Mississippi River, 11.3 km S US 82 bridge, Even Oaks Lodge	10 Jul. 1975	2	HWR	SAU
	Mississippi River, sandbar across from Grand Lake	10 Jul. 1975	25	HWR	ASUMZ 071075A-1
	Mississippi River, 4.8 km N US 82 bridge	11 Jul. 1975	5	HWR	SAU
Phillips	Mississippi River at Helena	1914	5	unknown	USNM 153841

Relative Abundance

It appears that *M. ohione* is a relatively rare shrimp in Arkansas with only 42 specimens from 2 counties (Fig. 1) documented during a collection period spanning nearly 100 years. Since our last collection in July 1975 (Table 1), we have not been able to locate vouchers of this shrimp in any museum collection or collect additional *M. ohione* in the state.

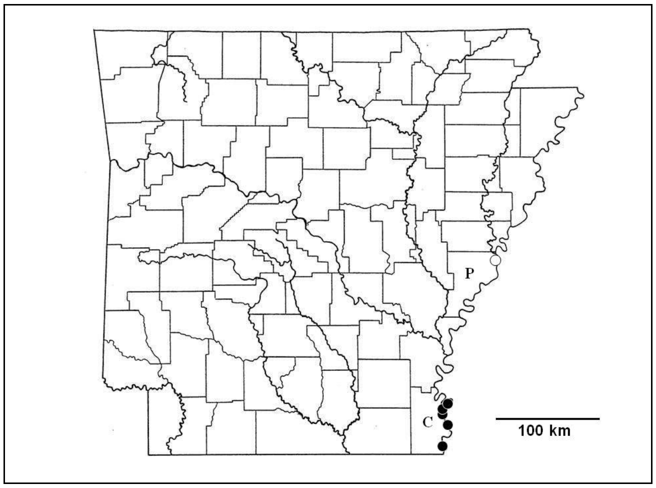

Figure 1. Arkansas counties with genuine vouchers of *M. ohione*. Open dot (previous USNM record); solid dots (new county record). Abbreviations: C (Chicot County); P (Phillips County).

Habitat

Barko and Hrabik (2004) found *M. ohione* occupied open side channels and main channel borders of the Mississippi River in Missouri. Conaway and Hrabik (1997) reported Ohio shrimp occupied low velocity waters; however, open side channels have flow during normal river elevations (Barko and Herzog 2003). They occur in the borders of the river channels, especially when the borders are flooded and plant and animal material are available for foraging (Truesdale and Mermilliod 1979). Hobbs (2001) reported this shrimp receives reproductive cues from spring floods and uses flooded terrestrial habitat for reproduction.

All specimens of *M. ohione* collected in Arkansas were taken from the Mississippi River. Specimens were seined over sandy substrates at depths of 0.6-0.9 m without vegetation. No appreciable current was detected in these areas 6-9 m offshore adjacent to sand bars.

Distribution

The Ohio shrimp was originally described from specimens collected from the Ohio River in Indiana (Smith 1874), and ranged up to the downstream end of Washington County, Ohio; however, there are apparently no recent records, museum or otherwise from those areas. The species occurs in the Mississippi River basin, Gulf Coastal drainages, and also in some Atlantic coast drainages from Georgia north to Virginia (Hedgpeth 1949, Holthius 1952, Hobbs and Massman 1952, Cooper 2011). The Ohio shrimp declined in abundance drastically after the 1930's (Page 1985) especially in the northern areas of its former range (Simon 2001). Less than 10 specimens have been reported from the Ohio River since 1977 (Taylor 1992, Conaway and Hrabik 1997). The species was formerly abundant in the Mississippi River as far north as Chester, Illinois (and possibly St. Louis, Missouri) and in the Ohio River as far upstream as southeastern Ohio (Poly and Wetzel 2002). Thoma and Jezerinac (2000) speculated that *M. ohione* may have been extirpated from Ohio due to migration obstruction by dams, levees and wing dikes. However, *M. ohione* remains abundant in the lower Mississippi River system of southern Louisiana (Truesdale and Mermilliod 1977) and apparently around Jackson, Mississippi (RT Bauer pers. comm.).

The Ohio shrimp has been collected in portions of the Mississippi River along Missouri and Illinois as far north as Grand Tower, Jackson County, Illinois (Taylor 1992, Conaway and Hrabik 1997) indicating that the species was increasing in numbers, was recolonizing portions of its former range, and/or was overlooked earlier because sampling methods were ineffective (Poly and Wetzel 2002).

In Arkansas, *M. ohione* has reportedly been taken from the Arkansas, Mississippi, and Red rivers (Bauer 2011a, fig. 3); however, documentation during this survey indicated occurrence only in the Mississippi River and we know of no recent specimens from any other stream in the state. One collection of 5 individuals was located in the Smithsonian Institution (USNM 153841) from the Mississippi River at Helena, Phillips County, collected in 1914 (Karen Reed, pers. comm.). This represents the only known occurrence from Phillips County (Fig. 1). The other 37 specimens were taken in August 1974 and July 1975 by the first author (HWR) while seining fish in the Mississippi River at various sites in Chicot County (Appendix, Fig. 1). Despite a search of additional regional and national museum collections, no additional specimens of *Macrobranchium* from Arkansas were located. Furthermore, there are only a few specimens of *M. ohione* reported from 3 counties of the Mississippi River of Missouri in the INHS (INHS 2010).

Life History Aspects

All U.S. species of *Macrobrachium* have a life-history pattern that is amphidromous, that is, they spawn in saltwater (optimally 10-15% salinity) and must migrate upstream to complete their life cycles (McDowall 1992, Bauer 2011a,b). Ortmann (1902) hypothesized that the genus *Macrobrachium* had probably only "recently" evolved migratory behavior into freshwater. However, recent estimates suggest radiation of their ancestors into freshwater during the Jurassic (see Bauer 2011a). Biological characteristics indicative of this relatively recent adaptation include high hemoglyph osmo-ionic concentrations, tolerance of high salinities, dependence on saline waters for larval development with many larval stages and migratory behavior (McNamara 1987).

The Ohio shrimp is the least colorful of the 6 species occurring in the U.S. The base color is pale gray to olivaceous with light blue spots and a blue telson and uropod (Hedgpeth 1949).

Ohio shrimp can reach a TL of over 100 mm, but average 60 mm TL (Hunter 1977, Taylor 1992). Males only reach about 70 mm TL (Hedgpeth 1949). The largest *M. ohione* found in our survey was a female measuring 68 mm TL. Females are larger than males with the former being as large as 110 mm TL, although ovigerous specimens as small as 35 mm TL are known (Bowles et al. 2000). To our knowledge, no ovigerous females have ever been collected in Arkansas.

Parasites

Several parasites have been reported from *M. ohione*, including the branchial bopyrid isopod, *Probopyrus pandalicola* Packard from the Atchafalaya and Mississippi rivers, Louisiana (Truesdale and Mermilliod 1977, Conner and Bauer 2010). We did not examine Arkansas *M. ohione* for any parasites.

Conservation Status

The Ohio shrimp has been collected sporadically and rarely over the past 40 years (Page 1985, Conaway and Hrabik 1997). Possible reasons for decline include overharvesting, river channelization, dredging, levee construction, water pollution, and habitat loss (Page 1985, Bowles et al. 2000). This shrimp must have a direct and/or unobstructed connection with estuarine areas (Bueno and Rodrigus 1995). In addition, larvae must be exposed to saline water in order to complete development (Bauer and Delahoussaye 2008, Rome et al. 2009).

The Nature Conservancy suggests that populations of the Ohio shrimp are apparently secure (G4) in rounded global status (NatureServe 2010) but there is no ranking for the species in Arkansas. Since a total of only 42 specimens were documented by seining from a single drainage system (Mississippi River) in only 2 counties of the state, we recommend a "threatened" conservation status for *M. ohione* in Arkansas because of its restricted distributional range. An intensive search for this species along the eastern tier of counties adjacent to the Mississippi River using additional collecting methods (trawling and trapping) is urged in the future, including possible rediscovery of *M. ohione* in Phillips County.

***Palaemonetes kadiakensis* Rathbun, 1902**

Taxonomic Remarks

Palaemonetes kadiakensis is one of 3 members of the genus found in surface streams in the U.S. (Strenth 1976). Three additional species are known from subterranean waters of Florida and Texas. This shrimp can de differentiated from the Ohio shrimp by having the second pair of legs only slightly longer than the first pair, only 6-8 teeth occurring along the upper edge of the rostrum, and possessing a branchiostegal spine, without a hepatic spine.

Relative Abundance

The Mississippi grass shrimp is relatively abundant in Arkansas. A total of 3,415 specimens of *P. kadiakensis* were documented during this study, including 2,901 (85%) deposited in the ASUMZ, and most were released at their collection site.

The entire USNM dataset (31 specimens) comprised only 4 sites in 4 counties (Ashley, Stone, White, and Woodruff) of the state (Appendix). In addition to the USNM collections, INHS data yielded 14 collections (91 specimens) taken from 11 Arkansas counties by various collectors (Appendix).

Habitat

The Mississippi grass shrimp is common in the vegetation of lentic habitats and slower moving streams as well as in the sheltered areas of more rapidly flowing environs below the Fall Line zone in Arkansas (Bouchard and Robison 1980). It has also been found in a rapid flowing tributary of the Sabine River in Louisiana (Bouchard and Robison 1980). However, in Illinois, Page (1985) found that *P. kadiakensis* was common in sluggish freshwater habitats, including backwaters of the Mississippi River and in swamps and swamp-like streams. In addition, Simon and Thoma (2003) documented this shrimp in the Patoka River basin of Indiana in wetland ponds and stream areas adjacent to vernal ponds.

Table 2. ASUMZ records of 2,901 specimens of *P. kadiakensis* from Arkansas.

County[1]	Locality	Date	Number	Collector	ASUMZ Acc. No.
Arkansas[1]	Roadside ditch, St. Hwy. 79, 3.2 km S of Stuttgart	1 May 1978	1	B. Stephens	BS092478A-1
	Crooked Creek off US 79, 11.3 km SW of Pine Bluff	26 Jul. 1982	4	GR. Harp	HP072682-3
	Big Island Chute, White River NWR	18 Nov. 1989	24	S. Chordas	SC 111889-4
	E of Ethel, S entrance to White River NWR	18 Nov. 1989	2	S. Chordas	SC 111889B-5
	Little White Lake, White River NWR	18 Nov. 1989	1	S. Chordas	SC 111889C-4
	Lake Gut, White River NWR	16 Dec. 1989	1	S. Chordas	SC 121689-5
	Burnt Lake, White River NWR	17 Dec. 1989	1	S. Chordas	SC 121789-7
	Hurricane Pond, White River NWR	17 Dec. 1989	18	S. Chordas	SC 121789C-5
	Columbus Lake, White River NWR	20 Jan. 1990	7	S. Chordas	SC 012090-5
	Prairie Bayou, White River NWR	20 Jan. 1990	52	S. Chordas	SC 012090A-6
	H-Lake, White River NWR	20 Jan. 1990	5	S. Chordas	SC 012090B-6
	Prairie Lake, White River NWR	20 Jan. 1990	27	S. Chordas	SC 012090C-7
	Wolf Lake, White River NWR	20 Jan. 1990	16	S. Chordas	SC 012090D-4
	Wolf Bayou, White River NWR	17 Feb. 1990	2	S. Chordas	SC 021790-7
	Honey Locust Bayou, White River NWR	18 Feb. 1990	4	S. Chordas	SC 021890A-6
	Reservoir in SW 1/4, White River NWR	18 Feb. 1990	45	S. Chordas	SC 021890B-3
	H-Landing, White River NWR	22 Jul. 1990	2	S. Chordas	SC 072290A-1
	Wolf Bayou at flood gate, White River NWR	11 Aug. 1990	19	S. Chordas	SC 081190-8
	Beaver Pond No. 1, White River NWR	11 Aug. 1990	8	S. Chordas	SC 081190A-4
	Big Horseshoe Lake, White River NWR	29 Sept. 1990	3	S. Chordas	SC 092990-2
	Escrogens Lake, White River NWR	30 Sept. 1990	75	S. Chordas	SC 093090A-8
	Essex Bayou, White River NWR	30 Sept. 1990	42	S. Chordas	SC 093090-6
Ashley	Lake Georgia Pacific, 19.3 km NW of Crossett	13 Nov. 1988	17	G. Harp	HP111388-4
Bradley	Warren Prairie NA	4 Mar. 1995	1	R. Smith	RS030495-11
Clark	Hollywood Creek at bridge off St. Hwy. 26	20 Feb. 1997	4	C. Davidson	CD022097B-5
Clay[1]	Current River, vic. St. Hwy. 211, 0.3 km S state line	18 Sept. 1976	5	P. Harp	PH091876A-3
	Lake Hubble, 3.2 km W, 1.6 km N of Peach Orchard	14 Jul. 1984	2	G. Harp	HP071484-1
	Sugar Creek off US 49S, Piggott	31 Aug. 1985	1	K. Cargill	KC083185A03
Chicot	Macon Bayou off US 82	12 Nov. 1988	20	G. Harp	HP111288B-2
Cleveland	Saline River at US 79, S of Rison	27 Jun. 1976	12	M. Johnson	MJ112776A-5
	Saline River, 1.6 km N, 4.8 km W of Rison	21 Aug. 1986	12	G. Harp	HP083186-4
Columbia	Lake Columbia, N side of bridge at boat ramp	25 Jan. 1991	2	J. Nichols	JN012591B-1
Craighead[1]	Big Creek, US 63B, Jonesboro	21 Nov. 1976	2	P. Harp	PH112176-3
	6.6 km S of St. Hwy 1	9 Feb. 1981	1	A. Berry	AB020981-3
	3.2 km S Jonesboro off St. Hwy 1, field ditch	2 Mar. 1981	2	A. Price	AP030281D-2
	7.2 km S Jonesboro off St. Hwy. 1, field ditch	2 Mar. 1981	2	A. Price	AP030281C-2
	8.9 km E of Cash, roadside pothole	5 Apr. 1981	3	A. Berry	AB040581B-2
	Big Creek, 4.2 km W jct St. Hwy 141/US 63B	16 Apr. 1981	1	R. Smith	RS 041681-1
	1.6 km S Sedgewick, roadside ditch	5 Mar. 1981	5	A. Price	AP030581-5
	St. Francis River at Lake City	18 Apr. 1981	3	U. Moka	UM041881-5
	Cooper's Pond off Airport Road, Jonesboro	3 Jan. 1983	37	L. Lee	LL030183-3
	Stumpy Riverlake Oxbow, St. Francis SL	22 Aug. 1987	104	B. Cochran	BC 082287C-10
	Cane Donnick Chute, St. Francis SL	22 Aug. 1987	213	B. Cochran	BC 082287D-10
	Gum Island Sawmill, St. Francis SL	19 Sept. 1987	29	B. Cochran	BC 091987-4
	St. Francis River, Lake City Boat Ramp	19 Sept. 1987	27	B. Cochran	BC 091987B-6
	Fletcher Landing, St. Francis River, SFSL	19 Sept. 1987	15	B. Cochran	BC 091287C-6
	Jake Butler Landing, St. Francis SL	19 Sept. 1987	40	B. Cochran	BC 091987D-4
	Cockle-Burr Ditch, St. Francis SL	19 Sept. 1987	9	B. Cochran	BC 091987E-4
	Deep Landing, St. Francis SL	17 Oct. 1987	29	B. Cochran	BC 101787-3
	Lake City boat ramp, St. Francis River, SFSL	23 Mar. 1988	13	B. Cochran	BC032388A-8
	Turkey Island Slough, St. Francis SL	22 Jul. 1988	37	B. Cochran	BC072288C-3
	St. Francis SL, 4.8 km E Lake City bridge	5 Feb. 1993	2	B. Richards	BR 020593A-3
	St. Francis River, E of Lake City bridge	5 Feb. 1993	4	B. Richards	BR 020593-4
	Slough at intersection Washington Ave. and St. Hwy. 18	13 Feb. 1993	18	B. Richards	BR 021393-4
	Jonesboro, jct. Washington Ave. and St. Hwy. 349	15 Feb. 1993	9	J. May	JM 021593-2
	St. Francis River at Lake City	28 Jan. 1995	4	S. Bearden	SB012895-4
	1.0 km S Sedgewick, slough at US 63 bridge	2 Apr. 1995	4	B. Posey	BP040295A-3
	ASU Pavilion Pond, Jonesboro	2 Apr. 1999	1	L. Morris	LM040299-1
Crittenden[1]	Borrow pit, Wapanocca NWR	24 May 1977	4	P. & G. Harp	PH052477A-7
	NW corner Woody Pond 2, Wapanocca NWR	11 Aug. 1977	6	P. & G. Harp	PH081177B-6
	Levee borrow pit, Wapanocca NWR	29 Oct. 1977	3	P. & G. Harp	PH102977A-5
	NW corner Woody Pond 1, Wapanocca NWR	28 Jul. 1978	4	P. & G. Harp	PH072878-3
	Unnamed slough, 8.0 km E of Marion	22 Oct. 1978	2	R. McDaniel	MC102278-1
	Wapanooca Lake NWR, observation platform	25 Mar. 1993	5	B. Richards	BR 032593A-3

Table 2. *continued.* ASUMZ records of 2,901 specimens of *P. kadiakensis* from Arkansas.

Cross	4.0 km S Cherry Valley, roadside ditch off St. Hwy. 1	1 Mar. 1981	1	A. Berry	AB030181-2
	NE corner of Village Creek SP	19 Mar. 1983	4	J. Reid	JR031983A-4
	0.2 km S of Fair Oaks off US 49	10 Jan. 1987	2	M. Marks	MM011687-1
Desha[1]	Slough at picnic area off US 65, McGehee	12 Nov. 1988	1	G. Harp	HP111288A-1
	Scrubgrass Bayou No. 1, White River NW	21 Apr. 1990	2	S. Chordas	SC 042190-6
	Scrubgrass Bayou No. 2, White River NWR	21 Apr. 1990	5	S. Chordas	SC 042190A-3
	East Moon Lake, White River NWR	22 Apr. 1990	8	S. Chordas	SC 042290A-4
Drew	Lake on UA-Monticello campus	11 May 1978	6	R. McDaniel	MC051178-2
	Seven Devils Swamp, E side, 4.8 km N of Collins	14 Apr. 1983	6	G. Harp	HP061483-2
	Seven Devils Swamp, W of dam, 2.6 km NW of Collins	14 Apr. 1983	2	G. Harp	HP061483A-2
	Saline River, Ozment Bluff Access, 2.4 km W St. Hwy. 8	14 Sept. 1993	1	B. Richards	BR 0901493E-1
Faulkner	East Fork Cadron Creek	7 Feb. 1981	1	J. Farris	JF020781-3
	Caney Creek, Conway	7 Feb. 1981	6	J. Farris	JF020781A-3
Greene[1]	Lake at Crowley's Ridge State Park	14 Jun. 1976	8	P. Harp	PH061476
	St. Francis River bridge at AR/MO state line	21 Apr. 1981	9	J. Dunivan	JD041281-2
	St. Hwy 69, roadside ditch along dirt road	20 Feb. 1983	4	L. Lee	LL022083-4
	Blue Hole Oxbow, SFSL	22 Aug. 1987	74	B. Cochran	BC 082287A-6
	Blue Hole exit, SFSL	22 Aug. 1987	27	B. Cochran	BC 082287B-9
	Lake Walcott, SE & E shoreline	10 Feb. 1991	1	P. Rust	PR 021091-1
	Lake Frierson overflow	23 Apr. 1993	1	J. May	JM 042393-1
Independence	Salado Creek at St. Hwy. 14 bridge	23 Feb. 1981	12	A. Carter	AC022381C-2
	Caney Creek at US 167, S of Batesville	7 Mar. 1987	2	G. & P. Harp	WN030787-2
Jackson	Village Creek S of Alicia	9 Oct. 1976	9	T. Burnham	TB100976B-3
	Village Creek off US 67, vic. Tuckerman	9 Oct. 1976	7	T. Burnham	TB100976C-2
	Village Creek at St. Hwy 14	9 Oct. 1976	315	M. Johnson	MJ 100976D-3
	Sewage lagoon, off St. Hwy. 18 in Grubbs	3 Jun. 1978	2	B. Stephens	BS110378A-1
	Swifton, 0.2 km E US 67	30 Jan. 1983	1	J. Reid	JR013083A-4
	4.8 km W Tuckerman off St. Hwy. 226, Hout Ditch	27 Feb. 1983	4	J. Reid	JR022783-4
	1.6 km S St. Hwy. 226, ditch	7 Mar. 1983	10	J. Reid	JR030783-3
	Cache River at St. Hwy. 14	22 Apr. 1989	3	S. Sifford	SS042289-1
	New Home Community, 7.2 km NW of Swifton	31 Jan. 1991	2	A. Holt	AH013191-2
	4.8 km NW Swifton off New Home Road	2 Feb. 1991	3	A. Holt	AH020291-4
	Tupelo Brake, 4.0 km N int. St. Hwy. 18/384	10 Mar. 1993	10	B. Richards	BR 031093-2
	Cache River at St. Hwy. 18, E of Grubbs	7 Mar. 1993	8	J. May	JM 030793-4
	Black Roll Creek, vic. Swifton	10 Apr. 1995	2	R. Smith	RS041095A-1
Jefferson	Bayou Bartholomew at US 79, S of Pine Bluff	27 Jun. 1976	25	M. Johnson	MJ112776B-1
	Borrow Pits N & S of US 79, jct. St. Hwy. 88	26 Jul. 1982	2	GR. Harp	HP072682A-3
Lawrence[1]	Village Creek, 1.6 km S Alicia off section road	23 Mar. 1974	28	G. Harp	GH-32374B-4
	Village Creek at St. Hwy. 37 bridge, Guffey Lake	23 Mar. 1974	18	G. Harp	GH032374C-4
	Village Creek at St. Hwy. 14 bridge	23 Mar. 1974	2	G. Harp	GH032374D-2
	Village Creek at Minturn	9 Oct. 1976	1	S. Bounds	SB100976-7
	Village Creek off St. Hwy. 37, E of Tuckerman	9 Oct. 1976	1	S. Bounds	SB100976C-1
	Portia Bay at US 63	19 Nov. 1976	2	S. Bounds	SB111976-4
	Hill Slough, Raney Brake WMA	3 Apr. 1981	2	U. Moka	UM040381-2
	Black River, Big Eddy, 9.7 km E of Lynn	3 Apr. 1981	3	J. Ferris	JF040381B-1
	Horseshoe Lake, Raney Brake WMA, SE of Lynn	3 Apr. 1981	2	J. Ferris	JF040381C-3
	Red Barn Creek, Raney Brake WMA	3 Apr. 1981	1	R. Smith	RS04031A-3
	Dry Creek, 2.4 km SE of Lynn, Raney Brake WMA	3 Apr. 1981	2	A. Price	AP040381-b
	Coon Creek at St. Hwy. 25, 1.1 km W of Walnut Ridge	26 Mar. 1983	31	G. Harp	HP032683D-2
	Strawberry River, 0.5 km N St. Hwy. 115	16 Jan. 1987	1	M. Marks	MM011687A-1
	Lake Charles at St. Hwy. 25	24 Jan. 1993	11	B. Richards	BR 012493B-2
	Slough at Shirley Bay Raney Brake WMA	20 Feb. 1993	6	J. May	JM 022093B-5
	Black River at St. Hwy. 25, Powhatan Landing	4 Feb. 1995	1	S. Bearden	SB020495-2
	Ditch N of Sedgwick off US 63	20 Feb. 1997	6	M. Barfield	MB022097A-1
Lee	Borrow pits near L'Anguille River at St. Hwy. 1	25 Mar. 1989	14	M. Harvill	MH032589A-5
	Bayou off US 79, 8.0 km W of Moro	18 Mar. 1995	1	S. Bearden	SB031895-6
Lincoln	Arkansas River backwater, Lock & Dam 3, USACE	1 Sept. 1986	34	G. Harp	HP090186-5
	Long Lake at St. Hwy. 11, 12.9 km N of Grady	1 Sept. 1986	3	G. Harp	HP090186A-2
Logan	Blue Mountain Lake, Hise Hill Use Area	2 Sept. 1984	8	G. Harp	HP090284-2
	Petit Jean River at St. Hwy. 23, 1.6 km S of Booneville	2 Sept. 1984	2	G. Harp	HP090284A-2
Lonoke	White Oak Branch (Sec. 26, T4N, R10W)	8 Feb. 1981	8	J. Farris	JF020881A-2
	Magness Creek off St. Hwy. 319, W edge of Ward	13 Aug. 1983	6	G. Harp	HP081383-2
	Prairie Creek at St. Hwy. 5	3 Mar. 1989	1	B. Justis	BJ030389-3
Mississippi	Mississippi River channel at island, vic. Luxora	14 May 1977	2	N. Childers	NC051477-1
	Big Lake, Big Lake WMA	2 Sept. 1978	7	J. Rettig	JR090278-1
	Butterfly Hole, Mississippi River levee, 3.2 km N of Tomato	27 Jan. 1981	2	A. Carter	AC012781A-4
	Lee's Pond, Mississippi River levee, 0.4 km E of Tomato	27 Jan. 1981	8	A. Carter	AC012781B-1
	Big Lake WMA, below bridge off St. Hwy. 18	5 Feb. 1993	7	B. Richards	BR 020593B-5

Table 2. *continued* ASUMZ records of 2,901 specimens of *P. kadiakensis* from Arkansas.

Monroe[1]	Waters Bayou at White River NWR	13 Oct. 1989	1	S. Chordas	SC 101389-2
	Swan Lake, White River NWR	14 Oct. 1989	21	S. Chordas	SC 101489-2
	Buck Lake, White River NWR	14 Oct. 1989	25	S. Chordas	SC 101489A-1
	Little Moon Lake, White River NWR	14 Oct. 1989	4	S. Chordas	SC 101489B-4
	Indian Bayou at St. Hwy. 1 bridge, White River NWR	14 Oct. 1989	15	S. Chordas	SC 101489C-4
	Indian Bay boat ramp, White River NWR	18 Nov. 1989	2	S. Chordas	SC 111889A-1
Nevada	St. Hwy. 24 and Caney Creek	25 Feb. 1995	6	P. Daniel	PD022595E-2
Ouachita	Freeo Creek at St. Hwy. 7	25 Jun. 1976	4	M. Johnson	MJ112576B-3
	Berg Lake, N side St. Hwy. 4B, W edge of Camden	27 Jul. 1982	2	GR. Harp	HP072782A-2
	Tates Bluff bridge, Ouachita River, off St. Hwy. 24	24 Feb. 1995	3	P. Daniel	PD022495B-4
Phillips[1]	Storm Creek Lake overflow	2 Apr. 1993	2	B. Richards	BR 040293-3
	Storm Creek, below Storm Creek Lake	2 Apr. 1993	1	J. May	JM 040293A-5
	Borrow Pit at refuge levee mile 36, White River NWR	22 Apr. 1990	6	S. Chordas	SC 042290B-5
	Borrow Pit No. 2, White River NWR	15 Sept. 1990	1	S. Chordas	SC091590A-5
Poinsett[1]	St. Francis River at ditch 23, 2.4 km E of Trumann	16 Jan. 1981	2	U. Moka	UM 011681-6
	Greenfield, off St. Hwy. 1, roadside ditch	20 Feb. 1983	17	L. Lee	LL022083B-3
	County Line Public Access, St. Francis River, SFSL	17 Oct. 1987	251	B. Cochran	BC 101787A-11a
	Steven's Landing, St. Francis River, SFSL	10 Oct. 1987	42	B. Cochran	BC 101787B-20
	Snoden's Field Bridge, St. Francis River, SFSL	10 Oct. 1987	123	B. Cochran	BC 101787C-13
	Oak Donnick Gage, St. Francis River, SFSL	21 Oct. 1987	20	B. Cochran	BC112187-6
	Railroad trestle at jct. 2 main channels, SFSL	21 Nov. 1987	4	B. Cochran	BC112187A-2
	Ditch 61, SFSL	21 Nov. 1987	8	B. Cochran	BC112187B-2
	Siphon Access, St. Francis River, SFSL	21 Nov. 1987	2	B. Cochran	BC112187C-2
	E end Ditch 10, SFSL	21 Nov. 1987	97	B. Cochran	BC112187D-4
	Main channel St. Francis River, E of Steven's Landing	23 Dec. 1987	5	B. Cochran	BC1222387-5
	St. Francis Lake, SFSL	23 Dec. 1987	12	B. Cochran	BC122387B-8
	Temporary stream, W of Snoden's Bridge, SFSL	26 Apr. 1988	3	B. Cochran	BC042688A-12
	Old River bank, St. Francis River, SFSL	20 Jun. 1988	17	B. Cochran	BC062088-10
	Oxbow, SFSL	20 Jun. 1988	2	B. Cochran	BC062099A-10
	Oak Donnick Chute, SFSL	22 Jun. 1988	11	B. Cochran	BC062288B-6
	Levee Milepost #50/51, SFSL	18 Jul. 1988	16	B. Cochran	BC071888-5
	Landing Strip N, SFSL	22 Jul. 1988	138	B. Cochran	BC072288A-10
	Pumping station, St. Francis River, SFSL	22 Jul. 1988	2	B. Cochran	BC072288B-1
	S shore of Lake Poinsett near boat ramp	20 Jan. 1991	2	P. Rust	PR012091-3
	Lake Poinsett overflow pool, below dam	21 Jan. 1993	2	B. Richards	BR 013193B-2
	0.8 km W Wiener, rice field pond	27 Feb. 1995	2	P. Daniel	PD022795A-2
Prairie	Cache River, 8.0 km S of Little Dixie	30 Aug. 1993	2	B. Richards	BR 083093C-1
Pulaski	Faulkner Lake, 1.6 km E of Protho Jct	23 Apr. 1981	1	A. Carter	AC042381-5
	Pinnacle Mountain SP	11 Feb. 1995	1	S. Clem	SC021195-2
	Bringle Creek downstream of St. Hwy. 10 bridge	30 Jan. 1997	2	C. Davidson	CD013097A-3
Randolph	Little Ditch off US 67, between Pocahontas/Fourche Creek	28 Feb. 1976	2	S. Bounds	SB022876-2
	Fourche River at US 67	17 Sept. 1976	8	M. Johnson	MJ091776-3
	Mill Creek, Pocahontas	5 Jun. 1977	1	N. Childers	NC110577B-3
	1804 Decker Street, pond	3 Mar. 1981	7	A. Price	AP030381-3
	Village Creek near St. Hwy. 90 bridge	6 May 1988	29	R. Looney	RL100688-1
	Fourche River, near St. Hwy. 328 bridge	27 Jan. 1991	5	P. Rust	PR012791-3
	Fourche Creek at St. Hwy. 115 bridge	27 Mar. 1993	5	B. Richards	BR 0327980-3
	Black River at Old Davidsonville SP	8 Feb. 1999	2	D. Feldman	DF020899-1
Saline	Saline River off US 67, Benton	24 Sept. 1978	6	K. Paige	KP092478-4
	Borrow pits near Saline River off I-30	24 Sept. 1978	10	L. Dorman	LD092478-2
Sharp	Martin Creek off St. Hwy. 63	11 Mar. 1983	1	L. Lee	LL031183B-4
St. Francis	County road bridge, 1.6 km S end St. Hwy. 261	2 Apr. 1993	2	B. Richards	BR 053093C-1
Union	Sandy Creek bridge between St. Hwys. 160 & 172	25 Mar. 1995	7	P. Daniel	PD032595C-5
White	Little Mingo Creek at US 64, 4.8 km E of Bald Knob	12 Apr. 1983	4	A. Price	AP041283A-3
	Big Creek near Letona	14 Feb. 1987	16	P. McLarty	PM021487-4
	Unknown stream entering Little Lake, N of Russell	12 Mar. 1993	6	B. Richards	BR 031293-4
	Mile marker 62, off US 67	12 Mar. 1993	6	J. May	JM 031393-4
	Hurricane Lake WMA	29 Feb. 1997	1	R. Mitchell	RM022997-1
Woodruff	Black Swamp, Cache River	30 Sept. 1978	6	L. Dorman	LD093078-3
	Cache River, Black Swamp area	30 Sept. 1988	16	R. Meurer	RM093078-5
Yell	Petit Jean River at St. Hwy. 10, Danville	1 Sept. 1984	4	G. Harp	HP090184A-01

[1]Records for these counties previously published (Harp and Harp 1980, Cargill and Harp 1987, Cochran and Harp 1990, Chordas et al. 1996, Harp and Robison 2006.)

Creaser (1932) reported high abundance of *P. kadiakensis* in pools with low fish abundance. Grass shrimp like high visibility and low water velocity (Barko and Hrabik 2004). In large rivers *P. kadiakensis* can be found associated with low velocity waters (Hobbs and Jass 1988). In an Oklahoma study, Pigg and Cheper (1998) found *P. kadiakensis* inhabiting large rivers, large turbid impoundments, and small turbid ponds filled with aquatic vegetation in the flood plains of large rivers or new pools and bar ditches filled by recent floodwaters.

In the present study, grass shrimp were commonly found in sluggish backwater regions of Coastal Plain streams especially in heavily vegetated lentic areas of pool regions. They appear to have an association with American lotus (*Nelumbo lutea*), swamp smartweed (*Polygonum hydropiperoides* var. *opelosanum*), water milfoil (*Myriopyllium* sp.) and marsh mermaidweed (*Proserpinacea palustris*), abundant aquatic plants of lowland streams. Page (1985) also found *P. kadiakensis* almost always associated with living aquatic vegetation. Occasionally, they were found in backwater reaches of larger rivers of the state, but generally occurred in smaller stream systems.

Distribution

Palaemonetes kadiakensis is commonly found below the Fall Line zone in the Gulf Coastal Plain (GCP) physiographic province of Arkansas, but ascends the Arkansas River Valley continuing west along the Arkansas River into eastern Oklahoma to LeFlore and Sequoyah counties and beyond (Cheper 1988, Pigg and Cheper 1998). By far, the 2,901 specimens of *P. kadiakensis* from the 193 individual collection sites of 39 counties housed in the ASUMZ (Table 2) added many new localities to the overall geographic distribution of *P. kadiakensis* in the state (Fig. 2).

During our study, 45 new collections of the Mississippi grass shrimp were documented (see Appendix). Of the total Mississippi shrimp collections, *P. kadiakensis* was found at 238 localities (Table 2; Appendix) in 49 of 75 counties (65% of Arkansas counties). While numerous new localities for *P. kadiakensis* were documented, most were located where they might be expected in the GCP of Arkansas; however, this shrimp was noticeably absent in most counties of the Ouachita and Ozark plateaus (Fig. 2).

Interestingly, a collection in 1972 of 15 specimens (USNM 237816) was made by an individual signified only by “jH” in North Sylamore Creek near Fifty-six, Stone County, Arkansas. This represents the farthest range penetration of *P. kadiakensis* into the Interior Highlands (Ozark Mountains) within the state (Fig. 2). The farthest upstream collections in the Arkansas Valley physiographic province are in Crawford and Sebastian counties (Fig. 2; Appendix).

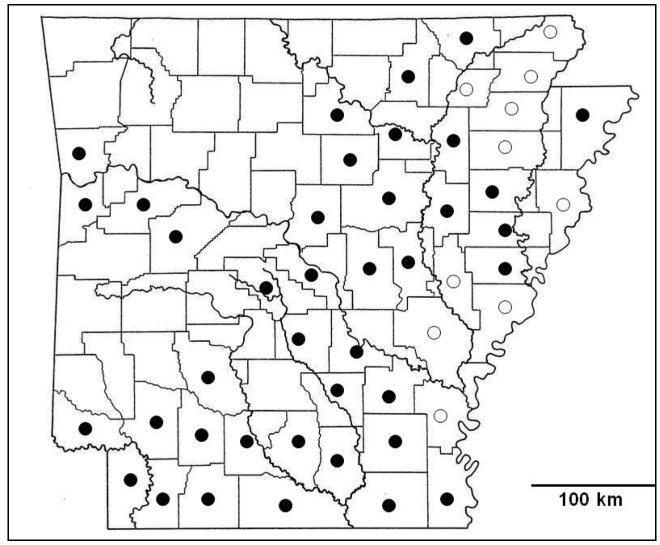

Figure 2. Arkansas counties with genuine vouchers of *P. kadiakensis*. Open circles (10 previous records); closed circles (39 new county records).

Life History Aspects

Life history of *P. kadiakensis* has been studied in Louisiana by Meehan (1936), in Missouri by Nielsen and Reynolds (1977) and in Wisconsin by Hobbs and Jass (1988). These studies indicated that shrimp reproduction occurs from May through August with a peak in mid-June. In Illinois, reproduction occurs from April-August. In Louisiana, reproductive period extends from February-October (Meehan 1936, White 1949), while in Missouri it is from May-August (Nielsen and Reynolds 1977). In Arkansas, our studies indicate reproduction occurs from April through July. The post-reproductive individuals die, and the larvae grow rapidly, obtaining 50% of their ultimate length in the first 3 months of life (Nielsen and Reynolds 1977). Mississippi grass shrimp populations in Arkansas seem to be made up of individuals that hatch in the summer, grow during the autumn months, survive the winter, and then reproduce and die in the late spring to early fall, thus having only a 1-yr life cycle, similar to that reported by Cheper (1992) in Oklahoma.

Living specimens are transparent with green eyes, red brown antennae, and many very small red-brown specks on the body. Often, a bright green vegetation-filled intestine is apparent (Page 1985).

Mississippi grass shrimp are reported to reach a TL of 53 mm in Louisiana (Meehan 1936), whereas Cheper (1988) reported a 46 mm TL specimen from Oklahoma. In our study, the smallest specimen was 13 mm TL and the largest 32 mm TL. Females were generally slightly larger than males while gravid females were much larger. Sex ratio of *P. kadiakensis* collected in our survey was 1♂:1.9♀. Ovigerous females were collected in April through July and eggs (embryos) on 12 females ranged from 38-141 (mean = 67.7). Also see Anderson (1985) for additional reproductive information.

Parasites

Unfortunately, we did not survey Arkansas *P. kadiakensis* for parasites. However, the digene *Alloglossidium renale* Font and Corkum has been reported from the antennary gland of *P. kadiakensis* from the Mississippi River of Louisiana (Carney and Brooks 1991) and Pike County, Alabama (Landers and Jones 2009). In addition, a ciliophoran (*Lagenophrys verecunda*) was described from the gill lamellae of *P. kadiakensis* from Lake Jackson, Florida (Felgenhauer 1982) and aquatic fungi (*Saprolegnia parasitica* and *Achlya flagellata*) infected laboratory-reared larval *P. kadiakensis* (Hubschman and Schmidt 1969).

Conservation Status

Page (1985) attributed the reduction in distribution and abundance of *P. kadiakensis* in Illinois to increased turbidity and sedimentation and the resultant loss of vegetation. In Arkansas, however, Mississippi grass shrimp have remained abundant and widespread in occurrence for the past 35 years. The Nature Conservancy lists populations of *P. kadiakensis* as secure (G5) in rounded global status. Indeed, Mississippi grass shrimp populations in Arkansas appear secure and in no need of special protection.

Acknowledgments

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APPENDIX. Locations of 514 specimens of *Palaemonetes kadiakensis* collected in Arkansas during this survey (locality [township, section and range or latitude/longitude in decimal degrees when available, as estimated from collection locations], date of collection, collector [all by HWR unless otherwise noted], museum collection, and number of specimens in parentheses, if known).

ARKANSAS (514 specimens)

ASHLEY COUNTY (12 specimens)

1. Hank's Creek, 0.6 km W of jct. of US 82 & St. Hwy. 52 on St. Hwy. 52. 1 May 1992. B. Burr. USNM 260374 (3).
2. Thompson Creek, 11.3 km NW of Crossett (Sec. 11, T18S, R9W). 23 Sept. 1994. SAU (9).

BRADLEY COUNTY (50 specimens)

1. Moro Creek at Moro Bay State Park (Sec. 21, T16S, R12W). 17 Oct. 1998. SAU (17).

2. Snake Creek at Broad (Sec. 30, T16S, R9W). 17 Jun. 2002. SAU (5).
3. L'Aigle Creek at co. rd., 14.5 km S of Hermitage (Sec. 18, T16S, R10W). 10 Jul. 2005. SAU (28).

COLUMBIA COUNTY (80 specimens)
1. Dorcheat Bayou at co. rd., 4.8 km SW of Philadelphia (Sec. 16, T18S, R22W). 4 Sept. 1993. SAU (23).
2. Big Creek at St. Hwy. 98, 6.4 km S of Village (Sec. 3, T18S, R19W). 5 Nov. 1993. SAU (13).
3. Sloan Creek at St. Hwy. 57 (Sec. 11, T16S, R19W). 5 Nov. 1993. SAU (29).
4. Horsehead Creek at US 19, 12.9 km SW of Magnolia (Sec. 32, T18S, R21W). 21 Nov. 2001. SAU (4).
5. Dorcheat Bayou at St. Hwy. 160, 6.4 km E of Taylor (Sec. 9, T19S, R22W). 19 May 2004. SAU (11).

CALHOUN COUNTY (6 specimens)
1. 1.0 km W of Locust Bayou. 8 Apr. 1982. L. Page, M. Retzer, R. Mayden, & D. Swofford. INHS 51 (6).

CHICOT COUNTY (3 specimens)
1. Crooked Bayou at St. Hwy. 82 (Sec. 22, T17S, R3W). 10 Sept. 1976. SAU (3)

CLARK COUNTY (14 specimens)
1. Tupelo Creek at St. Hwy. 7 bridge (Sec. 35, T7S, R19W). 20 Oct. 1978. SAU (14).

CLEBURNE COUNTY (6 specimens)
1. Tributary of Little River, 9.0 km W of Hiram on Cooter Neck Rd. (35.47417°N, 91.96686°W). 29 Oct. 2008. B. Wagner & S. Sanders. INHS 11089 (6).

CLEVELAND COUNTY (2 specimens)
1. Panther Creek at US 79, 1.6 km NE of Kingsland (Sec. 6, T10S, R11W). 13 Oct. 1977. SAU (2).

CRAWFORD COUNTY (7 specimens)
1. Crooked Slough, 2.6 km SE of Dyer (35.47335°N, 94.11531°W). 5 Dec. 2007. B. Wagner & S. Sanders. INHS 11028 (7).

DREW COUNTY (20 specimens)
1. Bayou Bartholomew, 3.2 km W of Winchester at St. Hwy. 138. 8 Apr. 1988. B. Burr & D. Fletcher. INHS 8499 (8).
2. Cut-Off Creek at St. Hwy. 35, 1.1 km E of Collins (Sec. 31, T13S, R4W). 13 Apr. 1993. SAU (12).

GRANT COUNTY (6 specimens)
1. Cane Creek, 16.9 km NNE of Sheridan on co. rd. 58 (34.4458°N, 92.3205°W). 21 Sept. 2001. B. Wagner & M. Miller. INHS 9266 (6).

HEMPSTEAD COUNTY (30 specimens)
1. Bois d'Arc Creek, 3.2 km SW of jct. St. Hwys. 73/195 (Sec. 13, T12S, R26W). 26 Nov. 1995. SAU (30).

INDEPENDENCE COUNTY (12 specimens)
1. Mud Creek S of Newark at Neark Energy Plant (35.68015°N, 91.42883°W). 29 Nov. 2006. B. Wagner & M. Kottmyer. INHS 10795 (12).

JEFFERSON COUNTY (24 specimens)
1. Drainage from Yellow Lake at Pine Bluff Arsenal (Sec. 35, T4S, R10W). 9 Oct. 1999. SAU (24).

LAFAYETTE COUNTY (69 specimens)
1. Bayou Bodcau, 1.6 km N of Lewisville (Sec. 7, T15S, R23W). 5 Jul. 1992. SAU (18).
2. Bayou Bodcau off US 82 (Sec. 7, T16S, R23W). 11 Oct. 1995. SAU (31).
3. Bayou Dorcheat, 1.3 km E of Buckner off US 82 bridge (35.35907°N, 93.41778°W). 25 Oct. 1993. J. Rader. INHS 10999 (20).

LINCOLN COUNTY (6 specimens)
1. Bayou Bartholomew at St. Hwy. 293, 12.9 km E of Star City (Sec. 15, T9S, R6W). 7 Nov. 1974. SAU (6).

LITTLE RIVER COUNTY (14 specimens)
1. Cypress Creek at St. Hwy. 234 in Winthrop (Sec. 7, T11S, R31W). 6 Jun. 1989. SAU (5).
2. Little River backwater at US 71, 3.2 km N of Wilton (Sec. 24, T11S, R29W). 5 Oct. 2001. SAU (9).

MILLER COUNTY (15 specimens)
1. Roadside ditch at Boggy Creek off US 71, 3.2 km S of Fouke (Sec. 33, T17S, R27W). 23 Sept. 1976. SAU (15).

NEVADA COUNTY (47 specimens)
1. Terre Rouge Creek, 11.3 km SE of Prescott on St. Hwy. 24 (Sec. 3, T12S, R22W). 20 Oct. 1983. SAU (22).
2. Middle Creek, 14.5 km N of Prescott on St. Hwy. 19 (Sec. 27, T9S, R23W). 21 Oct. 1983. SAU (9).
3. Caney Creek, 4.8 km N of Bluff City on St. Hwy. 24 (Sec. 22, T11S, R20W). 21 Oct. 1983. SAU (16).

OUACHITA COUNTY (7 specimens)
1. Flooded roadside ditch, 1.7 km N of Amy (Sec. 35, T11S, R17W). 9 Oct. 1978. SAU (7).

PULASKI COUNTY (2 specimens)
1. Fourche Creek, 3.2 km W of Mabelvale (34.6561°N, 91.4234°W). 18 Oct. 2002. B. Wagner et al. INHS 9287 (2).

SALINE COUNTY (5 specimens)
1. Otter Creek, 6.0 km WSW of Mabelvale on Alexander Rd. (34.6408°N, 92.4122°W). 18 Oct. 2002. B. Wagner & F. Leone. INHS 10931 (4).
2. Lorance Creek, 4.8 km. WSW of Iron Springs on Chicot Rd. (34.5805°N, 92.3666°W). 23 Oct. 2003. B. Wagner. INHS 9362 (1).

SEBASTIAN COUNTY (4 specimens)
1. 11.3 km N Greenwood, tributary of Grayson Creek (35.31623°N, 94.27109°W). 28 Nov. 2007. B. Wagner & F. Leone. INHS 10931 (4).

STONE COUNTY (15 specimens)
1. North Sylamore Creek at Fifty-six. 6 Sept. 1972. "Jh." USNM 237816 (15).

UNION COUNTY (35 specimens)
1. Smackover Creek at co. rd. 68, 3.2 km N of Norphlet (Sec. 3, T16S, R15W). 20 Sept. 1992. SAU (9).
2. Grand Marais Lake at Felsenthal (Sec. 16, T19S, R10W). 18 Sept. 1996. SAU (12).
3. Ouachita River backwater at US 167 (Sec. 10, T16S, R14W). 26 May 1997. SAU (14).

WHITE COUNTY (15 specimens)
1. Tributary of Overflow Creek, 2.3 km SE of Bald Knob (35.29253°N, 91.55329°W). 1 Oct. 2008. B. Wagner & S. Sanders. INHS 11076 (6).
2. Little Mingo Creek, 6.0 km ESE of Bald Knob at US 64 bridge (35.29654°N, 91.50343°W). 21 Oct. 2008. B. Wagner & S. Sanders. INHS 11091 (4).
3. Pumpkin Branch, 13.4 km NW of Bald Knob off St. Hwy. 157 (35.39145°N, 91.67546°W). 18 Nov. 2008. B. Wagner. INHS 11082 (5).

WOODRUFF COUNTY (8 specimens)
1. Fair Oaks off US 64, 3.2 km W of St. Hwy. 39. 14 Apr. 1973. H. H. Hobbs, Jr. USNM 149827 (8).

The Fishes of Crooked Creek (White River Drainage) in Northcentral Arkansas, with New Records and a List of Species

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Abstract

A survey of the fishes of Crooked Creek, White River Drainage, in northcentral Arkansas was conducted using personal collections, historical records, literature records, and the Arkansas Fishes Database. The study revealed a total of 65 species of fishes distributed among 14 families. Earlier records of only 36 species in 10 families were documented. This study documents a total of 29 species and four families as new to the Crooked Creek stream system. In addition, no endangered or threatened species were collected.

Key Words: Crooked Creek; White River; northcentral Arkansas; fishes; Arkansas Fishes Database; ichthyofauna; Smallmouth Bass.

Introduction

Crooked Creek is hailed state and region-wide as a premier Smallmouth Bass (*Micropterus dolomieu*) stream in Arkansas by area fishermen, local and state media, Arkansas Department of Parks and Tourism, and the Arkansas Game and Fish Commission (AG&F). Ironically, the fishes of this well-known stream are poorly documented and no study, to date, has been attempted specifically aimed at elucidating the ichthyofauna of Crooked Creek. In this study, we assembled a list of the fishes of Crooked Creek from our personal collections of this system over the past 30 years, collections of several state ichthyologists and fishery biologists, previous literature citations, museum collection records, and historical collections contained in the Arkansas Fishes Database (AFD), the files of which are maintained by the AG&F. In addition, we recently collected fishes from Crooked Creek to further document the ichthyofauna of this Ozarkian system.

Materials and Methods

Survey Methods

Documentation of the fishes of Crooked Creek was accomplished by a combination of previous collections of fishes from the system by the authors and several state ichthyologists and fishery biologists, museum specimens, literature records based on previous collections from Crooked Creek, and fish records housed in the AFD. Collecting gear included the use of seines, hook and line, and a boat electrofisher and backpack electroshocker in an effort to use various methods of capture. Collections in riffles and runs were primarily made using a 3.1 × 1.8 m seine with 3.2 mm mesh, whereas in wider pool regions, a 6.1 × 1.8 m seine with 3.2 mm mesh was utilized extensively. In addition, boat and backpack electrofishing was accomplished under the auspices of the AG&F. Power settings using an ETS boat electrofisher was DC current 504 volts, 14 amps peak, and 60 cycles/sec, and those with an LR24 Smith-Root model backpack electroshocker was 60 hz, 25% duty, and 300 volts.

Voucher specimens were preserved in the field with 10% formalin and later placed in 45% isopropyl alcohol for permanent storage in the fish collections at Southern Arkansas University (SAU) and the University of Arkansas at Fort Smith (UA-FS). Scientific and common names follow those of Robison and Buchanan (1988) or Nelson et al. (2004).

Study Area

The Ozark region of northern Arkansas is one of the most faunistically rich sections of the United States (Robison and Beadles 1974). Within this area, the White River drainage supports a tremendous diversity of fish species (see Robison and Buchanan 1988). Crooked Creek is a nationally known spring-fed, upland White River tributary stream located on the Ozark Plateau of northcentral Arkansas (Daly et al. 2002). It originates near Marble Falls in Newton County and flows north and east for nearly 130 km

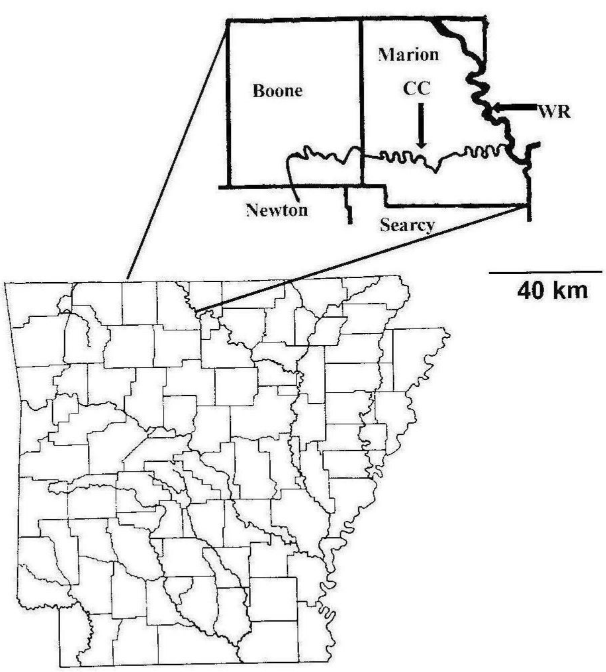

Figure 1. Location of Crooked Creek in northcentral Arkansas. Abbreviations: CC = Crooked Creek; WR = White River.

through Boone County, and continues east across Marion County to join the White River just below the city of Cotter (Fig. 1). The clear upper section of the stream flows through oak-hickory forests and cedar glades and is characterized by shallow rocky pools separated by swift, gravelly riffles. The lower portion consists of larger pool regions (up to 25 m wide), some with emerged, large boulders in the pool regions as it winds through oak-hickory forests and pastureland. This lower portion, at times, becomes almost intermittent under extreme drought. However, it is rated a Class I to II rapids for canoe/floating rides of about 84 km with public access.

Historical Review

Fishes have been collected from Crooked Creek by various collectors; however, Cashner (1967) was the first to collect fishes systematically. He sampled one station in the lower portion of the creek using a boat electrofisher as part of a larger thesis project on a survey of the fishes of the cold tailwaters of the White River system. Cashner (1967) reported 15 species in seven families. Neither Keith (1964) nor Brown (1967) collected specifically in Crooked Creek, although they did inventories of fishes of portions of the White River system. Robison and Buchanan (1988) reported 36 fish species in 10 families inhabiting the Crooked Creek stream system. Although he did not collect fishes, Drope (1997) conducted a physicochemical survey of Crooked Creek in which he reported pollution from the towns of Harrison and Yellville.

Crooked Creek has received national acclaim as having some of the best Smallmouth Bass fishing of any stream and is considered the “blue-ribbon smallmouth stream in the state” by regional and state planning organizations (http://www.arkansas.com) as well as the AG&F. Thus, Crooked Creek is a state and national treasure as a Smallmouth Bass stream. Numerous studies involving the collection of sport fishes by the AG&F tend to support these statements. In addition, Crooked Creek was considered by Daly et al. (2002) to provide excellent habitat for Smallmouth Bass due to its continuing series of riffles and pools. Indeed, Daly and coauthors captured 433 *M. dolomieu* from 10 sites on Crooked Creek during the summers of 1988-1990. Smallmouth Bass populations have been previously studied in Crooked Creek for yellow grub (*Clinostomum marginatum*) trematode parasites (Daly et al. 1987, 1991, 2002) and more recently, CTM, R. Bonett (University of Tulsa), and HWR (unpublished) have collected *M. dolomieu* to assess the present health of the Smallmouth Bass fishery in this stream.

Crooked Creek is a very productive source for sand and gravel and has historically been involved in litigation between the state of Arkansas and local gravel mine owners. Because of rapid population growth and new construction in northern Arkansas, demand for sand and gravel has increased. Large-scale gravel mining has become a serious threat to the water quality and biota (not the least of which is sportfishing) of Crooked Creek and the impairment is not avoidable or reparable (Brown et al. 1998). In addition, Crooked Creek drains a primarily rural area, although the cities of Harrison and Yellville apparently affect the stream physicochemically (Drope 1997).

Results and Discussion

A total of 54 collections and 13,145 specimens of fishes collected from 1984 to 2011 were used in our analysis of the fishes of Crooked Creek. We were able to document the current presence of 65 species of fishes from Crooked Creek, which were distributed among 14 families (Appendix). Previously, Robison and Buchanan (1988) provided distribution records for only 36 species contained within 10 families. Our present study adds 29 species as new drainage records for the Crooked Creek stream system. The diversity of fishes in Crooked Creek is primarily characteristic of the Ozark uplands. Most commonly collected in the system were the Central Stoneroller (*Campostoma pullum*), Duskystripe Shiner (*Luxilus pilsbryi*), Ozark Minnow (*Dionda nubila*), Black Redhorse (*Moxostoma duquesnei*), Yellow Bullhead (*Ameiurus natalis*), Ozark Bass (*Ambloplites constellatus*), Smallmouth Bass (*Micropterus dolomieu*), Longear Sunfish (*Lepomis megalotis*), and Rainbow Darter (*Etheostoma caeruleum*) (Appendix).

Several species more rarely encountered in Arkansas were collected during our study including the Chestnut Lamprey (*Ichthyomyzon castaneus*), American Eel (*Anguilla rostrata*), River Redhorse (*Moxostoma carinatum*), Pealip Redhorse (*Moxostoma pisolabrum*) and Yellow Perch (*Perca flavescens*). No state, federally threatened, endangered species and/or species of special concern or of greatest conservation need (Anonymous 2004; Anderson 2006, Jelks et al. 2008; NatureServe 2010) were found to occur in Crooked Creek during our study.

The 3 most often collected species found in the system were Smallmouth Bass, Longear Sunfish, and Duskystripe Shiner. A total of 4,352 (33.1%) individual *M. dolomieu* of the 13,145 specimens in the 54 collections we enumerated reflects its great abundance in Crooked Creek and substantiates its reputation as a premier Ozark Zone Blue Ribbon Smallmouth Bass stream in Arkansas. However, this figure may be a bit misleading as fish collections by the AG&F were used in this analysis and often they were primarily collecting game fishes to assess the sportfishery of the stream.

With 65 species of fishes, Crooked Creek compares favorably with other well-documented streams of the Ozark Mountains such as the nearby Buffalo River, which has 67 species (Cashner and Brown 1977), Piney Creek, which supports 47 species (Matthews and Harp 1974; Matthews, 1978), and the Strawberry River, which has 109 species (Robison and Beadles 1974, Robison 1979, McAllister et al. 2009). Undoubtedly, additional new records of fish from Crooked Creek will be reported with further collecting efforts.

Acknowledgments

Appreciation is expressed to former SAU students, including N. Covington, K. Ball, J. Rader, and C. Brummett, who assisted HWR in field collections over the years. S. Todd (AG&F), also helped during electrofishing trips to Crooked Creek. We specifically thank B. Wagner (AG&F), for the use of fish records from Crooked Creek which he maintains in the AFD. In addition, we thank S. Filipek, M. Oliver, and J. Quinn, of the AG&F who graciously supplied their records of fishes of Crooked Creek in order that we have a more complete list. We also thank the AG&F for collecting permits 030820104 to HWR and 083120093 to CTM.

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Appendix. Fishes documented from Crooked Creek, White River Drainage, Arkansas.

Family/Species/Authority	Common Name
Petromyzontidae	
Ichthyomyzon castaneus Girard[1]	Chestnut Lamprey
Lepisosteidae	
Lepisosteus osseus (Linnaeus)	Longnose Gar
Anguillidae	
Anguilla rostrata (Lesueur)	American Eel
Clupeidae	
Dorosoma cepedianum (Lesueur)	Gizzard Shad
Cyprinidae	
Campostoma oligolepis Hubbs & Greene	Largescale Stoneroller
Campostoma pullum (Rafinesque)[1]	Central Stoneroller
Cyprinella galactura (Cope)	Whitetail Shiner
Cyprinella whipplei Girard	Steelcolor Shiner
Cyprinus carpio Linnaeus	Common Carp
Erimystax harryi (Hubbs & Crow)	Ozark Chub
Hybopsis amblops (Rafinesque)	Bigeye Chub
Luxilus chrysocephalus Rafinesque[1]	Striped Shiner
Luxilus pilsbryi (Fowler)[1]	Duskystripe Shiner
Nocomis biguttatus (Kirtland)	Hornyhead Chub
Notropis boops Gilbert	Bigeye Shiner

Notropis greenei Hubbs & Ortenburger....Wedgespot Shiner
Notropis nubilus (Forbes)....Ozark Minnow
Notropis percobromus (Cope)....Carmine Shiner
Notropis telescopus (Cope)....Telescope Shiner
Phoxinus erythrogaster (Rafinesque)....Southern Redbelly Dace
Pimephales notatus (Rafinesque)[1]....Bluntnose Minnow
Semotilus atromaculatus (Mitchill)....Creek Chub

Catostomidae
Carpiodes carpio (Rafinesque)....River Carpsucker
Carpiodes cyprinus (Lesueur)....Quillback
Carpiodes velifer (Rafinesque)....Highfin Carpsucker
Ctenopharyngodon idella (Valenciennes)[2]....Grass Carp
Hypentelium nigricans (Lesueur)[1]....Northern Hog Sucker
Moxostoma carinatum (Cope)....River Redhorse
Moxostoma duquesnei (Lesueur)....Black Redhorse
Moxostoma erythrurum (Rafinesque)....Golden Redhorse
Moxostoma pisolabrum (Trautman & Martin)....Pealip Redhorse

Ictaluridae
Ameiurus melas (Rafinesque)....Black Bullhead
Ameiurus natalis (Lesueur)....Yellow Bullhead
Ictalurus punctatus (Rafinesque)....Channel Catfish
Noturus albater Taylor....Ozark Madtom
Noturus exilis Nelson....Slender Madtom
Noturus flavater Taylor....Checkered Madtom
Pylodictis olivaris (Rafinesque)....Flathead Catfish

Salmonidae
Oncorhynchus mykiss (Walbaum)[1,2]....Rainbow Trout

Atherinopsidae
Labidesthes sicculus (Cope)[1]....Brook Silverside

Fundulidae
Fundulus catenatus (Storer)....Northern Studfish
Fundulus olivaceus (Storer)....Blackspotted Topminnow

Poeciliidae
Gambusia affinis (Baird & Girard)....Western Mosquitofish

Cottidae
Cottus carolinae (Gill)....Banded Sculpin
Cottus immaculatus Kinziger & Wood[1,3]....Immaculate Sculpin

Centrarchidae
Ambloplites constellatus Cashner & Suttkus[1]....Ozark Bass
Lepomis cyanellus Rafinesque[1]....Green Sunfish
Lepomis macrochirus Rafinesque[1]....Bluegill
Lepomis megalotis (Rafinesque)[1]....Longear Sunfish
Lepomis microlophus (Gunther)....Redear Sunfish
Micropterus dolomieu Lacépède[1]....Smallmouth Bass
Micropterus punctulatus (Rafinesque)....Spotted Bass

Micropterus salmoides (Lacépède)[1]	Largemouth Bass
Pomoxis nigromaculatus (Lesueur)	Black Crappie

Percidae

Etheostoma blennioides Rafinesque	Greenside Darter
Etheostoma caeruleum Storer	Rainbow Darter
Etheostoma euzonum (Hubbs & Black)	Arkansas Saddled Darter
Etheostoma flabellare Rafinesque	Fantail Darter
Etheostoma juliae Meek	Yoke Darter
Etheostoma spectabile (Agassiz)[4]	Orangethroat Darter
Etheostoma zonale (Cope)	Banded Darter
Perca flavescens (Mitchill)	Yellow Perch
Percina caprodes (Rafinesque)	Logperch
Percina maculata (Girard)	Blackside Darter
Percina sciera (Swain)	Dusky Darter

[1]Previous records from Cashner (1967).
[2]Introduced species.
[3]Formerly Arkansas populations of Ozark Sculpin, *Cottus hypselurus* Robins & Robison; *C. hypselurus* is now restricted to Missouri.
[4]This may actually represent an undescribed species according to Page and Burr (2011).

Seasonal Activity, Population Characteristics, and Age Estimation in the Aquatic Salamander, *Siren intermedia nettingi* (Goin)

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Abstract

We conducted a study of the Western Lesser Siren (*Siren intermedia nettinigi*), at a locality termed the Airport Road site in Jonesboro (Craighead County, AR) from November 2004 until March 2007. This site consisted of a network of roadside ditches in cultivated lawns in an industrial park. Even though sirens are known to occur frequently in ditches, most *studies* of the genus *Siren* have taken place in natural wetlands. We compiled mark-recapture data at the Airport Road site for each season to determine if the seasonal activity pattern for sirens in northeast Arkansas varied from activity data previously published from other localities in the range of this species. Capture rates were higher in the fall and spring. The predicted overall population size was 110 sirens at a density of 0.81 sirens per linear m. This density was less than the densities (in sirens/m^2) reported by previous studies. We found two prominent peaks in sirens per size class: the first at 161-170 mm, and the second at 201-210 mm. Other researchers have assumed that the two most abundant size classes in siren populations represent one-year-old and two-year-old cohorts. The sirens captured at the Airport Road site are smaller, on average, than those reported in previous population studies. We found no significant difference between the growth rates of sirens larger than 200 mm SVL and those smaller than 200 mm snout-vent length (= SVL; P = 0.957, confidence interval -1.945, 2.045, n = 16). Our mean growth rates did not significantly differ from growth rates reported for sirens elsewhere. We sectioned siren humeri to identify and quantify lines of arrested growth (LAGs) as part of a skeletochronological analysis. The use of SVL was a poor indicator of number of LAGs. The difference in the weather pattern history in each of the voucher sirens used likely resulted in broad ranges of LAGs for each SVL size class.

Introduction

The Western Lesser Siren, *Siren intermedia nettingi,* is rarely encountered even though this animal can be found in high numbers in suitable habitats, such as agricultural and roadside ditches or wetlands managed for waterfowl (Frese et al. 2003). Sirens have been found to occur in higher densities than any other salamander including all terrestrial salamanders except for the San Marcos Salamander, *Eurycea nana* (Gehlbach and Kennedy 1978, Tupa and Davis 1976). The Western Lesser Siren is a relatively large amphibian; adults range from 18 to 50 cm in total length (Conant and Collins 1998). Males are typically larger than females (Sugg et al. 1988). External gills are present anterior to the sole pair of forelimbs and coloration is variable ranging from olive-green to blue-gray (Trauth et al. 2004). Sirens are highly fecund, typically producing around 100-300 eggs and in somecases over one thousand ova can be produced (Gehlbach and Kennedy 1978, Trauth et al. 2004). Gehlbach and Kennedy (1978) suggest that sexual maturity is likely attained in one year for both sexes of sirens; however, Trauth et al. (1990) reported size class data illustrating that females reproduce at two years of age.

In a natural drainage, sirens appear to feed opportunistically by filter feeding in the mud and by randomly ingesting pieces of aquatic plants to obtain small animals occurring upon the plants (Altig 1967). Sullivan et al. (2000) reported that *Siren intermedia* are random suction feeders which do not rely heavily upon visual or chemical cues during foraging. The relative dearth of information on sirenids prompted us to study sirens in an urban setting. Comparisons of population characteristics between our study and past studies are useful in assessing the effect of urbanization on sirens and aquatic salamanders in general. Age data, determined through skeletochronological analysis, further illuminates population characteristics found at Airport Road.

Seasonal activity.—Whereas many salamanders aestivate during periods of sustained heat and/or drought, sirenids have a unique repertoire of behaviors and structures that allow them to withstand longer periods of aestivation when the aquatic environment dries (Petranka 1998). During periods of drought, sirens can burrow into the substrate and survive for extended periods of time until rains inundate the habitat (Gehlbach et al. 1973). Once inundated with water, an aestivating siren will become active in about one day; however, its activity levels will peak only after feeding (Gehlbach et al. 1973). Since the Western Lesser Siren inhabits areas where there is a dramatic seasonal fluctuation in precipitation and temperature, these animals may have multiple periods of inactivity per year (Petranka 1998). As the temporary water in pools, ponds, or ditches dries up in the summer, sirens must aestivate (Trauth et al. 2004). When temperatures become too low for poikilothermic activity in the winter, sirens become torpid (per. obs.). It is not known at what temperature sirens become inactive. However, it is intuitive that sirens will become inactive when the liquid water completely dries or freezes in their habitat.

Population size and density.—Sirens in natural drainages have been reported to occur in high densities (Altig 1967). Sirens in a Missouri wetland occurred at a standing crop biomass of 1.35 to 2.17 sirens/m^2 with 44.9 to 72.2 grams/m^2 (Frese et al. 2003). In that study, home ranges of individuals varied in size and overlapped frequently. Ditches are structurally different from the wetland mentioned above. Ditches have greater length with a relatively narrow width, whereas the Missouri wetland is mostly equal in size between its two dimensions (B. Wheeler, pers. comm.); however, we expected the population density of *Siren intermedia nettingi* at the Airport Road site to be similar to the standing crop biomass of 1.35 to 2.17 sirens/m^2 reported by Frese et al. (2003).

Size classes.—Gehlbach and Kennedy (1978) found that four distinct size classes occur at 1-20 g, 21-50 g, 51-70 g, and 71-160 g. In five-year-old beaver ponds in Texas, the largest male measured snout-vent length (SVL) 313 mm, total length (TL) 465 mm, and mass 265.4 g. The largest female measured SVL 215 mm, TL 321 mm, and mass 76 g (Gehlbach and Kennedy 1978). The record size *Siren intermedia nettingi* measured 502 mm in total length (Conant and Collins 1998). However, in unpublished records, Western Lesser Sirens measuring up 630 mm TL have been collected (McDaniel 1969). We aimed to determine if the low diversity of vascular plants and spatial nature of the urban ditch network at the Airport Road Site had an effect on sizes and size class distribution of these
animals.

Growth rates.—The Western Lesser Siren is a relatively large amphibian; adults range from 18 to 50 cm in total length (Conant and Collins 1998). Male Western Lesser Sirens are typically larger than females (Sugg et al. 1988). Gehlbach and Kennedy (1978) suggested that sexual maturity is likely attained in one year for both sexes of sirens; however, Trauth et al. (1990) report size class data illustrating that females first reproduce at two years of age. Sexes occur in a 1:1 ratio (Gehlbach and Kennedy 1978). Regardless of sex, first year sirens grow more rapidly than mature individuals (Frese et al 2003). An accurate method for determining the sex of live sirens has not yet been documented, but sex can be determined confidently upon dissection of euthanized animals. We aimed to determine if sirens from an urban setting grew at similar rates to those from more natural areas. Such a determination is important to estimate the impact of urbanization on aquatic salamanders in general.

Skeletochronological analysis.—As periosteal growth occurs, new layers of bone are deposited on endochondral long bones (Zug 1991). Within cross sections of these bones, lines of arrested growth (LAGs) can be counted to infer age. Lines of arrested growth are caused by a cessation in growth due to inactivity and a halt in feeding. The zones in between the LAGs represent periods of activity and regular feeding (Zug 1991, Wake and Castanet 1995).

Materials and Methods

Study area

We studied a population of *Siren intermedia nettingi* at a specific ditch site in Jonesboro, Arkansas along Airport Road (35˚ 49' 50.4 " N, 90˚ 39' 36.7" W). The interconnected ditch network is adjacent to industrial facilities such as warehouses, metal working factories, and masonries. There are five ditches all within 150 m of each other and all potentially contiguous when water levels are high. These ditches were designated site 1-5 from north to south. Although formerly a floodplain, the surrounding area now consists of large treeless lawns of regularly maintained turf grasses.

Field methods

The Airport Road site was monitored from November 2004 until March of 2007. Sirens were collected from the site using dip nets and traps. When water levels in these ditches were high, >25 cm, we trapped daily; traps were checked in the morning and were baited if necessary in the evening. The traps were left out permanently until the water level became too low. These cylindrical traps are typically made of rubber-coated steel. Commercially available traps such as these are quite reliable at catching and retaining snakes, *Amphiuma,* and sirens (Wilson et al. 2005).

Seasonal activity

The date of collection was recorded for each siren captured. These data were represented graphically to illustrate trends in seasonal activity. We followed Raymond (1991) and conducted a pairwise comparison of mean number of siren per month collected per season. Using Minitab 14®, we employed an Analysis of Variance and a Tukey's Pairwise comparison test to compare seasonal activity. Since the duration of our study does not represent three complete years, we chose to represent mean captures per month compiled from all years studied.

Population size and density

Captured sirens were observed for previous marks or were marked for the first time. We used visible implant elastomer dye primarily due to its ease and efficacy (pers. obs.). Care was taken to mark the animals in a manner so they could be individually recognizable upon recapture. To accomplish this, the pattern and/or color were changed with every animal marked.

Population density estimate

Population estimates were calculated using the Schumacher and Eschmeyer population index (Krebs 1998). This population estimate method was useful when multiple samples were collected. The equation is as follows:

$$\hat{N} = \frac{\sum_{t=1}^{s} (C_t M_t^2)}{\sum_{t=1}^{s} (R_t M_t)}$$

The variable C is the total number of sirens caught in this study and R equals the number of sirens recaptured. N represents the estimated total population at the Airport Road site while M denotes the number of marked individuals. The method for estimating standing crop biomass for sirens by trapping used in Frese et al. (2003) was employed to determine population density.

Size classes

Before each animal was released, we recorded the following information: date of collection, specific location, TL, SVL, mass, mark type, method of collection, weather conditions, approximate water depth, and collector(s). We assigned size classes at 10 mm increments. The size classes were graphically represented to illustrate trends such as bimodality. The size classes with the most representatives were reported. We compared the mean length of the predominant size classes and size of the largest sirens captured to the data from previous studies.

Growth rates

We followed the procedures used by Houck (1982) to determine growth rates based on change in snout-vent length. When sirens were recaptured and measured the amount of growth that occurred between capture events was calculated by subtracting the original SVL from the final snout-vent length. When the amount of growth was divided by the duration of time between the two capture events, an individual growth rate, irrespective of sex, was determined. The population was divided into juveniles (those not yet reproductive) and mature specimens to determine if there were a difference in growth rates between juveniles and adults as reported by Frese et al. (2003). Sirens under 200 mm SVL were designated as "small" and were compared to those designated as "large" (sirens with an SVL greater than 200 mm). A two sample T-test of unequal variance was employed to determine the difference in growth rates between recaptured *Siren* designated small and those designated as large (Minitab 14®).

Skeletochronological analysis

The Arkansas State University Museum of Zoology (ASUMZ) houses about 150 voucher sirens. These have all been collected from various areas in Arkansas within the last 40 years. We prepared 30 of these specimens for skeletochronological age estimates. Presnell and Schreibman (1997) provided detailed guidelines for preparing the tissue for examination. A preserved humerus with its surrounding tissue was dehydrated in an ethanol series and was cleared with xylene finally being placed in paraffin tissue blocks (Presenell and Schreibman 1997, Trauth and Worley 1997). The tissue blocks were sectioned at thicknesses between 8 and 22 µm due to the varying difficulty in tissue ribbon formation. An Erlich's hematoxylin and eosin stain was applied. Once the micrographs were generated with a Nikon Eclipse E600 light microscope, we estimated age by counting lines of arrested growth (LAGs) in the humerus cross sections at 200X magnification (Parham et al. 1996) (Figs. 4-9). We used a correlation test (Minitab 14®) with regression analysis (alpha level = 0.05) to test the relationship between SVL (mm) and number of LAGs (Sokal and Rohlf 1981).

Results

Seasonal activity

In early spring, more sirens were collected than in the preceding months of winter. We found no significant difference between the number of sirens captured in the spring and fall (P = 0.967; $F_{1,4}$ = 0.00). Although statistically insignificant, fewer sirens were caught in summer and winter as compared to spring and fall (P = 0.069; $F_{1,10}$ = 4.15). In March, the greatest number of sirens (n = 24) were collected. During the summer, few sirens were collected. However, in June, 10 sirens were collected. In the spring, from 0 to 24 sirens were collected per month (mean 11.00 +/- 7.00). In summer, monthly collection ranged from 0 to 10 (mean 5.00 +/- 2.89). In the fall, we collected 8 to 14 sirens per month (mean 11.33 +/- 1.76). Monthly winter collection ranged from 0 to 7 (mean 2.33 +/- 2.33). We grouped all collections from each year into these calculations (Fig. 1).

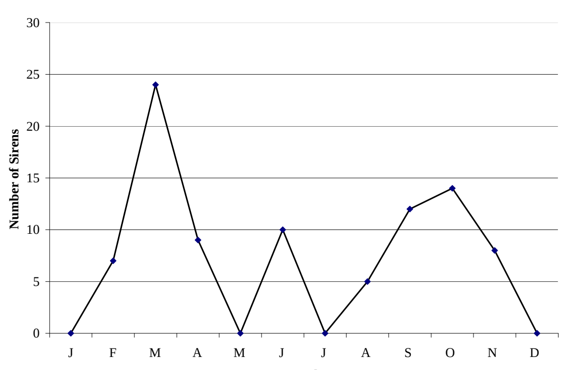

Figure 1. Number of sirens, *Siren intermedia nettingi*, collected from the Airport Road, Jonesboro, AR from November of 2004 to March of 2006. All values represented monthly samples inclusive of all years.

Population size and density

From October 2004 to November 2006, 62 sirens were collected at the Airport Road site. Of these, 19 were recaptured at least once; seven were recaptured at least twice; three were recaptured at least three times, and one of these was recaptured a fourth and fifth time. Thirty-one percent of all sirens collected were recaptured at least once. As calculated by the Schumacher-Eschmeyer method, the estimate for total population of *Siren intermedia* in the Airport site is 110 individuals (+/- 0.00091). Since the ditches involved in this study exhibit an extreme fluctuation in depth and width, density can best be reported by animals per linear m. The trapped portion of the ditches at the Airport Road site totaled 136.6 linear m. The linear density of sirens is therefore estimated to be 0.81 sirens/m.

Size classes

There is a major peak in number of sirens per size class at the 201-210 mm size class. In general, size classes between 160 mm and 240 mm had more representatives than size classes with larger or smaller sirens (Fig. 2). No sirens with a SVL of less than 13 mm were found at Airport Road. This result was expected since newly hatched sirens measure ca. 13 mm TL (Bishop 1943). The largest sirens collected had a SVL of 255 mm, smaller than the largest sirens captured by Gehlbach and Kennedy (1978) and Sugg et al.1998. The mean SVL for all animals captured in this study (181.1 mm) is less than the mean SVL for both male and female *Siren* collected by Sugg et al. (1988) 282.4 and 216.9 mm, respectively (Table 1). Our overall mean TL (277.3 mm) is less than the TL for both sexes (males 348.2 mm, females 286.8 mm) reported by Frese et al. (2003) and is less than the mean TL for male sirens (321.9 mm) reported by Sugg et al. (1988); however, the mean TL for female sirens reported by Sugg et al. (1988) is 189.5 mm, which is less than the mean TLs reported by Frese et al. (2003) and our study (Table 1). The length to mass relationship is similar to that reported in previous studies (Gehlbach and Kennedy 1978).

Growth rates

Upon comparison of the growth rates of sirens under 200 mm SVL to those with an SVL of 200 mm or greater, we found that there was no significant difference between the growth rates of large and small *Siren* (P = 0.957; T11 = 0.06; n = 16). Growth rates of *Siren* less than 200 mm SVL ranged from -1.00 to 1.40 mm/day with a mean of 0.055 (SE = 0.32; n = 10). In

Table 1. Comparison of the mean and range of total length and snout-vent length (in mm) of Western Lesser Sirens from northeast AR (this study), central AR (Sugg 1988), southern MO (Frese et al. 2003) and southern TX (McDaniel 1969).

N	mean SVL	SVL range	SVL SD	mean TL	TL range	TL SD	Sex	Study
59	181.1	135-255	49.3	277.3	170-365	47.6	Both	This study
ca. 1200	282.4	122-315	45.0	321.9	179-461	60.9	M	Sugg et al. 1988
ca. 1200	216.9	138-282	29.9	189.5	221-439	38.2	F	Sugg et al. 1988
911	-	-	-	348.2	317-403	23.2	M	Frese et al. 2003
911	-	-	-	286.8	215-365	32.9	F	Frese et al. 2003
378	-	-	-	-	60-630	-	M	McDaniel 1969
378	-	-	-	-	60-520	-	F	McDaniel 1969

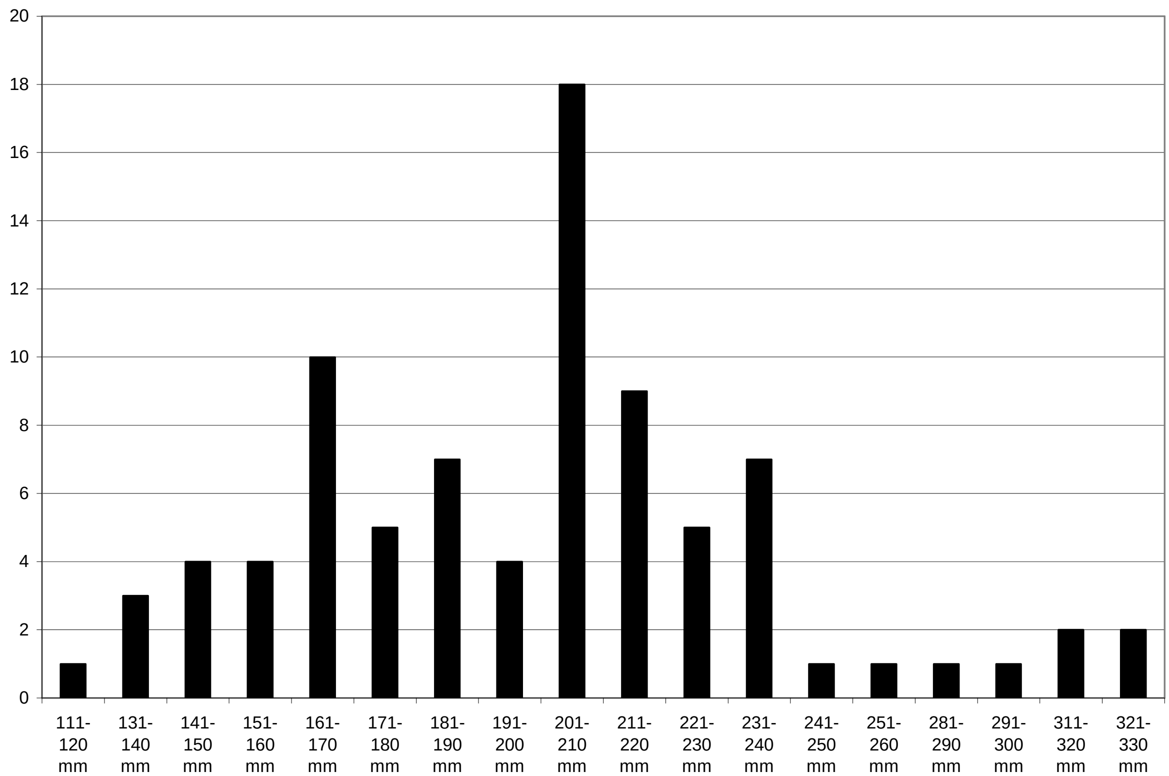

Figure 2. Number of representatives per size class. Data are from all sirens collected at the Airport Road site throughout the duration of this study. Size classes are based on snout-vent lengths.

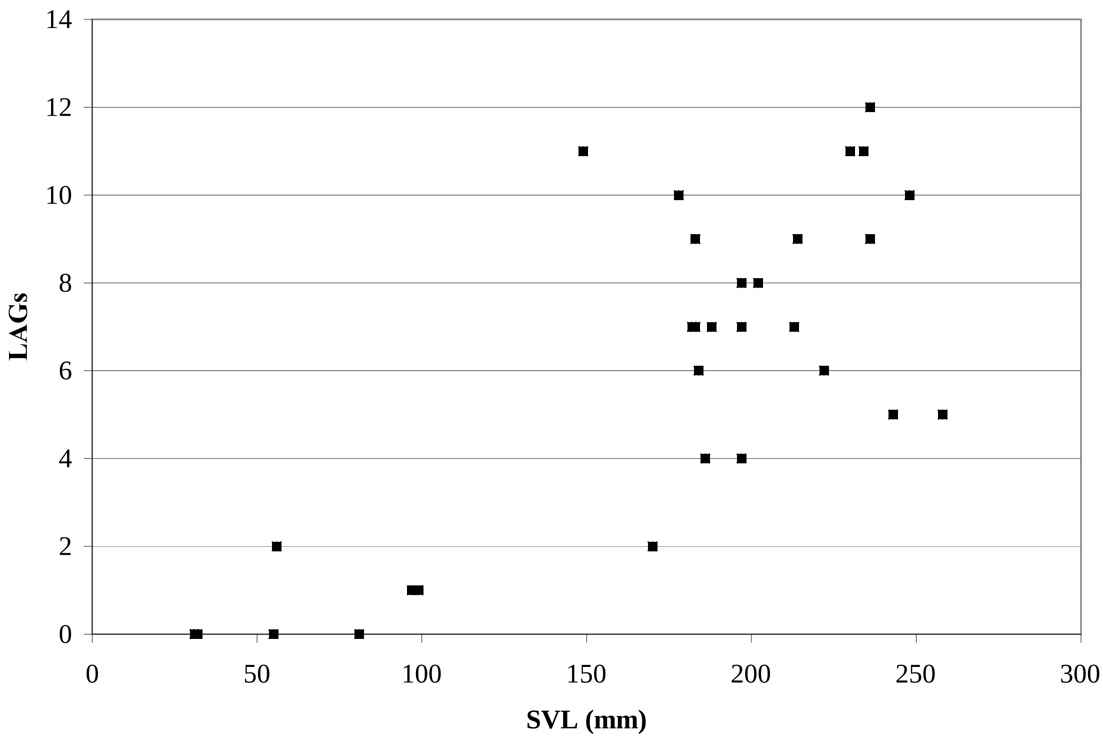

Figure 3. Relationship between snout-vent length (SVL) and lines of arrested growth (LAGs) in 30 *Siren* from the ASUMZ.

Siren larger than 200 mm, the growth rates ranged from -5.33 to 6.00 mm/day with a mean of 0.005 (SE = 0.848) (n = 6). With respect to TL (total length), growth rates of "small" *Siren* ranged from -0.24 to1.72 mm/day with a mean of 0.371mm/day (SE = 0.208) (n = 10). Growth rates of "large" *Siren* ranged from -0.15 to 2.29 mm/day with a mean 0.639 mm/day of (SE = 0.365) (n = 6). *Siren* designated as "small" exhibited a mean mass growth of -0.203 g/day (SE = 0.14) (n = 10). "Large" *Siren* grew at 0.371 g/day on average (SE = 0.23) (n = 6).

Skeletochronological analysis

The SVL of the 30 sirens examined ranged from 31 to 258 mm. The number of LAGs ranged from 0 to 12. By employing a correlation test with regression analysis, we found a significant correlation between SVL and LAG (P <0.001; SE coefficient =1.143). Two unusual observations could not be included in the statistical analysis. One was a siren with an SVL of 149 mm that possessed 11 distinct LAGs; the other had the other had an SVL of 258 mm and had 5 LAGs (R = 2.54 and -2.50, respectively). The relationship between LAGs and SVL is weakly positively correlated (Fig. 3); but animals measuring about 200 mm SVL, the number of LAGs is highly variable and unpredictable (see Figs. 4-9).

Discussion

Our study of an urban population of the Western Lesser Siren at the Airport Road site represents an interesting setting for ecological study. This site hosts numerous animal species that are typically found in undisturbed natural ecosystems. Differences in population characteristics between our study and previous *Siren intermedia* studies may be attributable to the juxtaposition of the Airport Road ditch network to possible sources of pollutants such as the nearby roads and factories (pers. observ.). With respect to seasonal activity, our results seem typical; sirens are the most active in the spring and fall. The heightened spring activity may result from increased movement preceding breeding (Noble and Marshall 1932; Johnson 1977, Trauth et al. 1990). Gehlbach and Kennedy (1978) and Raymond (1991) both reported relatively high levels of activity in the spring.

The former study reported high activity in the fall, similar to our results even though that study was conducted in extreme southern Texas. This increase in activity may be a life history strategy of sirens for increasing nutrient reserves before winter torpor. However, Raymond (1991) stated that sirens exhibit no increased level of activity in fall. Perhaps those sirens were relatively more active in the winter and fall due to permanent water or mild winter temperatures in Louisiana. We found that the population density at Airport Road was less than the siren densities reported by Frese et al. (2003) and Gehlbach and Kennedy (1978). This difference may be due to factors present in urban environments not found in more natural settings. In Frese et al. (2003), sirens were studied in an intensively managed wetland and Gehlbach and Kennedy (1978) studied sirens in a natural wetland. The sirens we studied may have occurred at lower densities due to a homogeneous vegetation structure that results in a lower diversity and abundance of potential prey items. The artificial ecosystem and subsequent low prey diversity may have been responsible for the relatively small size of sirens at our site compared to previous studies (McDaniel 1969; Sugg et al. 1988, Frese et al. 2003). Each of the previous mentioned studies reports multiple sirens larger than the largest siren we collected at the Airport Road site. Low densities and smaller size classes are likely results of low prey diversity; however, we report growth rates that are not significantly different than those reported by Gehlbach and Kennedy (1978) and Frese et al. (2003). Perhaps low abundance of food at Airport Road causes low densities and smaller sizes but individual growth rates are independent (Van Buskirk and Smith 1991). We initially expected our calculated growth rates to vary from previous studies since seasonal fluctuations in weather can cause long periods of dormancy which would bring a halt to feeding and regular growth. This was not the case. In Texas, Missouri, and Arkansas, sirens grow at approximately the same rate, on average (Gehlbach and Kennedy 1978, Frese et al. 2003). However, even small fluctuations in weather apparently cause differential rates of osseous deposition in long bones. When examining siren humeri, minor LAGs were often problematic when trying to estimate age. Minor LAGs, those LAGs occurring within individual MSGs, were often nearly as dark and thick as there corresponding major LAG. Even though SVL and number of LAGs were found to have a significant correlation, it appears that skeletochronology is not a good tool for estimating age in sirens. As suggested by Eden et al. 2007, the deposition of minor LAGs due to extreme weather events and endosteal resorption limit the usefulness of skeletochronology in temperate salamanders.

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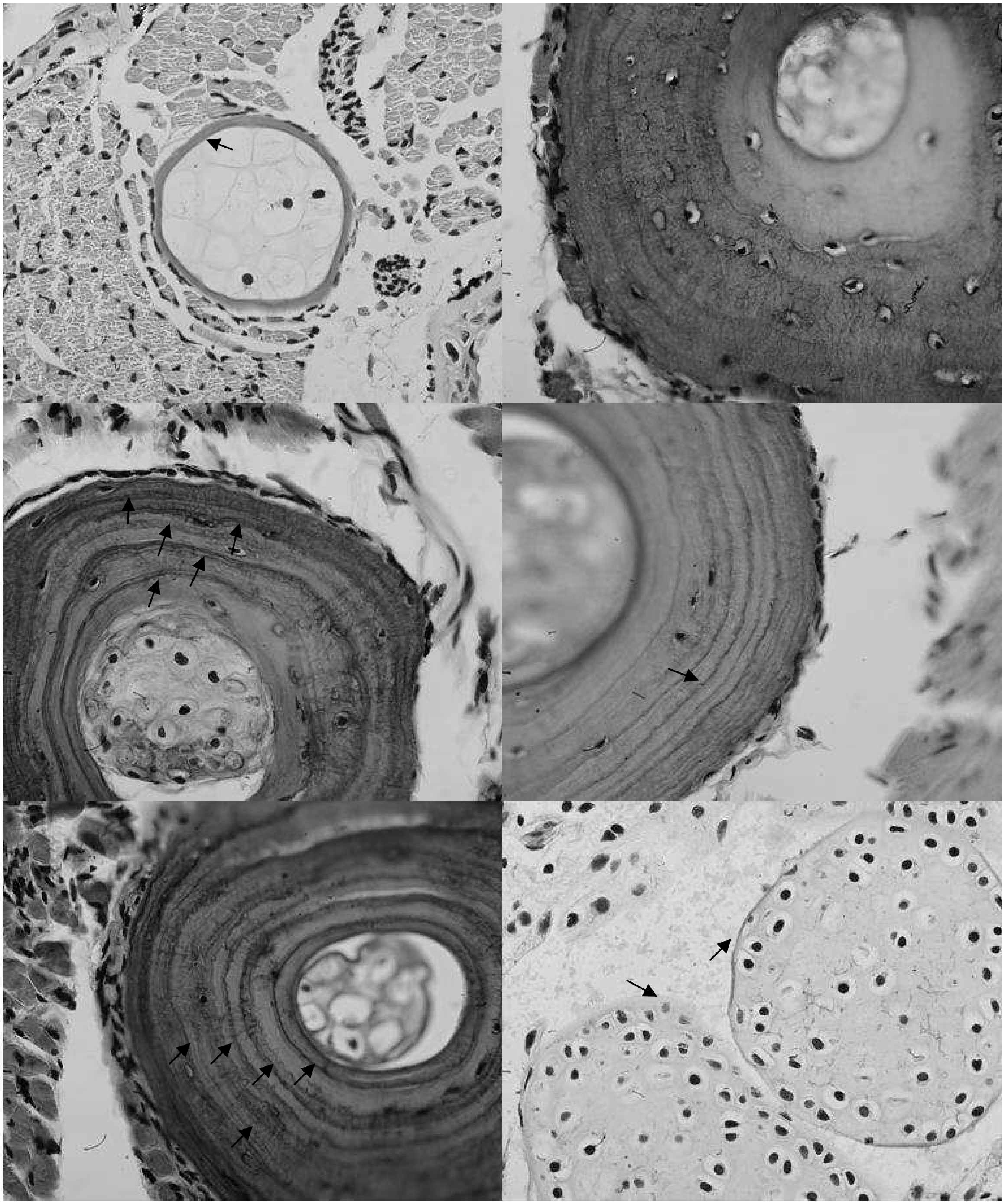

Figures 4-9. Clockwise from top left: 4. A humerus from a young siren showing no LAGs; 5. A humerus from an adult siren showing 5 LAGs that are not distinct; 6. A humerus with very thin MSGs and numerous LAGs; 7. The radius and ulna of a young siren; note the lack of ossified periosteum; 8. A humerus from an adult siren with 6 distinct major LAGs and numerous thin minor LAGs; 9. A humerus exhibiting apparent endosteal resorption of bone. All were photographed at 200X magnification.

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A Biological Inventory of Meacham Cave (Independence County, Arkansas)

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Abstract

During September 2008 through June 2011, we compiled a biological inventory of Meacham Cave in Independence County, AR. Compared to other caves in the region, Meacham Cave houses few vertebrates, but non-aquatic invertebrates were relatively common. A transiently-increased bacterial load in the cave's only pool of water indicated recent fecal contamination. The combination of vandalism, low vertebrate populations, and high coliform bacterial load reveals that human abuse of the cave has significantly disrupted its ecosystem. Gating the cave in such a way as to allow the movement of bats, salamanders and other animals, while excluding humans, may allow the cave ecosystem to recover. The close proximity of the cave to Lyon College makes it ideal for long-term investigation.

Introduction

Meacham Cave is privately-owned and located approximately 5 miles north of Lyon College in Independence County, AR (Lat 35.81°, Lon -91.61°). The cave is situated beneath the Batesville Sandstone formation (United States Geological Survey 2000). Most of the cave features were eroded from sandstone with secondary depositional calcite speleothems. The Little Rock Grotto of the National Speleological Society mapped Meacham Cave in 1996 (Little Rock Grotto 1997). Members of the COBRA (Cavers of the Batesville Region of Arkansas) Grotto added an additional passage to the map in 2009. Meacham is a relatively small cave that consists of one large chamber to which several smaller passages converge. The entrance faces east, and the 2 longest passages extend to the north and northwest. During wet weather, an ephemeral pool forms in the lowest part of the main chamber. Local knowledge of the cave's location, unfortunately, has resulted in extensive graffiti, breakage of speleothems and other vandalism. Vandals have damaged or removed all except the very highest formations. A fire ring inside the cave at the bottom of the entrance slope had been used recently.

Methods

The cave was explored in accordance with National Speleological Society guidelines (Jones and Dale 2009). We visited the cave 25 times between September 2008 and June 2011. Three OM-EL-USB data loggers (Omega Engineering, Inc., Stamford, CT) monitored temperature and humidity in the main chamber, and at the ends of the north and northwest passages. Soil texture was determined by volumetric assortment of soil particles (Sammis 2009). Replicate samples for soil texture analysis (n=3) were collected at approximately the same locations at which the data loggers were placed.

Macroscopic organisms – inside and outside of the cave – were counted and photographed for identification. Organisms were identified using commonly-available field guides and online resources (Behler and King 1979, Harvey 1986, Harvey et al. 1999, Milne and Milne 1980, Sealander and Heidt 1990, Trauth et al. 2004, Van Dyk 2011). In order to preserve the fragile cave biota, very few organisms, other than microbes, were collected or otherwise intentionally removed from the cave.

Soil and water samples were analyzed for microbial biomass via fluorescein diacetate (FDA) hydrolysis assays (Adam and Duncan 2001) modified for low-volume samples (Thomas et al. 2008). Replicate soil samples (n = 6) for the FDA assays were collected along a linear path from the bottom of the entrance to the back of the northeast passage of the cave. Replicate water samples (n=2-6) from the ephemeral pool were tested for coliform bacteria using Petrifilm (3M) media. Other cave bacteria were grown on low-nutrient agar plates (Spilde et al. 2005). Duplicate Petrifilm subsamples were incubated at 37°C and 44°C, to determine total coliforms and fecal coliforms, respectively, as recommended by the manufacturer. All other microbiological media were incubated at 12°C - 13°C (near cave temperature). Cultured and *in situ* microbes were identified by 16S ribosomal RNA sequences amplified using "universal" primers (Boutte et al. 2006, Nubel et al. 1997): 352F 5'- CTCCTACGGGAGGCAGCAG-3' (forward) and 1492R 5'-TACGGYTACCTTGTTACGACTT-3' (reverse).

DNA sequences for identification/phylogenetic analysis were obtained using two methods: culture-independent and culture-dependent. For culture-independent analysis, large environmental water samples (50+ mL) were filtered through 0.45 µm membranes using a filtration manifold (Millipore, Billerica, MA). Microbes were rinsed from the filters with Tris-EDTA (TE) buffer (pH 8). Microorganisms in the TE buffer were subjected to a CTAB, freeze-thaw DNA extraction method (Doyle and Doyle 1987) and the DNAs were precipitated using isopropanol. Microorganisms for culture-dependent analysis were obtained by picking colonies growing on culture media with a sterile loop and suspending the cells in 50 µL of TE buffer. DNA extraction employed the same CTAB method. All 16S DNAs were amplified over 35 cycles of the polymerase chain reaction (PCR) under the following conditions: 94°C for 50 seconds; 54°C for 50 seconds, 72°C for 50 seconds, and a final "polishing" step of 72°C for 10 minutes. Amplified DNAs were visualized using 1% agarose electrophoresis, then correct-sized bands were excised and the DNA purified from the gel matrix using the Cyclo-prep kit (Ameresco, Solon, OH). DNAs amplified for the culture-dependent method were sent directly for DNA sequencing (DNA Resource Center, Division of Agriculture, University of Arkansas, Fayetteville, AR). However, the heterogeneous DNAs from culture-independent PCR amplification were separated by cloning into the TOPO vector (Invitrogen, Carlsbad, CA) and positive clones selected for DNA sequencing.

DNA alignment and analysis used a combination Sequencher (Gene Codes, Ann Arbor, MI) and Se-Al (Oxford, UK). Related sequences were searched using the BLAST application on the National Center for Biotechnology Information (NCBI) nucleotide database. Phylogenetic analyses, tree building and bootstrapping used the maximum-likelihood method in PAUP* v. 4.0b10 (Swofford 2002). Trees were estimated using the HKY85 substitution model, set transition to transversion ratio, and approximated gamma distribution. All trees were swapped by random stepwise addition with tree-bisection-reconnection (TBR) branch swapping. Bootstrap values were obtained using the same HKY85 substitution model, conducted for 100 replicates.

Results and Discussion

Throughout the study period, the temperature in the back of the cave remained stable at 14°C. Near the entrance, however, the temperature varied between 12°C and 15°C. Relative humidity remained at 100% in the rear of the cave, and varied between 95-100% near the entrance. Clays dominated the soils in the back of the cave, whereas soil closer to the entrance contained approximately equal amounts of clay and silt. Sand comprised 10% or less of the cave soils (Figure 1).

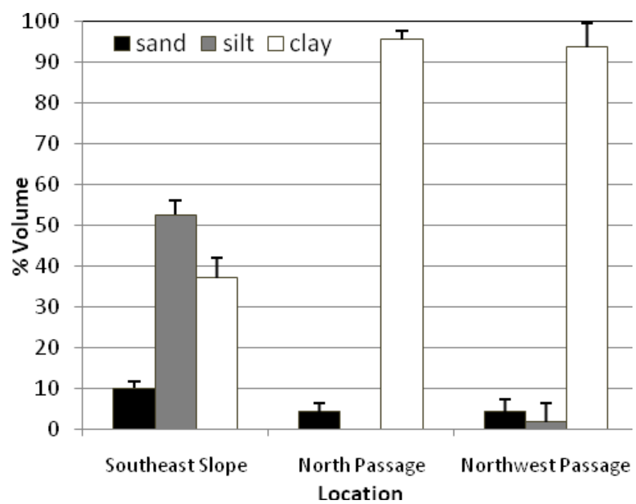

Figure 1. Soil texture in Meacham Cave. With the exception of the soil on the southeast slope (near the entrance), clays dominated the cave soils (n = 3, bars = s.d.). No silt was detected in samples from the North passage.

Total soil microbial biomass, as measured by FDA hydrolysis activity, was highest near the entrance (Figure 2). Presumably, this was due to the input of nutrients by leaf litter and other detritus that falls into the cave. Coliform bacteria were detected in every cave water sample (however, water was not present in the cave at every visit). The population of coliforms loosely correlated (r^2 = 0.56) with total microbial biomass in the water samples (Figures 3 & 4). With the exception of the first two samples, microbial populations in the water were relatively small. The source of the bacteria is unclear, but may have been due to animal waste deposited in or near the water just prior to the sampling period.

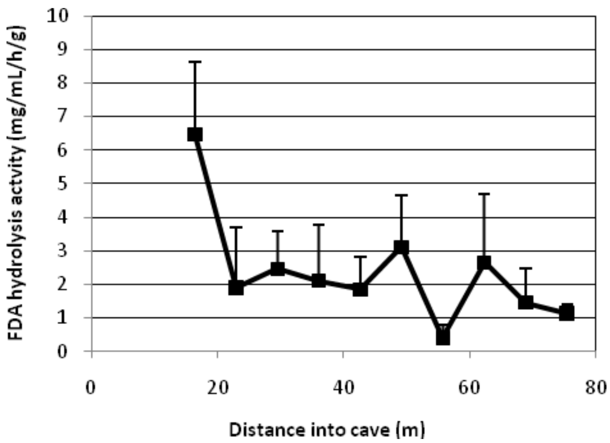

Figure 2. Soil microbial biomass as a function of distance from the entrance. The distance shown is actual distance along the cave floor surface, not horizontal distance (n = 6, bars = s.d.). Extensive leaf litter at the cave entrance made samples before 15 m impractical.

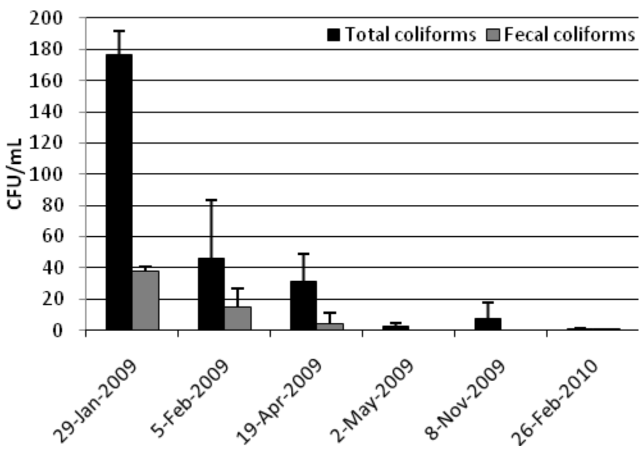

Figure 3. Coliforms and fecal coliforms in cave water (in order from left, n = 2, 8, 4, 4, 2, 8; bars = s.d.; CFU = colony forming units). Fecal coliforms were not detected in the last three samples.

Coliform and fecal (thermotolerant) coliform bacteria are standard indicator organisms of fecal contamination. In particular, the thermotolerant bacterium, *Escherichia coli*, is a specific indicator of fecal contamination. Other coliforms can be present without necessarily being of fecal origin (reviewed in (Moe 2002, Toranzos et al. 2002). A small number of vertebrates live in the cave (Table 1), and we saw feces and nests of small animals in many areas of the cave. In addition, we observed small amounts of bat guano pellets in the water during most visits. Finally, we cannot rule out the possibility of human contributions to the fecal coliform population. Even the most careful and conscientious explorers can contaminate cave water by their presence (Hunter et al. 2004).

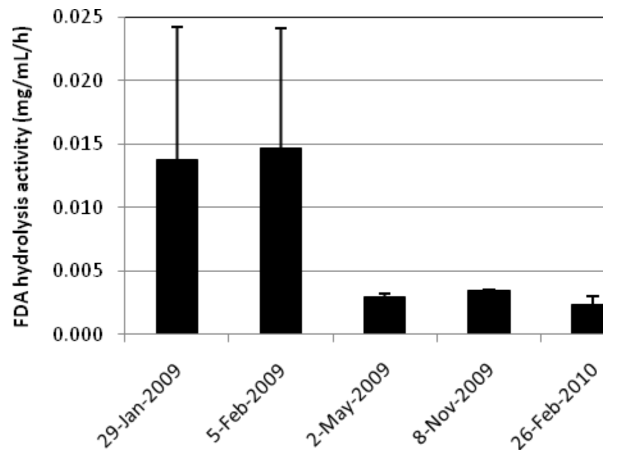

Figure 4. Water microbial biomass. Samples from around the pool were averaged for each date (in order from left, n = 12, 32, 4, 2, 7; bars = s.d.).

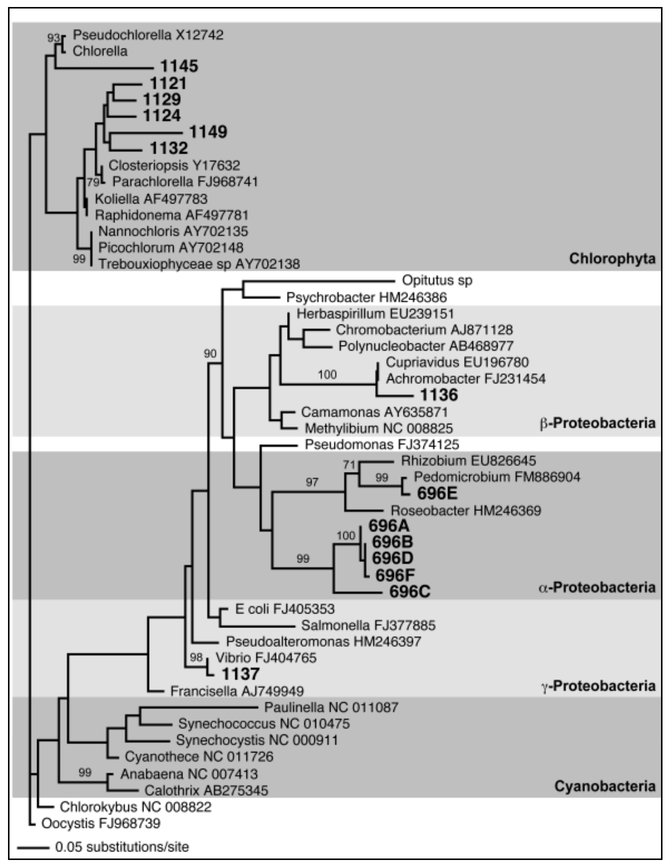

Figure 5. Phylogenetic tree of isolated microorganisms. Taxa identified with numbers (only) are sequences generated from this study. All of the isolates from Meacham Cave grouped into the Chlorophyta and Proteobacteria divisions. Only bootstrap values greater than 70% are shown.

Table 1. Animals in and around Meacham Cave.

Outside of the cave (within 5 m of entrance):	
Vertebrates	
Eumeces fasciatus (Five-lined skink)	
Plethodon serratus (Southern red-backed salamander)	
Sciurus carolinensis (Gray squirrel)	
Invertebrates	
Acrosternum hilare (Green stink bug)	
Bombus sp. (Bumblebee)	
Camponotus pennsylvaticus (Black carpenter ant)	
Ceuthophilus maculatus (Spotted camel cricket)	
Leiobunum sp. (Eastern daddy longlegs)	
Leucage venusta (Venusta orchard spider)	
Musca domestica (House fly)	
Pardosa sp. (Thin-legged wolf spider)	
Phiddipus audax (Bold jumping spider)	
Pisauridae family (Nursery web spider)	
Thysanura sp. (Jumping bristletail)	
Inside of the cave:	
Vertebrates	
Eptesicus fuscus (Big brown bat)	
Perimyotis (formerly *Pipistrellis*) *subflavus* (Tri-colored bat, formerly Eastern pipistrelle)	
Eurycea lucifuga (Cave salamander)	
Lithobates (formerly *Rana*) *palustris* (Pickerel frog)	
Invertebrates	
Abacion sp. (Millipede)	
Arrhopalitidae family (Globular springtails, two different)*	
Cambala minor (Lesser cave-loving millipede)*	
Cantheridae family (Soldier beetle larva)	
Causeyella sp. (Cave millipede)*	
Ceuthophilus maculatus (Spotted camel cricket)*	
Culicidae family (Mosquito)	
Dolomedes tenebrosus (Dark fishing spider)	
Heleomyzidae family (Heleomyzid fly)	
Leiodidae family (Round fungus beetle larva)	
Linyphiidae family (Sheet-weaving spider)	
Litocampa sp. (Cave two-pronged bristletail)*	
Lumbricus terrestris (Earthworm)	
Macrocera nobilis larva (Ozark webworm)*	
Oxidus gracilus (Greenhouse millipede)	
Parajulidae family (Millipede)	
Patera perigrapta (Engraved bladetooth snail)	
Phoridae family (Humpbacked fly)	
Pseudopolydesmus sp. (Millipede)	
Psychodidae family (Moth fly)	
Rhagidiidae family (Mite)	
Sinella sp. (Springtail)*	
Sphaeroceridae family (Dung fly)*	
Tineola bisselliela (Clothes moth)	
Tomoceridae family (Springtail)	

*Indicates likely troglophilic or troglobitic organisms.

Aside from the coliforms, two major microbial groups were identified by 16s ribosomal gene sequences (Figure 5). The number of identified isolates was disappointingly low, and probably was the result of difficulties in extracting DNA from the microorganisms and environmental samples. All of the bacteria that we identified were members of the Proteobacteria division. The Proteobacteria division is the single largest group in both epigean and hypogean environments (Romero 2009) and includes the coliforms. Isolate 696E, a culture-independent sample, was identified as being homologous with *Pedomicrobium*, a Mn-oxidizing bacterium (Larsen et al. 1999) that has been implicated with MnO_2 deposits in caves (Northup et al. 2003). In some caves, metal-oxidizing bacteria, like *Pedomicrobium*, are the chemoautotrophic bases of food webs (Barton et al. 2007, Northup et al. 2003, Spilde et al. 2005).

Members of the Chlorophyta division (green algae) comprised the other major group of microbes identified from the cave. The role and origin of algae in the cave is unclear. While light from the entrance is visible from the pool, the amount of incident light (<1 μmol photons m^{-2} s^{-1}) is far below the threshold of 12-28 μmol photons m^{-2} s^{-1} required for photosynthesis in chlorophytes (Richardson et al. 1983). Studies from Hungarian caves indicate that some algae utilize heterotrophic metabolism in place of photosynthesis (Claus 1962, Claus 1964, Hahdu 1966, Kol 1967). Another possibility is that epigean algae are carried by water as it percolates into the cave from the surface. In show caves, which are periodically illuminated by floodlights, algae may receive enough energy to grow at a slow rate, and may become "nuisance organisms" to cave owners (Aley 2004, Smith and Olson 2007). In wild caves, non-facultatively heterotrophic algae would eventually die in the cave, if not for the fortuitous collection by cave biologists.

In both microbial divisions, more specific identifications were not possible for two major reasons. First, BLAST comparisons often yielded close matches with "environmental samples" – uncharacterized organisms within the same taxon. Second, the "universal" primers used are not always long enough to allow species-level comparisons.

Table 1 lists the animals observed to date. Most of the epigean organisms were found within 5 meters of the entrance. Hypogean organisms were found throughout the cave, but were concentrated near the entrance and the main chamber. Cataloguing of the epigean organisms occurred during February through April 2009. Cataloguing of the hypogean organisms occurred throughout the 25 visits. We did not find any aquatic invertebrates during any of the visits – probably due to the transient nature of the cave pool. Invertebrates were more common and more diverse than vertebrates. The total number of vertebrates found during any visit seemed low as compared to other caves in the area. We found no more than three bats, frogs or salamanders during each visit with one notable exception – 12 Western slimy salamanders (*Plethodon albagula*) were found during a single visit in June 2010.

For comparison, Cave Point Cave and Logan Point Cave (both in neighboring Stone County), are of similar or smaller volumes than Meacham Cave, but during a typical visit to Cave Point Cave, we have found 50 or more bats and 5 or more salamanders. During a single visit to Logan Point Cave, we found 3 bats and 20 salamanders (unpublished data). While the numbers of salamanders seem low in comparison to the two other caves mentioned, a survey of salamander use of 93 small caves in Crawford County (northwestern Arkansas), found average numbers of salamanders similar to what we reported here for Meacham Cave (Briggler and Prather 2006). A similar study on tri-colored bats (*Perimyotis subflavus*) in 54 northwestern Arkansas caves found >3 bats per visit for caves similar in length to Meacham Cave (Briggler and Prather 2003). However, that study also indicated that the bats preferred hibernacula with east-facing entrances; Meacham Cave's entrance faces west.

The seemingly low number of salamanders may actually be normal for a cave the size of Meacham, but the low bat count may be due to other causes. Specifically, the burning of wood in the fire pit, noted previously, may be responsible for the low bat population. A study that modeled smoke and fire effects on tree-dwelling bats showed that carbon monoxide poisoning and ear burns occurred during wildfires and prescribed fires (Dickinson et al. 2010). In the arboreal environment, CO poisoning was critical only directly above flames. However, in the enclosed environment of a cave, we would expect CO concentrations to be higher with smaller fire sources. Additionally, smoke irritants and CO may have more intense effects on bats in torpor or hibernation (Dickinson et al. 2009).

Conclusions

Leaf litter and other organic matter from the surface are the likely sources of energy for Meacham Cave's ecosystem. The algae found in the cave were not in suitable locations for photosynthesis, and bat guano was scarce. A single potentially chemosynthetic bacterial isolate was found, but the contribution of chemosynthesis to the cave's ecosystem probably is minimal at best. The number and diversity of vertebrates is low, especially for bats, and may be due, in part, to human abuse of the cave.

Meacham Cave's proximity to Lyon College makes it a useful long-term research site, and our results provide a baseline for continuing studies. As the threat of white nose syndrome – a fatal disease of bats associated with the fungus *Geomyces destructans* – continues to grow, the low bat population is of particular concern (Blehert et al. 2009, Chaturvedi et al. 2010, Gargas et al. 2009). Gating the cave entrance to prevent entry by vandals – while allowing ingress and egress of cave animals – may help to increase the populations of bats and other cave animals.

Acknowledgements

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Rapid Reservoir Inundation Causes Complete Extirpation of the Eastern Collared Lizard (*Crotaphytus collaris*) Along the Shoreline of Bull Shoals Lake in Northern Arkansas

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Abstract

The eastern collared lizard (*Crotaphytus collaris*) is a large saxicolous predatory lizard, which dwells in patchy, cedar glade environments characteristic of much of the Ozarks. The species can also be found in scattered populations along rocky shoreline habitats of large impoundment reservoirs of northern Arkansas. These lizards time their entrance into and exit from underground, overwintering retreats with decreasing and increasing ambient temperatures of the fall and spring months. During an average spring, several sustained days of warm temperatures from mid-March into April are the primary environmental cues for collared lizards to exit their shelters. Excessive winter/spring precipitation in the Arkansas Ozarks, however, can drastically alter reservoir hydrology of the impoundments on the White River system. In years of catastrophic flood conditions, such as in 2008, the rapid inundation of suitable shoreline habitats preceded the exiting of lizards from hibernation burrows; thus, these populations of collared lizards (i.e., those that occurred along both Bull Shoals and Norfork lakes) were effectively entombed in their hibernation burrows, which putatively resulted in a complete population crash of this species within exposed shoreline environments.

Introduction

During the late 1940s and early 1950s, the U. S. Army Corps of Engineers (USACE) constructed two large hydroelectric dams/flood control impoundments (Bull Shoals and Norfork lakes) on the lower stretches of the White River system. The reservoirs inundated this drainage region in both the Ozarks of northern Arkansas and southern Missouri. Following the construction of dams and their gradual filling, these lakes have routinely experienced fluctuating hydrologies due to the variable amounts of annual precipitation that fall in the Ozarks. Several years, in particular, have experienced severe late winter/early spring rains. For example, the normal power pool level of Bull Shoals Lake is 654 ft. above sea level, and flood pool is 691 ft. Over its history, the lake water levels regularly fluctuate between 630 ft. and 680 ft. Four notable flooding events, however, have occurred on Bull Shoals Lake during its 58+ year history. A water level of 694.4 ft. above sea level was recorded on July 2, 1957, and a similar flood level was reached on May 9, 1990 at 691.4 ft. On June 18, 2002, the lake reached a level of 688.8 ft, and the highest water level ever recorded occurred on April 15, 2008, at 695.03 ft. (http://www.swl-wc.usace.army.mil/mcharts.htm).

The eastern collared lizard, *Crotaphytus collaris*, inhabits Ozark sandstone or limestone exposed environments, commonly called “cedar glades,” which are scattered throughout the Ozark Highlands in Arkansas and Missouri. These natural habitats occupy around 200,000 hectares in each state (Crawford et al., 1969). The size of individual cedar glades varies greatly from less than 0.1 hectare to many hectares. Cedar glade habitats are mostly dry open areas of exposed, eroded sedimentary bedrock or igneous rocks that are often accompanied by other rocky outcroppings, which exhibit little or no vegetation (Baskin and Baskin 2000). *Crotaphytus collaris* often dwells in these patchy, cedar glade environments (Angert et al. 2002); this species can also be found in scattered populations along the rocky shoreline habitats of man-made reservoirs.

These lizards time their entrance into and exit from underground, overwintering retreats to decreasing and increasing ambient temperatures of the fall and spring months (Trauth et al. 2004). During an average spring, several sustained days of warm temperatures from mid-March into April, are the primary environmental cues for eastern collared lizards to exit their overwintering shelters.

The objective of the present paper is to provide a historic account of the impact of reservoir inundation on populations of the eastern collared lizard along the shoreline of Bull Shoals Lake in northern Arkansas. This information reveals the dramatic effects that periodic flooding episodes can have on shoreline habitats along with the resulting extirpation of lizard populations occupying these shoreline environments.

Materials and Methods

Historic collection localities for *Crotaphytus collaris* along the shoreline of Bull Shoals Lake (Fig. 1) have been visited periodically for the presence of lizards since 1971. These localities are described elsewhere (Trauth 1974). Two of these historic habitats have received more scrutiny for lizard activity than others over the years. On occasion, photo vouchers or museum specimens were gathered at these two sites. Historic collection site 1 is located on Promise Land Ridge at the end of Promise Land Road (Marion County: 36°24’20.22”N; 92°34’26.38”W). The shoreline is a southeast-facing exposure of shelf rock that is intermittently vegetated with various annual and perennial grasses and other annual herbaceous plants. This site, until recently, has supported a lizard population for at least 55 years (S. Trauth, pers. observ.). This lizard population has also tolerated human traffic and disturbances for the same amount of time. Shoreline vegetation above the flood pool level at this site is a mixture of oak-hickory deciduous hardwoods and, to a lesser extent, some eastern red cedar. Historic site 2 is a southwest-facing, moderately-inclined, rocky tiered-bluff shoreline (Fig. 2) situated along the former White River channel between Howard and Noe creeks (Marion County: 36°23’50.36”N; 92°33’12.37”W). Access to historic site 2 is accomplished only by boat. Shoreline vegetation is minimal here with sparse areas of annual and perennial grasses and annual herbs below the flood pool level. Dominant woody vegetation immediately above the flood pool level is mostly eastern red cedar with some oak-hickory hardwoods.

Results and Discussion

During the past 58 years, populations of *Crotaphytus collaris* have persisted in spite of the unpredictably of the environmentally disturbed rocky shoreline habitats that surround this reservoir. During the reservoir’s early years and following the lake’s initial inundation, a severe drought (1953-1955) in the area depleted the water table level, which created emigration corridors for these lizards as they expanded their populations horizontally from native habitats into newly exposed rocky environments. A critical measure of the sustainability of these new lizard populations, however, still exists today; i.e., the interplay between the timing of the fluctuating hydrology of the lake and the phenological life cycle of the lizard. During the catastrophic flood of 1957 (and in those years immediately following the flood), *C. collaris* undoubtedly survived by moving into higher elevations (native cedar glade environments contiguous to the lake shore) above the flood pool water level and, thereby, the lizards effectively outpaced the rising flood waters, which peaked on July 2 of that year. Favorable habitat conditions above the flood pool level of the young reservoir were presumably remnants of native xeric habitats that were still prevalent at that time above the exposed shoreline. In years following the 1957 flood, the original riparian shoreline vegetation above power pool was now wiped out, thus creating an open environment that allowed for immediate access by lizards, and their populations presumably increased. I repeatedly observed populations of this lizard at historic site 1 throughout the 1960s, a circumstance that actually led me into investigating the biology of this lizard species in Arkansas as well as to document additional populations (via water access) along much of Bull Shoals Lake’s lower shoreline during the lizard activity seasons of 1971 and 1972 (Trauth 1974).

The ability of lizard populations to survive rapid inundation of the lake can also be linked to the exact timing of each flooding episode. The 1957 high water mark was reached during mid summer at a time when most reproductive behaviors were waning, leading possibly to less contact between adult lizards and their predators within the high water line habitats. In addition, adult gravid females were capable of laying their egg clutches in non-inundated microhabitats, thus insuring progeny for the next generation.

Another flooding event similar to the hydrological conditions of 1957 occurred again in 1990 (Fig. 3). As was the case in 1957, the high water mark was reached at a time (May 9) that, presumably, did not interfere with successful courtship and mating activities (for details on the reproductive cycles in this species, see Trauth 1978, 1979). Again, lizards were observed during the spring of 1992 at historic site 1 (photographic confirmation by B. A. Trauth, unpubl.).

A third flooding event, recorded in 2002, largely mirrored the previous two described above. In that year the high water mark occurred on June 18. Evidence for lizard survival of this inundation was recorded three years later at historic site 2 on August 9, 2005 (Fig. 2). My graduate student (Phillip Stewart) and I were able to capture and release several adults perched high on this bluffy shoreline on this date. We did not, however, observe any lizards at other historic sites, and, in particular, none was observed at historic site 1. This paucity of visual recording for this species in August is not totally surprising at this time of the year, given that all adults had ceased reproductive activity, had become mostly lethargic, and had escaped the intense summer heat by retreating into shelters during most of the day.

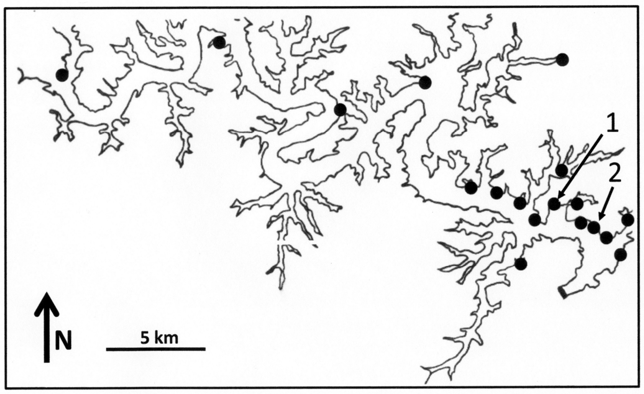

Figure 1. Historic collection sites (solid symbols) for *Crotaphytus collaris* along shoreline of Bull Shoals Lake in northern Arkansas. Collection sites designated as 1 and 2 are discussed in the text. Locality data are from Trauth (1974).

Figure 2. Historic collection site 2 for *Crotaphytus collaris* along Bull Shoals Lake in northern Arkansas, as seen on August 9, 2005. Arrow points to power pool level. Graduate student, Phillip Stewart, can be seen standing in the upper left quadrant of the photo.

A fourth flooding event, which occurred in 2008, resulted in the most devastating inundation of all high-water episodes recorded for this lake. It represents the worst case scenario for not only populations of *Crotaphytus collaris*, but also for any poikilothermic vertebrate species unfortunate enough to have overwintered in underground denning sites in shoreline habitat retreats situated below the flood pool level on this lake. Calamitous conditions arose due to severe and unseasonable, late winter/early spring rainfall, which caused a rapid inundation of the reservoir with the high water mark being reached on April 15 (Fig. 4). The greatest amount of rainfall, 6.59 inches, occurred over a 3-day period (March 18-20) and contributed to a rapid rise in the water table from 658.4 ft. to 678.4 ft. in 14 days. Most populations of *C. collaris* had not become active at this time and could not have escaped

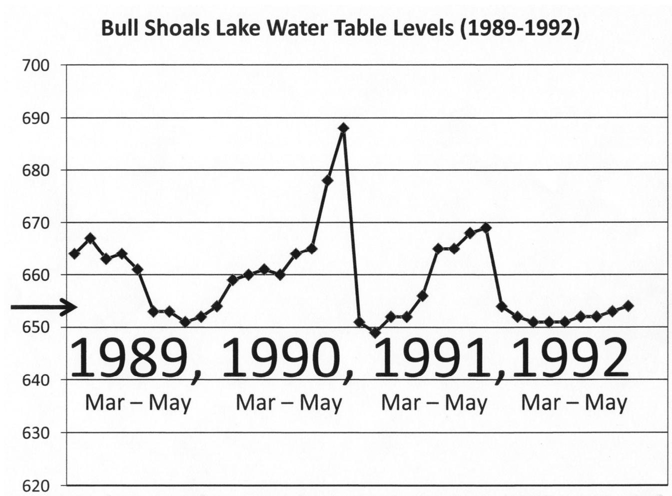

Figure 3. Variation in the Bull Shoals Lake water table levels for the March-May time intervals from 1989-1992. Time separation between symbols equals 15 days. Arrow indicates power pool level.

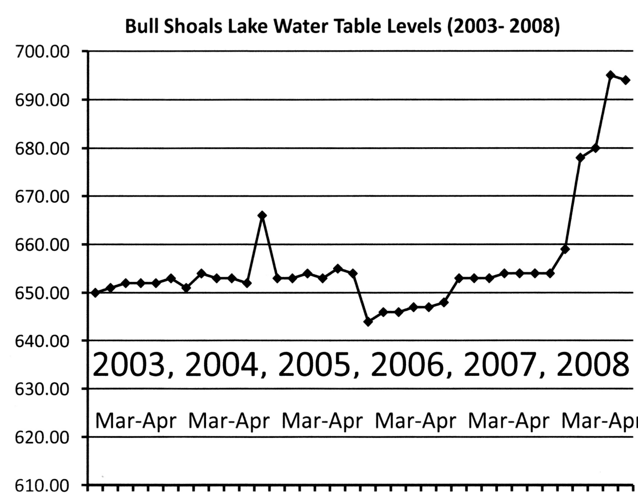

Figure 4. Variation in the Bull Shoals Lake water table levels for March-April time intervals from 2003-2008. Time separation between symbols equals 15 days.

this initial rapid rise in the water table. Presumably, all lizards dwelling within the lower lakeshore habitats were lost by submersion. An additional 6.09 inches of rainfall fell between April 1and April 15, resulting in a final rise of 16.6 ft. to reach flood pool. During these two weeks, any lizards occupying higher shoreline habitat levels were submerged, forced out of their primary dens into unsuitable hardwood habitats, or became easy prey items for predators. Ultimately, no optimal cover rocks, basking perches, or open habitats were accessible above the flood pool level in virtually all lower lake shorelines; consequently, all populations of this lizard presumably suffered a catastrophic crash.

I visited historic sites 1 and 2 (Fig. 5) as well as five others on May 18, 2010; the power pool level of the lake then was 660.3 ft. Upon habitat inspection, normal shoreline features of the past were evident. A preponderance of driftwood along the flood pool mark was present; otherwise, I saw no obvious indication that a flood had occurred two years prior in these exposed shorelines. I examined the dominant rocky ledges and outcroppings where lizards had been common in the past. I found no lizards or traces of *Crotaphytus collaris* scats (an indication of recent saurian surface activity) in any of the historic sites. Thus far in May, the lake region had experienced 10 days of over 24.0° C (75.0° F) temperatures, more than sufficient, thermally, for collared lizard activity.

As Bull Shoals Lake has aged over its six decades of existence, natural vegetational succession as well as succession exacerbated by human intervention has greatly modified native glade habitats lying above the flood pool mark. A major cause for alarm regarding lizard population survivorship is directly related to the overall loss of remnant shoreline glades, largely absent today due to a combination of continual encroachment of the hardwood forests and the overgrowth of cedar thickets in former glade environments. The suppression of fire is a major contributing factor leading to loss of native glade habitats (Trauth 1989, Brisson et al 2003).

Figure 5. Historic site 2 (in background; see Fig. 2) on Bull Shoals Lake on May 18, 2010. Notice separation between vegetation at the flood pool level (above arrow) and exposed shoreline (below arrow).

A complete population crash would seem to be a rare event for these lizards along Bull Shoals Lake. One would generally assume that some lizards should have survived by escaping into remote or marginal habitats above the flood pool level. The most representative habitat to possess a combination of suitable above flood-pool features for *Crotaphytus collaris* is located along the shoreline at historic site 2. Several sheer rocky, bluff exposures (as shown in Fig. 2), however, could not have easily accommodated lizards in 2008. Moreover, an examination of average daytime and nighttime temperatures as well as total precipitation for the 17-day time period (March 1-17) prior to the 2008 flood surge strongly suggest that most lizards would not have ventured far out of their local denning sites, making escape to higher ground highly unlikely. For example, the average nighttime low temperature was 0.8° C (32.9° F), and the average daytime high temperature was 14.0° C (57.4° F) during this time period. In addition, during the first week of March, 3 snowfalls occurred and only on 2 consecutive days (13th and 14th) did daytime high temperatures reach beyond 21° C (70° F). Collared lizards generally require 2-3 days of intense sunshine at this time of year to initiate departure from overwintering retreats and provide sufficient warmth for the onset of territorial, basking, and predatory behavior.

Few land use/management practices or glade rehabilitation efforts have been conducted on Bull Shoals Lake to enhance the historic native environments that immediately surround the lake shore. One notable exception can be found on the Point 6 peninsula in Big Sister Creek (Marion County: 36°25’44.63”N; 92°34’26.08”W), where USACE biologists and fire management personnel have begun restoring a native glade with the use of prescribed burns (Jon Hiser and Bruce Caldwell, *pers. comm.*). Another possible exception would be Jones Point Wildlife Management Area (36°26’24.43”N; 92°42’38.90”W), a mostly isolated upland (757 ft.) peninsula where populations of *Crotaphytus collaris* still exist on native glades.

Conclusions

Catastrophic reservoir inundation, like the one that occurred on Bull Shoals Lake in 2008, presumably resulted in the localized extirpation of the eastern collared lizard, *Crotaphytus collaris*. This lizard species had become adapted to a highly disturbed ecosystem by its occupation of a flood-prone, semi-natural shoreline habitat. Vegetative succession through time had essentially eliminated any potential ecological corridor for escape or avoidance of an unfavorable environmental condition, such as a flood. The ecological instability of this lizard's linear habitat dramatizes the need to maintain biodiversity in man-made semi-natural ecosystems for the preservation and well-being of native species. (Addendum: Following the submission of this manuscript in April 2011, Bull Shoals Lake set a new record high water level at 696.46 ft. on May 28, 2011.)

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Summary of Previous and New Records of the Arkansas Darter (*Etheostoma cragini*) in Arkansas

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Abstract

The Arkansas Darter, *Etheostoma cragini*, has an extremely limited distribution in Arkansas and is designated as a candidate for listing under the federal Endangered Species Act. It was first documented in the state in 1979 in Wilson Spring near Fayetteville. Between 1979 and 1985 it was collected in 4 additional headwater streams in Benton and Washington counties. A 1997 study documented the persistence of the species in 3 of the 5 historic streams, but 1 stream yielded only a single individual. A 2004-2005 study reassessed the status of the 5 historically known populations and searched broadly for new populations, documenting *E. cragini* at 15 sites, all within a 2-km radius of historic sites. In 2010-2011, more concentrated sampling efforts were made in the sub-basins with prior records of the species. These efforts documented populations at 13 additional sites, greatly improving the resolution of the distribution of this species within Arkansas.

Introduction

The Arkansas Darter, *Etheostoma cragini*, was originally described from a site near Garden City, Kansas (Gilbert 1885). It inhabits small spring-fed tributaries of the Arkansas River basin in Colorado (Beckman 1970), Kansas (Cross and Collins 1995), Oklahoma (Miller and Robison 2004), Missouri (Pflieger 1997), and Arkansas (Robison and Buchanan 1988). It is rare in Arkansas and is of special concern due to its limited habitat in the state (Robison and Buchanan 1988). Past collections have documented this species in 4 areas. We made more concentrated searches in and around these areas, discovering populations in additional streams within the 4 areas and in additional streams nearby.

Methods

ESRI ArcMap™ geographic information system software and ground reconnaissance with local landowners were used to identify spring run habitats within the sub-basins where *E. cragini* had previously been documented. After receiving landowner permission, these habitats were sampled by using 1/3-m, 1/8-inch mesh dip-nets. One hundred eight sites were sampled between November 2009 and March 2011. Sampling by 2 to 4 netters was focused on aquatic vegetation, submerged terrestrial vegetation, undercut banks, and backwater areas with fine substrate deposits, where *E. cragini* individuals are typically encountered based on our past experience. When specimens of *E. cragini* were collected in areas likely to represent new populations, 1 to 3 voucher specimens were preserved in 10% formalin. Vouchers have been or will be deposited in the collections of the University of Arkansas – Fort Smith or Arkansas Game and Fish Commission – Nongame Aquatics Program.

The small watercourses where *E. cragini* occurs are often unnamed and not marked on published maps, making relocation of some historic sites problematic. Geographic positioning system (GPS) devices now provide more accurate location designations. We have included GPS locations in decimal degrees, North American Datum 1927, for all locations where we collected *E. cragini.*

Results

We summarize collections from all major studies of *E. cragini* in Arkansas and several new discoveries to provide a comprehensive look at distribution of the species in the state (Figure 1).

The first known occurrence of *E. cragini* in Arkansas was based on the collection of 5 specimens in 1979 from what is now known as Wilson Spring in northwestern Fayetteville (Harris and Smith 1985).

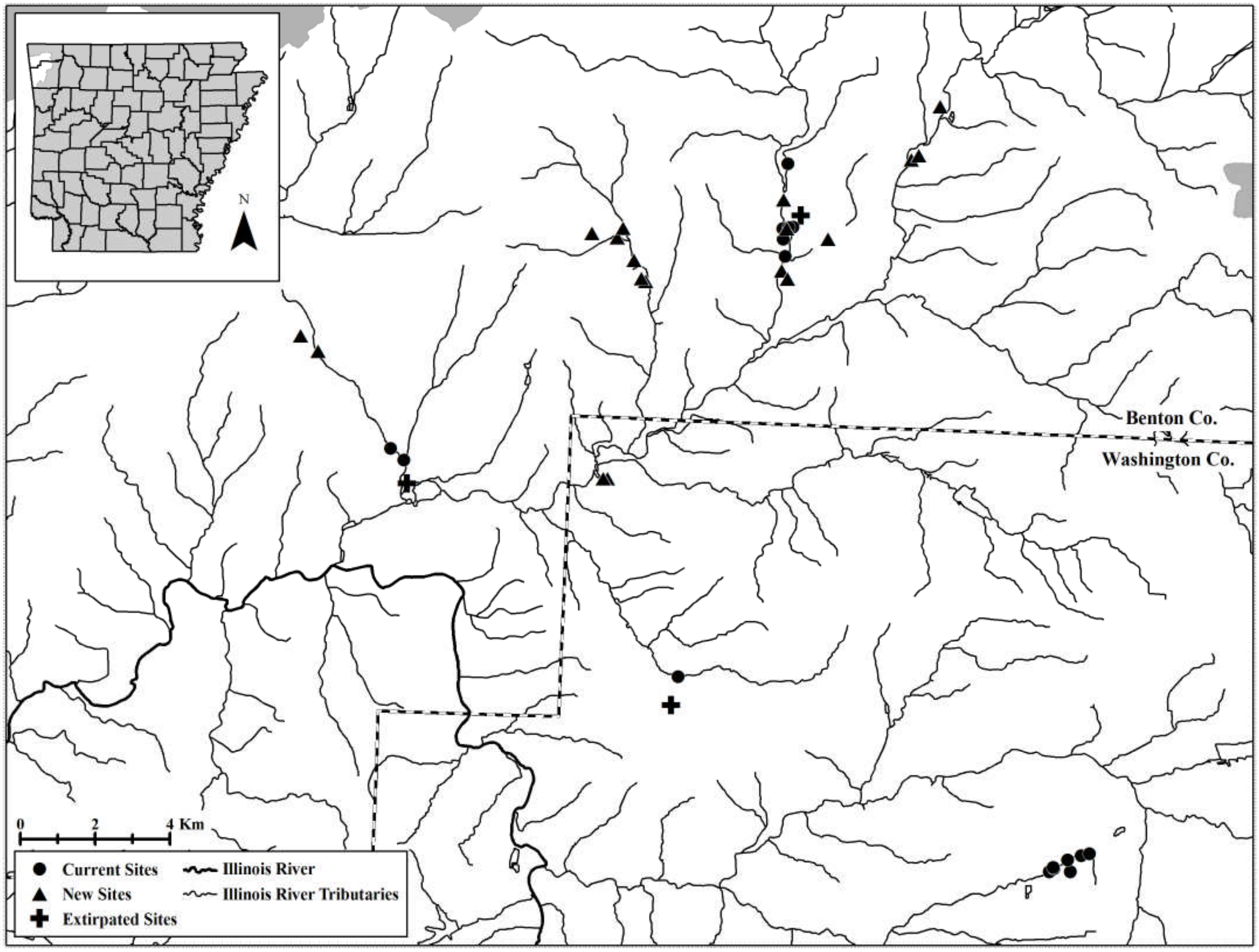

Figure 1: Map of Benton and Washington counties, Arkansas, depicting all sites where *Etheostoma cragini* has been collected. Current sites were documented prior to this study. Adjacent sites connected by occupied habitat are a single "population."

Intensive sampling in 1997 for a mark-recapture population estimate (Hargrave 1998, Hargrave and Johnson 2003) captured 207 specimens from this spring. Extensive sampling in 2004 yielded 60 specimens, confirming the species' presence in Wilson Spring; in Clabber Creek downstream of Wilson Spring to the beginning of a broad, deep, channelized section; in the lower end of a spring run entering from the opposite side of the creek; upstream in the creek at least to the Interstate Highway 530 crossing; and throughout a drainage ditch flowing into the creek upstream of Arkansas Highway 112 (Wagner and Kottmyer 2006).

- Washington County: Unnamed spring run at junction of Arkansas Highway 112 and U.S. Highway 71 bypass in Fayetteville (T17N R30W sec. 33), 19 March 1979, 5 specimens uncatalogued (Harris and Smith 1985).
- Washington County: Wilson Spring run at junction of Arkansas Highway 112 and U.S. Highway 71 bypass in Fayetteville (T17N R30W sec. 33 NW), 19 October 1997, 207 released alive (Hargrave 1998, Hargrave and Johnson 2003).
- Washington County: Wilson Spring run at junction of Arkansas Highway 112 and U.S. Highway 71 bypass in Fayetteville (T17N R30W sec. 33 NW, 36.10677 N 94.18809 W), 9 April 2004, 6 released alive (Wagner and Kottmyer 2006), 2 November 2009, 5 released alive.
- Washington County: Clabber Creek near junction of Arkansas Highway 112 and U.S. Highway 71 bypass in Fayetteville (T17N R30W sec. 33 NW, 36.10603 N 94.18950 W), 9 April 2004, 18

released alive (Wagner and Kottmyer 2006), 2 November 2009, 9 released alive.

- Washington County: Clabber Creek behind Landers Auto near junction of Arkansas Highway 112 and U.S. Highway 71 bypass in Fayetteville (T17N R30W sec. 28 SE, 36.10997 N 94.17997 W), 9 April 2004, 43 released alive (Wagner and Kottmyer 2006).
- Washington County: unnamed spring tributary of Clabber Creek near junction of Arkansas Highway 112 and U.S. Highway 71 bypass in Fayetteville (T17N R30W sec. 33 NW, 36.10712 N 94.18828 W), 9 April 2004, 1 released alive (Wagner and Kottmyer 2006).
- Washington County: marshy seep tributary of Clabber Creek at Truckers Lane in Fayetteville (T17N R30W sec. 33 N, 36.10891 NE 94.18406 W), 9 April 2004, 1 released alive (Wagner and Kottmyer 2006).
- Washington County: ditch tributary of Clabber Creek at drive-in theater in Fayetteville (T17N R30W sec. 28 SE, 36.11048 N 94.17760 W), 9 April 2004, 5 released alive (Wagner and Kottmyer 2006).

Harris and Smith (1985) reported *E. cragini* from Healing Spring Run and Little Osage Creek based on a 1981 collection at their confluence. Intensive sampling in 1997 for a mark-recapture population estimate (Hargrave 1998, Hargrave and Johnson 2003) yielded 43 specimens from Healing Spring Run. Wagner and Kottmyer (2006) sampled widely in the area, increasing definition of the geographic scope of populations in this area, including population in four additional spring tributaries to Little Osage Creek in the area. Recently, we walked all of Little Osage Creek in this area searching for suitable habitat and collected single *E. cragini* specimens in 2 disjunct patches of vegetated backwater habitat along the main creek. These observations lead us to believe that the mainstem of Little Osage Creek does not provide significant habitat for this species, but rather is occasionally occupied by individuals from the tributary populations straying into patches on suitable backwater habitat.

- Benton County: Healing Spring Run and Little Osage Creek at Arkansas Hwy. 264 crossing (T18N R31W sec. 10), 21 August 1981, 5 specimens (ASUMZ 9340; Harris and Smith 1985).
- Benton County: Healing Spring Run at Arkansas Hwy. 264 crossing (T18N R31W sec. 10 NW), 5 November 1997, 43 released alive (Hargrave 1998, Hargrave and Johnson 2003).
- Benton County: Healing Spring Run at Arkansas Hwy. 264 crossing (T18N R31W sec. 3 SW, 36.26073 N 94.27032 W), 4 May 2005, 11 released alive (Wagner and Kottmyer 2006), 3 November 2009, 15 released alive, 10 June 2010, 3 released alive.
- Benton County: unnamed spring run tributary to Healing Spring Run (T18N R31W sec. 3 SW, 36.25808 N 94.27301 W), 27 October 2005, presence noted (Wagner and Kottmyer 2006).
- Benton County: unnamed spring-fed ditch above a pond on Mill Dam Road (T18N R31W sec. 3 E, 36.26387 N 94.26602 W), 27 October 2005, 9 released alive (Wagner and Kottmyer 2006). Recent visits indicate this population is extirpated.
- Benton County: unnamed spring run tributary to Little Osage Creek (T19N R31W sec. 34 SW, 36.27636 N 94.27004 W), 5 October 2005, 27 specimens (25 released alive, 2 UAFS-1740; Wagner and Kottmyer 2006), 4 November 2009, 15 released alive.
- Benton County: unnamed spring run #1 tributary to Little Osage Creek (T18N R31W sec. 3 SE, 36.26098 N 94.26819 W), 28 October 2005, presence noted (Wagner and Kottmyer 2006), 3 November 2009, 5 released alive.
- Benton County: unnamed spring run #2 tributary to Little Osage Creek (T18N R31W sec. 3 SW, 36.26092 N 94.26949 W), 28 October 2005, presence noted (Wagner and Kottmyer 2006).
- Benton County: backwater on east bank of Little Osage Creek (T18N R31W sec. 3 NW, 36.26770 N 94.27115 W), 18 November 2010, 1 released alive.
- Benton County: Little Osage Creek across from mouth of Healing Spring Run (T18N R31W sec. 10 NW, 36.25391 N 94.27040 W), 15 November 2005, 1 specimen (UAFS-1690, Wagner and Kottmyer 2006).
- Benton County: unnamed spring run tributary to Little Osage Creek on Colonel Meyers Road (T18N R31W sec. 10 SW, 36.24857 N 94.26967 W), 15 November 2010, 7 specimens (6 released alive, 1 AGFC uncatalogued).
- Benton County: unnamed spring run tributary to Little Osage Creek on Arkansas Highway 264 (T18N R31W sec. 2 SW, 36.25831 N 94.25769 W), 21 October 2010, 30 specimens (29 released alive, 1 AGFC uncatalogued).

Harris and Smith (1985) reported 2 unnamed spring run tributaries of Osage Creek near the community of Logan as occupied by *E. cragini* based on 1982 collection records. When resurveyed in 1997 (Hargrave 1998, Hargrave and Johnson 2003), one of these was described as Gailey Hollow and yielded 1 specimen. The second was denoted as Lower Palmer Spring and yielded no specimens. In 2005, what was thought to be Lower Palmer Spring and the creek channel in Gailey Hollow were both dry. Wagner and Kottmyer (2006) encountered 42 *E. cragini* throughout 2 spring branches that merge and would flow into Gailey Hollow during wetter conditions. Subsequent visits have found flow and small numbers of *E. cragini* reaching Gailey Hollow on occasion. Our recent surveys documented populations 3.25 km northwest of the previously known population, separated by a losing stream section that apparently has surface flow only during extreme flood conditions.

- Benton County: unnamed spring run tributary to Osage Creek near Logan community (T18N R32W sec. 27), 23 March 1982, 12 specimens (NLU 54208; Harris and Smith 1985)
- Benton County: Gailey Hollow (T18N R32W sec. 27 SW), *unknown date* 1997, 1 released alive (Hargrave 1998, Hargrave and Johnson 2003).
- Benton County: two spring branch tributaries to Gailey Hollow (T18N R32W sec. 27 SW, 36.20622 N 94.38728 W), 7 June 2005, 42 specimens (41 released alive, 1 UAFS-1606; Wagner and Kottmyer 2006).
- Benton County: unnamed spring run tributary to Osage Creek near Logan community (T18N R32W sec. 34), 28 July 1982, 3 specimens (ASUMZ 9396; Harris and Smith 1985).
- Benton County: unnamed spring run tributary to Osage Creek near Logan community (T18N R32W sec. 17 SW, 36.23326 N 94.41459 W), 2 March 2011, 5 specimens (4 released alive, 1 AGFC uncatalogued).
- Benton County: unnamed spring run tributary to Osage Creek near Logan community (T18N R32W sec. 20 NE, 36.22952 N 94.40927 W), 2 March 2011, 6 specimens released alive.

Harris and Smith (1985) reported an unnamed spring run tributary of Wildcat Creek as occupied by *E. cragini* based a 1982 collection. When resurveyed in 1997 (Hargrave 1998, Hargrave and Johnson 2003), the location was described as Huffmaster's Spring, and yielded no specimens. Wagner and Kottmyer (2006) discovered a small new population nearby, possibly the source of the 1982 specimen. Extensive searches in the area have failed to uncover additional populations.

- Washington County: Spring run tributary to Wildcat Creek northeast of White Oak Church and cemetery (T17N R31W sec. 17), 20 April 1982, 1 specimen (NLU 54206; Harris and Smith 1985).
- Washington County: Spring run tributary to Wildcat Creek northeast of White Oak Church and cemetery (T17N R31W sec. 17 NE, 36.15200 N 94.30072 W), 22 September 2005, 19 specimens (18 released alive, 1 uncatalogued; Wagner and Kottmyer 2006), 8 April 2008, 3 released alive, 16 November 2010, 3 released alive.

The expansion of *E. cragini* records in tributaries of Little Osage Creek prompted a focus of searches in other parts of the Osage Creek watershed. The known distribution of the species is expanded to the northeast by 2 new Benton County records, and a Washington County record was in a direct Osage Creek tributary located centrally between 3 of the previously known areas of record.

- Benton County: unnamed spring run tributary to Osage Creek 1/8 mile north of Evening Star Road (T19N R31W sec. 36 NE, 36.27877 N 94.23096 W), 10 June 2010, 4 specimens released alive; slightly upstream 26 October 2010, 3 released alive.
- Benton County: unnamed spring run tributary to Osage Creek on Shadow Valley Golf Course (T19N R31W sec. 25 SE, 36.29073 N 94.22485 W), 15 November 2010, 25 released alive.
- Washington County: unnamed spring run tributary to Osage Creek 1/4 mile west of Thornsberry Church (T18N R31W sec. 31 NE, 36.19941 N 94.32376 W), 3 December 2010, 26 released alive.

Lick Branch is the next watershed west of Little Osage Creek. It is highly karst influenced, with several losing segments that are dry at normal flow separating resurging segments where we collected *E. cragini* in the upper part of the watershed. We also documented significant populations in several spring tributaries to Lick Branch.

- Benton County: Lick Branch due east of junction of Benton County Road 221 and 216 (T18N R31W sec. 8NW, 36.25101 N 94.31352 W), 14 December 2010, 50 released alive.

- Benton County: unnamed spring run tributary #1 of Lick Branch east of junction of Benton County Road 221 and 216 (T18N R31W sec. 8 SW, 36.24760 N 94.31193 W), 14 December 2010, 30 released alive.
- Benton County: unnamed spring run tributary #2 of Lick Branch east of junction of Benton County Road 221 and 216 (T18N R31W sec. 8 SW, 36.24821 N, 94.31322 W), 14 December 2010, 10 released alive.
- Benton County: unnamed spring run tributary of Lick Branch along Arkansas Highway 264 (T19N R31W sec. 6 SW, 36.25891 N, 94.32812 W), 1 March 2011, 60 released alive.
- Benton County: unnamed run below a pond tributary to Lick Branch (T19N R31W sec. 6 SE, 36.25814 N 94.32078 W), 1 March 2011, 2 released alive.
- Benton County: Lick Branch north of Arkansas Highway 264 (T19N R31W sec. 6 SE, 36.26122 N 94.31868 W), 1 March 2011, 4 released alive.

Conclusion

More concentrated efforts to sample in small spring habitats within the watersheds where *E. cragini* has been observed in the past have led to discovery of several additional local populations in northwestern Arkansas. This has greatly increased the resolution of our understanding of the species geographic distribution within the state. While these efforts have significantly increased the total estimated number of *E. cragini* in the state, the populations are highly isolated. Due to the extent of intervening stream reaches that appear to be unsuitable habitat based on the lack documented *E. cragini* records, there seems to be little opportunity for movement between most populations. This leaves the local populations highly susceptible to extirpation, as has been observed in the case of one population discovered in 2005. In light of this, we consider the species to remain at risk in the state and encourage continued protection and conservation efforts.

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Assessment and Characterization of Physical Habitat, Water Quality, and Biotic Assemblages of the Tyronza River, Arkansas

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Abstract

Few studies within the last few decades have addressed water quality and biotic assemblages within Arkansas's large channel-altered deltaic rivers. The Tyronza River is located in northeast Arkansas and its watershed has a heavy agricultural presence that drastically affects habitat quality. Meanwhile, the Tyronza River hosts one of the more recent documented range extensions of the federally endangered fat pocketbook mussel [*Potamilus capax* (Green, 1832)]. The purpose of this study was to assess physical habitat, water quality, and biotic assemblages of the Tyronza River using the Arkansas Department of Environmental Quality's (ADEQ) regional biometrics. Water samples were collected at 9 stations across 4 seasonal intervals. Physical habitat, fish, and macroinvertebrates were collected at 9 stations during summer and fall. U.S. EPA Rapid Bioassessment Protocols for habitat indicated that habitat quality was suboptimal. Distinct seasonal differences were observed among all water chemistry parameters; however, seasonality was not as clear among nutrient constituents. Macroinvertebrate assemblages varied drastically among sites: taxa richness ranged from 3 to 14 and the Arkansas Macroinvertebrate Index for Small Watersheds values ranged from 16 to 28 (poor to very good condition). Fish Community Structure Indices were less variable among sites ranging from 6 to 16 (Not Similar to Somewhat Similar). The lack of instream habitat and habitat richness is likely resulting in low taxa richness in the biotic communities. Results from this study will provide managers and scientists with valuable information on seasonal variation of select water quality parameters and into the integrity of aquatic assemblages of the Tyronza River.

Keywords: Water quality, rapid bioassessment, Tyronza River

Introduction

Mississippi Alluvial Valley rivers and streams within Arkansas are understudied compared to those of other ecoregions. Few studies within the last few decades have addressed the spectrum of physical habitat quality, water quality, and biotic assemblages within Arkansas's large channel-altered deltaic rivers. Many early studies focused on fundamental differences in water quality and biotic assemblages among least-disturbed and channel-altered conditions (Marsh and Watters 1980, ADPCE 1985). Water quality issues are an increasing concern within the Mississippi Alluvial Valley, particularly within Arkansas where 1375 stream miles were listed as impaired on the 303 (d) list (ADEQ 2010, *submitted*). In 2004, the Tyronza River was added to the list of impaired waterbodies for exceeding ecoregion turbidity criteria (ADEQ 2004). With the completion of a total maximum daily load (TMDL) study in 2006, the Tyronza River was removed from the 303 (d) list (ADEQ 2006).

The Tyronza River increased in ecological value with the discovery of an extant population of the fat pocketbook mussel, *Potamilus capax* (Green, 1832*)*, a federally endangered species (Wentz et al. 2009). The fat pocketbook is uncommon throughout its historic range along the Mississippi River drainages from Illinois to Louisiana; however, the St. Francis River drainage hosts one of the largest populations (Harris et al. 2009). Harris et al. (2009) further stresses major threats to the fat pocketbook include decreased water quality and habitat alteration. The purpose of this study was to assess physical habitat, water quality, and biotic assemblages of the Tyronza River with an end goal of determining the systems integrity.

Study Area

The Tyronza River originates 10 km southeast of Blytheville as Ditch No. 31 (Figure 1). Ditch No. 31 is a shallow, channelized agricultural ditch with little riparian corridor and flows for approximately 55km. The end of channelized section 5 km north of Dyess, Arkansas also ends the identification as Ditch No. 31 and begins the Tyronza River. At that point Tyronza River flows 70 km through an agriculture-dominated watershed until the confluence with the St. Francis River at Parkin, Arkansas. The Tyronza River is the third largest tributary to St. Francis River, behind the L'anguille and Little River watersheds (Christensen et al. 1967).

Methods

Sampling Design

Physical habitat data, macroinvertebrates, and fish were collected once at each of the 9 Tyronza River sample sites during the summer and fall of 2007 (Figure 1). The above sites were established based on freshwater mussel surveys of the Tyronza (Wentz et al. 2009). For ease of sampling, water quality samples were collected from 9 bridge sites crossing the Tyronza River going from upstream to downstream seasonally (i.e. summer, autumn, winter, and spring) from July 2008 to April 2009 (Figure 1).

Physical Habitat Assessment and Characterization

The Basin Area Stream Survey (BASS) protocol was followed at each of the 9 Tyronza River reaches to uniformly name habitats via a standardized nomenclature and to semi-quantitatively measure habitat variables (Clingenpeel and Cochran 1992). Habitat variables measured included: water depth (m), wetted and bankfull width (m), canopy cover (%), substrate type (e.g. % boulder, cobble, gravel, sand, silt), pool substrate characterization, bank angle (degrees) and vegetation cover (%), and instream cover (e.g. % large woody debris, small woody debris, clinging vegetation). Bankfull width is not easily defined within a channel-altered system, so we measured the channel width between the top the banks or the top of the scoured vegetation line (Roni et al. 2005).

Habitat assessments were conducted using the US EPA Rapid Bioasssessment for low gradient streams protocol to categorize each sample reach as optimal, suboptimal, marginal, or poor (Barbour et al. 1999). Metrics for low gradient streams include: 1) epifaunal substrate/available cover, 2) pool substrate characterization, 3) pool variability, 4) sediment deposition, 5) channel flow status, 6) channel alteration, 7) channel sinuosity, 8) bank stability, 9) bank vegetative protection, 10) riparian vegetative width. The US EPA habitat RBP condition category scores range from 0-200 with 0-50 classified as poor, 51-100 as marginal, 101-150 as suboptimal, and 151-200 as optimal. Categories were based on a series of both characterization and assessment of the habitats at each sample reach in an attempt to determine possible limiting factors for aquatic life.

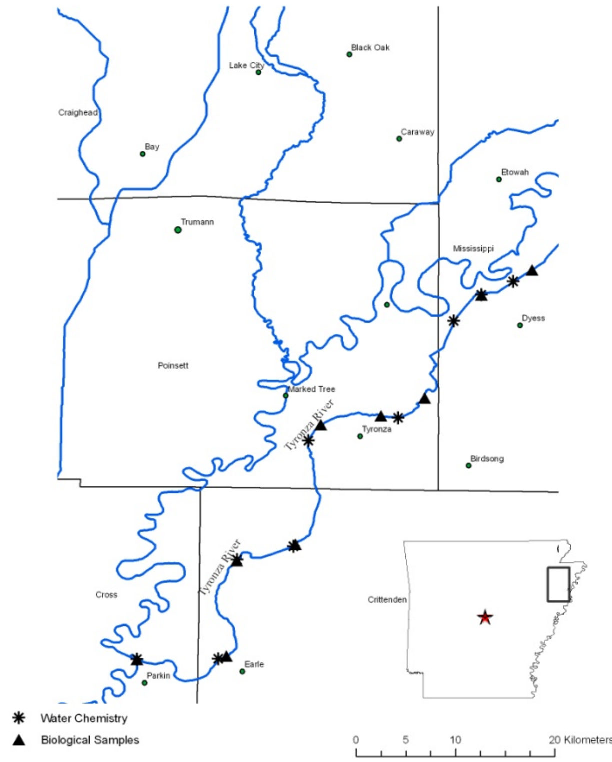

Figure 1. The Tyronza River, Arkansas from Dyess to Parkin showing water quality (asterisks) and habitat and biotic assessment (filled triangles) sampling sites. Biotic and water quality Sampling sites are consecutively numbered downstream 1-9.

Water Quality Assessment

Grab-water samples were collected seasonally by lowering an 8 L plastic bucket from the bridge into the river surface. From this 8 L sample, a 2 L sample was transferred to an acid washed Nalgene plastic bottle. The 2 L water samples were stored on ice until being processed with 48 hours in the laboratory. Conductivity and dissolved oxygen measurements were measured on site using a YSI-85 (Yellow Springs International, Yellow Springs, Ohio). These parameters were not measured for the spring sampling event due to equipment malfunction. A Beckman F295 pH meter (Beckman Coulter, Inc, Brea, California) was used to measure pH and temperature.

In the laboratory, the 2 L water samples were filtered through pre-weighed and ashed 47 mm glass fiber filters (Pall A/E; 1 μm nominal pore size) for total suspended solids (TSS) and unashed 47 mm glass fiber filters (Pall A/E; 1 μm nominal pore size) filters were used to measure chlorophyll. TSS filters were dried at 60°C for 24 hours and weighed. The filtrate for each filtered sample was saved for the analysis of ammonia, nitrate, and orthophosphate. A Lachat QuikChem® 8500 Series Flow Injection Analysis System (Lachat Instruments, Hach Company, Loveland, Colorado)was used to measure ammonium (NH_4-N) (method # 10-107-06-2-C), nitrate (NO_3-N) (method # 10-107-04-1-C), and orthophosphate (PO_4-P) (method # 30-115-01-1-B). Chlorophyll filters were placed in the freezer until analyzed for total chlorophyll using a buffered acetone extraction and measured using ultraviolet spectrophotometry (Clesceri et al. 1998).

Water quality parameters were compared with ADEQ's ecoregion criteria for channel-altered delta streams outlined within Regulation 2 (APCEC 2008). Regulation No. 2 describes a channel-altered delta stream as one that has suffered substantial alteration to the morphology of the main channel and tributaries; whether it be through straightening, re-routing, or removal of instream obstructions.

Macroinvertebrate Assemblage Assessment and Characterization

Benthic macroinvertebrates were sampled once at each of the 9 Tyronza River sites during the summer of 2007. The sample reach at each site was determined by measuring the wetted width, multiplying the wetted width by 10, and adding that distance to the Wentz's (2009) freshwater mussel assemblage length both upstream and downstream (Barbour et al. 1999). Prior to any sampling, the total length of the sample reach was recorded and the upstream and downstream sections were flagged.

Sampling protocols were based on EPA Rapid Bioassessment, where at each site a total of 20 sweeps or jabs were collected with a d-frame dip net at low water sites (Sites 1-8) and an Eckman grab and d-frame, when possible, were used at deeper sites (Barbour et al. 1999). The 20 sweeps or grabs were distributed proportionally among the available habitat within each sample reach. Samples were fixed in 10% formalin, sieved using 425 and 600 μm stackable sieves, and sorted in the laboratory. Organisms were identified to the lowest possible taxon, generally genera; however, chironomids were only identified to sub-family or tribe with the aid of dichotomous keys within Simpson and Bode (1980), Merrit and Cummins (1996), and McCafferty (1998).

Macroinvertebrate community samples were evaluated with ADEQ's Arkansas Macroinvertebrate Index-Small Watersheds (AMISW) for Arkansas Bioregion 3. Arkansas Bioregion 3 consists of lowland streams within the Arkansas River Valley, Gulf Coastal Plain, and Delta ecoregions. The AMISW is based on the concept that streams reflect the lands they drain, and therefore can be used to extrapolate data at the regional level (ADEQ 2003). Metrics used to evaluate macroinvertebrate communities were: Total Taxa Richness, Ephemeroptera, Plecoptera, Trichoptera (EPT) Index, % Dominant Taxa, % Diptera, Hilsenhoff Biotic Index (HBI), and % Collectors. Once the total score was calculated, it was assigned to 1of 4 categories: Very Good (27-34), Good (18-26), Poor (10-17), and Very Poor (0-9).

Fish Assemblage Assessment and Characterization

A 5 m long X 2 m high seine (1.5 mm mesh) was used at 8 of the 9 Tyronza River sites. So as not to increase bias into the study, 20 seine hauls were evenly distributed across the sample reach (Barbour et al 1999). Areas of increased depths that could not be sampled with a seine, 4 sites (1, 4, 6, and 8), were sampled with two gill nets. An experimental gill net comprised of five 20 m X 2.4 m panels (2.54, 3.81, 5.08, 6.35, and 7.62 cm^2 mesh) was used to reduce fish size selectivity (Hubert 1996). A large mesh gill net (10 cm) also was used to collect larger species of fish [e.g. buffalo (*Ictiobus* spp.), and gar (*Lepisosteus* spp.)]. Gill nets were set from bank to bank to block any fish passage in the river. Each gill net was set for a total of 4 hours. Tyronza River Site 9 was sampled using boat electrofishing due to the increased depths. Electrofishing was completed in cooperation with the United States Fish and Wildlife Service and the Arkansas Game and Fish Commission. All 9 sites were sampled May through September. Supplemental gill net sampling only occurred once at each of the 4 sites. All fish collected from the seine hauls, excluding larger species, were preserved in 10% formalin for later identification and measurement. Larger species were identified, measured to the nearest millimeter, and released. After identification and measurement, specimens were cataloged and deposited in the Arkansas State University Museum of Zoology-Ichthyofauna Collection (ASMZ #12923-13066).

Fish assemblage data were evaluated using ADEQ's Community Structure Index (CSI) for

Channel Altered Delta Streams. Metrics used for evaluation of the CSI included: % Sensitive Species as determined by ADEQ, % Cyprinidae, % Ictaluridae, % Centrachidae, % Percidae, % Primary Feeders, % Key Individuals as determined by ADEQ, and Shannon-Weiner Diversity Index (Table 1). Richness and abundance also were calculated for each site. Once the total value for the CSI was calculated, it was then designated to a category based on the similarity to the regional reference stream and categories are: Most Similar (28-22), Generally Similar (21-15), Somewhat Similar (14-8), and Not Similar (7-0).

Table 1. ADEQ's Community Structure Index for channel-altered delta streams (ADEQ 2003).

METRIC	SCORE		
	4	2	0
% Sensitive species	NA	NA	NA
% Cyprinidae	10.0-26.0	2-10 or 26-34	<2 or >34
% Ictaluridae	6 - 40[1]	3 – 6 or 40 - 50[1]	<3 or >50 or >3% bullheads
% Centrarchidae	6 - 40[2]	3 – 6 or 40 - 55[2]	<3 or >55 or>30% green sunfish
% Percidae	>0.1	0.1-0.05	>0.05
% Primary feeders	<20	20-30	>30
% "Key" Individuals	>25	25-10	<10
SW Diversity Index	>2.51	2.51-2.30	<2.30

Total Score		
22-28	Most Similar	
21-15	Generally Similar	
14-8	Somewhat Similar	
7-0	Not Similar	

[1]no more than 3% bullheads

[2]no more than 30% green sunfish

Results

Physical Habitat Assessment and Characterization

The Basin Area Stream Survey (BASS) resulted in the classification of 8 major habitat types with runs comprising 38.6% of the habitat surveyed, followed by corner pools and glides, 18.6 and 17.1%, respectively. Mean thalwag depth of reaches was 3.5 (SD 1.6) ft or approximately 1 m. River left bank was less stable than the river right bank, 83.6 (SD 15.7) versus 96.7 (SD 12.1) % intact, while the most eroded site was only 10% intact. Native instream habitat was relatively non-existent throughout the majority of the Tyronza River reaches. Only 2 sample sites, Site 8 and Site 9, had measurable instream habitat, specifically large and small woody debris. Non-native habitat (i.e. tires, furniture, and appliances) were quite prevalent at sites near bridges and along paralleling roads. Unfortunately, habitat indices used for this study provide no metric or evaluation criteria for such habitat. Site 1 was the only reach with any rooted vegetation, and instream vegetation ended at the transition from Ditch 31 to the Tyronza River. The riparian corridor width ranged from 0m at uppermost sites to >40m at several lower sites and consisted primarily of grasses and small to medium shrubs and trees.

Following US EPA RBPs for assessing habitat quality of a lowland stream, the Tyronza River has suboptimal habitat. While no sites exceeded the suboptimal category, Site 5 was the lowest, with a score of 110 (Figure 2). Quality of riparian corridors (in particular the amount of vegetation, the width of vegetation, and bank stability) had the most influence on US EPA RBP values.

Water Quality Assessment

Mean yearly temperature for the Tyronza River was 18.0 (SD 8.9) °C with seasonal variations ranging from 10.9 to 32.8 °C (Figure 3a). During the summer sampling event, only 2 water sites had temperatures approaching the ecoregion criteria of 32 °C. As one would expect, temperatures were highest during the summer sampling event compared to any other season (Figure 3a). Despite high temperatures during the summer event, dissolved oxygen concentrations never dropped below the standard of 5.0 mg/L (Figure 3b). Highest concentrations of dissolved oxygen were observed during the winter sampling event, which coincided with the lowest recorded temperatures. The winter sampling event had slightly higher pH than other seasonal events (Figure 3c). This was in part to the pH at 4 sites were equal to the ecoregion standard of 9.0 SU. Total chlorophyll ranged from 0 to 120 μg/L and was highest in winter and spring compared to autumn (Figure 3d). Summer mean conductivity (553.67 SD 29.83) far exceeded any other season (Figure 3e). Total suspended solids ranged from 34.8 to 1365.3 mg/L with highest concentrations observed during the autumn sampling event (Figure 3f).

Nitrate-nitrogen exhibited little seasonal differences with an autumn mean (2.98 mg/L SD 1.90) only slight higher than other seasons (Figure 3g). Autumn and winter mean ammonium concentrations were similar (0.07 mg/L SD 0.03), while mean spring concentrations were higher (Figure 3h). Concentrations of orthophosphate were comparable among summer, autumn, and winter with mean concentrations of 0.25 (SD 0.02), 0.27 (SD 0.09), and 0.29 (SD 0.18) mg/L, respectively. Mean concentration of orthophosphate nearly double for spring events (Figure 3i).

Macroinvertebrate Assemblage Assessment and Characterization

Twenty-three taxa consisting of 627 individuals were collected from the 9 Tyronza River sites. The most abundant taxon within the Tyronza River was *Argia* spp (Odonata: Coenagrionidae), comprising 24% (n=151) of all individuals. The second, third, and fourth most abundant taxa were grass shrimp, *Palaemonetes* spp. (Decapoda: Palaemonidae), midges [specifically Tribe Chironomini (Diptera: Chironomidae)], and Hemiptera: Corixidae; comprising a total of 23, 18, and 12% (n=146, 119, and 72), respectively. The four most abundant taxa comprised 77% of all individuals collected. Mean taxa richness was 10 (SD 4.2) taxa per site and ranged from 3 to 14 taxa per site. Shannon-Wiener Diversity index scores ranged from 1.1 to 2.2, with a mean score of 1.7 (SD 0.3). The mean AMISW score was 23 (SD 5.1) with a range from 16 to 28. Overall, the mean score AMISW score of 23 is considered "Good", while the lowest score of 16 is designated as a "Poor condition", and the highest score of 28 is designated as a "Very Good" condition (Table 2).

Fish Assemblage Assessment and Characterization

A total of 1611 individuals and 42 species were collected during three sampling periods. Fish abundance ranged from 61 to 406 individuals per site, with a mean abundance of 176 (SD 101.2) individuals. Richness ranged from 4 to 15 species per site, with a mean of 10.1 (SD 4.4). The most abundant species collected was the blacktail shiner (*Cyprinella venusta*), which represented 25% of all fish collected among sites. The second and third most abundant species collected were gizzard shad (*Dorosoma cepedianum*) and emerald shiner (*Notropis atherinoides*), comprising 20 and 15 % of all fish from the Tyronza River, respectively. Shannon-Weiner diversity indices ranged from 0.5 to 2.6 per site, with a mean of 1.7 (SD 0.5). Community Structure Index scores ranged from 4 to 20 with a mean score of 12 (SD 4.1), which ranked in the "Somewhat Similar" range in reference to the regional reference streams. The lowest CSI value was observed at Site 9, a value of 6, and is considered "Not Similar" in reference to the regional reference streams. The highest CSI values were observed at Sites 4 and 5 with values of 16, which falls within the category of "Generally Similar" (Table 3).

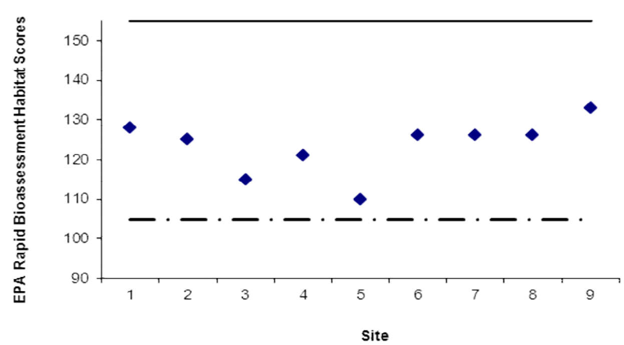

Figure 2. US EPA Habitat Rapid Bioassessment scores for the Tyronza River, Arkansas. Site scores indicated by filled diamonds, marginal habitat level indicated by a dashed line, and suboptimal habitat score indicated by a solid line.

Table 2. Raw metric value, metric score, and interpretation for Arkansas Macroinvertebrate Index for Small Watersheds (AMISW) for the 9 Tyronza River, Arkansas sites.

METRIC	1		2		3		4		5		6		7		8		9	
Total Taxa Richness	10	2	3	0	12	2	13	2	7	0	12	2	5	0	16	4	12	2
EPT Index	2	2	1	0	4	4	4	4	3	4	2	2	2	2	4	4	3	4
% Dominant Taxa	42.86%	4	33.33%	6	30.54%	6	24.69%	6	30.77%	6	38.89%	4	20.00%	6	54.69%	2	44.92%	4
% Diptera	11.90%	6	0.00%	6	7.19%	6	22.22%	4	76.92%	0	43.06%	2	40.00%	2	7.81%	6	48.31%	2
% Collectors	28.57%	6	33.33%	6	14.37%	4	30.86%	6	84.62%	6	65.28%	6	100.00%	6	15.63%	6	50.00%	6
Hilsenhoff Biotic Index (HBI)	5.39	6	3	4	6.22	6	4.65	6	5.1	0	5.5	2	3.4	0	4.4	6	5.4	4
AMISW Value		26		22		28		28		16		18		16		28		22
Interpretation	Good		Good		Very Good		Very Good		Poor		Good		Poor		Very Good		Good	

Table 3. Raw metric value, metric score, and interpretation for Community Structure Index (CSI) for the 9 Tyronza River, Arkansas sites. NS=Not Similar; SS=Somewhat Similar; GS=Generally Similar

METRIC	1		2		3		4		5		6		7		8		9	
% Sensitive	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
% Cyprinidae	74.4	0	93.35	0	57.15	0	40.25	0	59.25	0	58	0	66.1	0	39.45	0	24.65	2
% Ictaluridae	1.35	0	1.05	0	5.35	2	6.35	4	12.25	4	0	0	3.25	2	9.25	4	0.15	0
% Centrachidae	20.6	4	3.6	2	32.05	4	29.35	4	8.65	4	20.3	4	18.9	4	40.6	2	6	4
% Percidae	-	0	-	0	-	0	-	0	-	0	-	0	-	0	-	0	-	0
% Primary Feeders	6.75	4	0	4	1	4	3.15	4	9.9	4	20.6	4	5.15	4	27.05	4	62.05	0
% Key Individuals	26.15	4	81.55	4	39.55	4	41.7	4	32.65	4	20.6	2	58.45	4	15.05	2	9.75	0
Diversity	1.95	0	0.75	0	1.7	0	1.95	0	1.7	0	2.6	4	1.45	0	2	0	1.65	0
CSI Totals		12		10		14		16		16		14		14		12		6
Interpretation	SS		SS		SS		GS		GS		SS		SS		SS		NS	

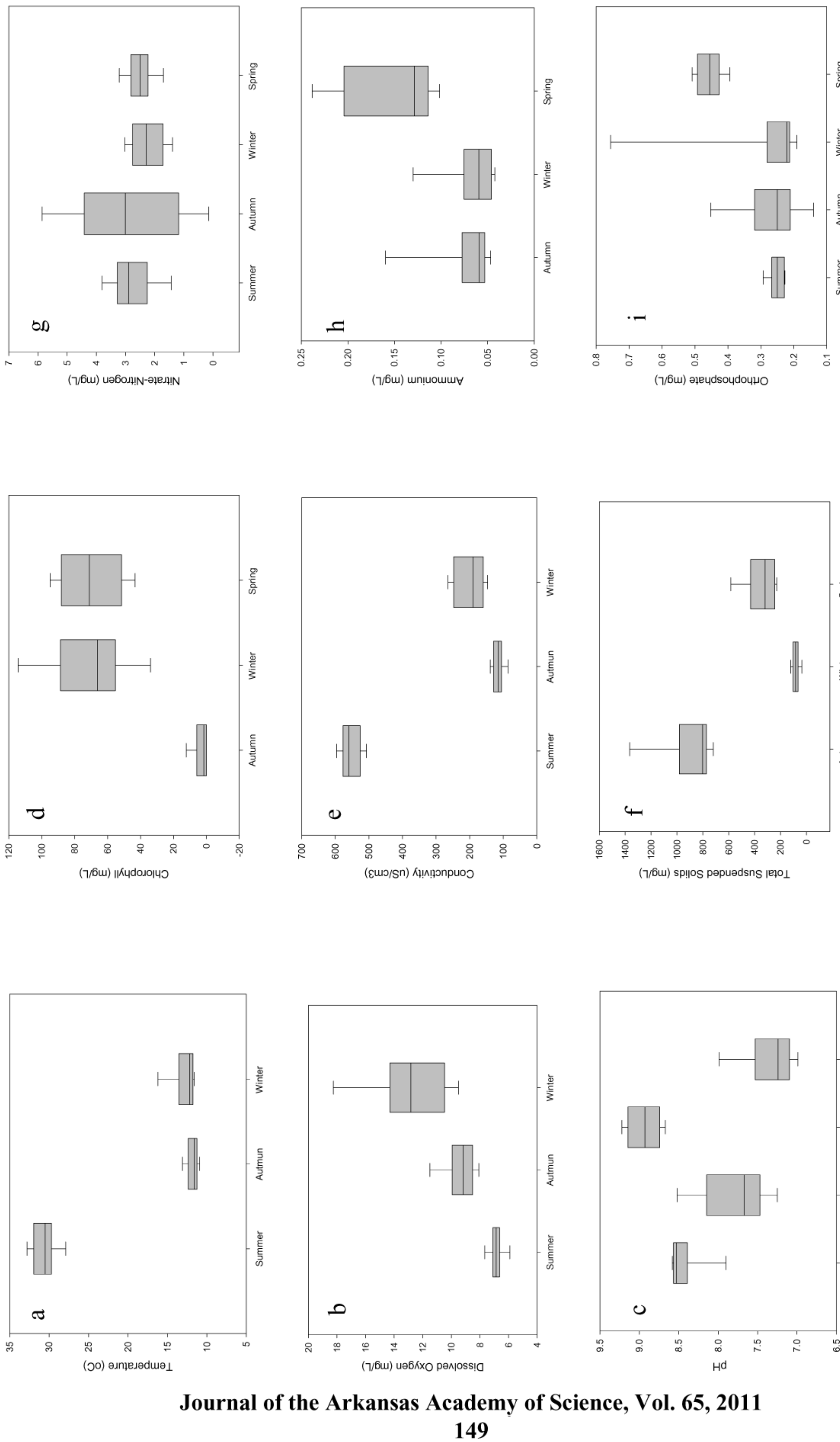

Figure 3. Plotted mean, maximum, and minimum seasonal water quality parameters: (a) temperature, (b) dissolved oxygen, (c) pH, (d) chlorophyll, (e) conductivity, (f) total suspended solids, and concentrations of (g) nitrate, (h) ammonia, and (i) orthophosphate for 9 Tyronza River, Arkansas sites.

Discussion

Habitat quality of channel-altered streams can greatly influence the quality of aquatic biota (Angermeir and Karr 1984, Benke et al. 1985). The Tyronza River, while having been modified and leveed, still exhibits suboptimal habitat for an altered system.

Several water quality parameters approached and were equal to ecoregion standards, but never exceeded. Seasonal variations of temperature, dissolved oxygen, and pH were similar to those reported by Arkansas Department of Pollution Control and Ecology (1987). The most surprising water chemistry finding was the lack of seasonal variation in nitrate-nitrogen, as the watershed is approximately 94% row crop (EPA 2005). Increased nutrient concentrations at baseflow and stormflow in agriculture dominated watersheds are documented to increase during spring and winter months (Owens et al. 1991, 1992), however, this was not observed for nitrate nitrogen in our study. Meanwhile, orthophosphate and ammonium exhibited substantial increases during the spring sampling event. Nutrient peaks during winter and spring months are most tied to the increase of storm-flow events and the lack of up-take by vegetation during this period (Vanni et al. 2001).

Our biotic communities exhibited little spatial variation. The little variability observed in the AMISW and CSI between sites is likely due to habitat availability. Habitat, in this instance woody debris, was removed during original channel modifications, levee construction, and subsequent maintenance. The importance of woody debris in lowland rivers and streams has been well documented and earliest reports of their value can be found in Hynes (1970). Loss of woody debris in lowland systems greatly affects the assemblage structure and biomass of macroinvertebrates, as these areas contain more than half of the taxa richness and production (Benke et al. 1985, Smock et al. 1985, Wallace et al. 1996, Benke and Wallace 2003). Absence of woody debris in lowland systems can affect fish assemblages by altering distribution, richness and abundance; which eliminate refugia from floods and rearing areas for juveniles (Zimmerman et al. 1967, Beschata 1979, Keller and Swanson 1979, Angermeir and Karr 1984, Gregory and Davis 1992, Jowett and Richardson 1996, Robertson and Crook 1999).

Overall, the Tyronza River exhibits relatively good water quality and biotic assemblages. The only other study of the Tyronza River determined it to be moderately degraded as classified by the Index of Ecological Integrity (IEI) Justus (2003). The purpose of the IEI was to develop a suite of physical, chemical, and biological metrics to characterize streams of the Mississippi Alluvial Valley. The IEI may have underscored and therefore underestimated the system's quality, as only one sample from one site was used for metric evaluation. Likewise to the IEI, ADEQ metrics may have under assessed the quality due to the original metrics being developed for much smaller systems. This is evident in the classification of the fish assemblage at Site 9 as being "Not Similar" to regional reference streams. We suspect that the low scoring is due to the site's close proximity to the St. Francis River, less than 800m; which is undoubtedly influencing the structure at this site due back flow during high flows in the St. Francis River. Additional refinement of existing metrics or development of metrics better suited for large river ecosystems is suggested to further evaluate the integrity of the Tyronza River's and other large Mississippi Alluvial Valley streams.

Implications

Water quality issues, more importantly nutrient and sediment reduction, are timely issues within the Mississippi Alluvial Valley, most recent being the Mississippi River Healthy Basin Initiative (MRBI). Funded through National Resource Conservation Service, the project aims to partner with local producers to implement practices to reduce sediment and nutrient run-off and restore/enhance wildlife habitat while maintaining agricultural productivity. The Cache, Little River, L'anguille, and lower St. Francis rivers in Arkansas have been selected for participation in the MRBI because of high levels of nitrogen and phosphorus (Alexander et al. 2008). Results of this study are pertinent for water quality managers and research scientists working within the St. Francis River watershed to reduce negative impacts associated with agricultural run-off.

Acknowledgements

We thank the Arkansas Game and Fish and Arkansas State University for providing funding for this project. A special thank you is in order to S. Barkley (retired) and S. Henry of the Arkansas Game and Fish Commission and D. French of the U.S. Fish and Wildlife Service's Mammoth Spring National Fish Hatchery for providing field assistance. We also thank J. Wise with Arkansas Department of Environmental Quality for providing ADEQ's water quality metrics and biological indices. We are enormously indebted to the ASU Aquatic Ecology Lab for invaluable support and assistance. Finally, we thank the anonymous reviewers for providing critical comments, insight, and subsequent improvement of this manuscript.

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Twenty Three True Bug State Records for Arkansas, with Two for Ohio, U.S.A.

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Over the past half decade, 64 Hemiptera (Heteroptera) species have been published as new records for Arkansas (Chordas and Kremers, 2009). New bug records reported herein were from three sources; recently collected specimens from the authors current and on-going Arkansas projects, specimens from the University of Arkansas-Monticello collection (UAM), and one of us (JK) captured bugs at his resident property in Clarksville (Johnson County) Arkansas. Identification of the true bugs from these sources revealed 23 species (in 9 families) that are new state records for Arkansas. The first author collected two of these species in Ohio and we include these as new records for that state as well. Further, Daniel Swanson (see acknowledgments) provided additional Reduviidae records we include (noted as *DS).

We newly report the following 23 species (alphabetically by family, then species): **Alydidae**: *Alydus pilosulus* Herrich-Schaeffer, 1848 (also from Ohio); **Anthocordiae**: *Cardiastethus assimilis* (Reuter, 1871); **Coreidae**: *Acanthocephala femorata* (Fabricius, 1775), *Hypselonotus punctiventris* Stål, 1862, *Leptoglossus clypealis* Heidemann, 1910; **Lygaeidae**: *Melacoryphus facetus* (Say, 1832), *Oncopeltus fasciatus* (Dallas, 1852); **Miridae**: *Collaria oculata* (Reuter, 1871), *Diphleps unica* Bergroth, 1924; *Eustictus necopinus necopinus* Knight, 1923, *Hyaliodes harti* Knight, 1941, *Lopidea robinae* (Uhler, 1861), *Phytocorus erectus* Van Duzee, 1920, *Tropidosteptes cardinalis* Uhler, 1878; **Nabidae**: *Pagasa fusca* (Stein, 1857); **Reduviidae**: *Narvesus carolinensis* Stål, 1859, *Oncerotrachelus acuminatus* (Say, 1832), *Rhiginia cruciata* (Say, 1832) (also from Ohio); **Rhopalidae**: *Harmostes fraterculus* (Say, 1832), *Jadera haematoloma* (Herrich-Schaeffer, 1847); **Rhyparochromidae**: *Atrazonotus umbrosus* (Distant, 1893), *Ozophora picturata* Uhler, 1871, *Paromius longulus* (Dallas, 1852). We also provide dorsal images of all 23 species, updated distribution maps (north of Mexico), and a few ecological notes.

Voucher specimens of all 23 species were deposited into the C.A. Triplehorn Insect Collection (The Ohio State University, Columbus Ohio), duplicates were retained by the first author (SWC) or JK and are housed in personal collections. Brailovsky (2006), Chordas et al. (2005 & 2008), Decker and Yeargan (2008), Henry and Froeschner (1988), Maw et al. (2000), McPherson (1992) and Schaefer and Schaffner (1994) were used as distributional references. Blatchley (1926), Hoebeke and Wheeler (1982), Knight (1941), McPherson et al. (1990) and Slater (1992) were used for species identifications; additional literature required for some identifications are listed under individual species discussion.

New State Records: Alphabetically by family.

Alydidae (Broad-Headed bugs): ***Alydus pilosulus*** is a widespread species across the US and was anticipated for Arkansas (Figs 1 & 2). Collection data **Arkansas**: Johnson County. Clarksville, Arkansas, Clark Road (runs parallel & between State Route 64 & U.S. Route 40). Joe Kremers. N35.46: W-93.49. Three specimens were collected, one each on 2-19 August 2005, 30 September 2005, 22 July 2007. We also identified one specimen collected with a sweepnet from Ohio. Collection data **Ohio**: Wayne County: SW portion; Shreve Lake wildlife area, off Brown Road. 1 August 2010. Steve Chordas III. N40.686: W-82.044.

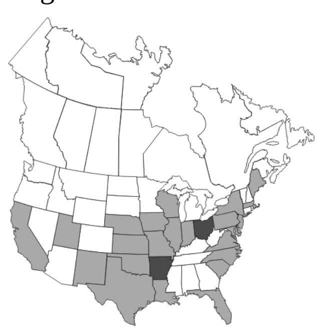

Figure 1. Distribution of *Alydus pilosulus* North of Mexico.

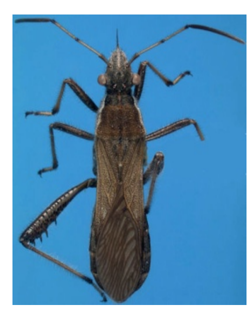

Figure 2. Dorsal view of *Alydus pilosulus*

Anthocoridae (Minute pirate bugs): Previously reported from only four scattered states (Fig. 3), ***Cardiastethus assimilis*** (Fig. 4) was an interesting find. A single specimen was collected. Collection data **Arkansas**: Garland County (West Edge), Camp Clearfork, Ouachita National Forest, ≈1km S of U.S. Route 270, ≈30 km W of Hot Springs, 20 June 2008, UV light, Brian Baldwin, N34.51: W-93.39.

Figure 3. Distribution of *Cardiastethus assimilis* North of Mexico.

Figure 4. Dorsal view of *Cardiastethus assimilis*

Coreidae (Leaf-footed bugs): ***Acanthocephala femorata*** was expected for Arkansas as it had been recorded from several surrounding states (Fig. 5). *Acanthocephala femorata* is a large distinctive bug (body length 28-34mm) (Fig. 6). This species is also figured nicely in both Henry and Froeschner (1988), page 70 and Brailovsky (2006), page 256. It is now the third species of this genus reported for Arkansas (Chordas et al. (2005) reported *A. terminalis*, Chordas and Kremers (2009) reported *A. declivis*). A single specimen, from the UAM collection, was collected in November 1980 from Drew County.

Figure 5. Distribution of *Acanthocephala femorata* North of Mexico.

Figure 6. Dorsal view of *Acanthocephala femorata*

Hypselonotus punctiventris (Fig. 7). A single specimen was collected off a bull thistle (*Cirsium vulgare*) flower. This species is not in Blatchley (1926). It was ultimately identified using illustrations in Distant (1880-1893; tab 14). The photo of this species (Fig. 8) is the field photo of the specimen just prior to it being hand collected. Collection data **Arkansas**: Ashley County, Crossett Arkansas, logging road off Hwy 133 south side of Crossett. 20 April 2008. Hand collected off of bull thistle flower. Renn Tumlison. N33.1097: W-91.9566.

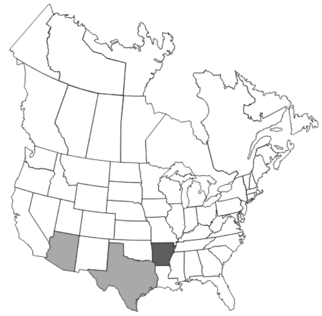

Figure 7. Distribution of *Hypselonotus punctiventris* North of Mexico.

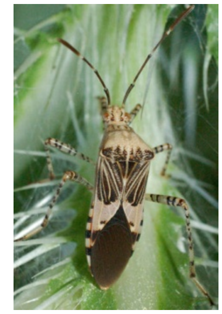

Figure 8. Field photo of *Hypselonotus punctiventris*

Leptoglossus clypealis is primarily a western species with Arkansas on the edge of its eastern range (Fig. 9). This species has a distinctive anterior spine that extends between the antennal bases (Fig. 10). Three specimens were collected (1 each on 24 May 2006, 19 July 2006, 13 August 2006) all from the Johnson county location (see *Alydus pilosulus*).

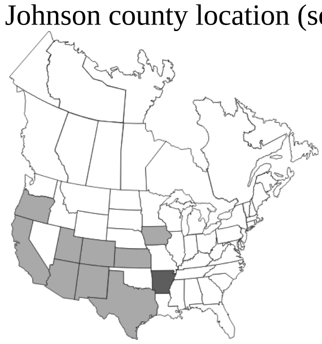

Figure 9. Distribution of *Leptoglossus clypealis* North of Mexico.

Figure 10. Dorsal view of *Leptoglossus clypealis*

Lygaeidae (Seed bugs): ***Melacoryphus facetus*** is known mostly in the south and the east (Fig. 11). A single specimen of this species (Fig. 12) was collected on 9 June 2005 from the Johnson county location (see *Alydus pilosulus*).

Figure 11. Distribution of *Melacoryphus facetus* North of Mexico.

Figure 12. Dorsal view of *Melacoryphus facetus*

Oncopeltus fasciatus, the large milk weed bug, is widespread and common in the eastern half of the US and Canada (Fig. 13). The photo (Fig. 14) is a field photo taken of one of the specimens just after a mating pair was hand collected. Although well known and expected for Arkansas, we found no literature record for this species and thus list it as a new for Arkansas. We also did not find a literature record for Kentucky, but did find the University of Kentucky Department of Entomology at (www.uky.edu; "critter files") lists this species with pictures, ID information, etc. Thus, we include Kentucky in our distribution map (shaded differently). Collection data **Arkansas**: Clark County, DeGray Lake, Spillway Dam Recreation Area off County Road 18. 26 July 2008. Hand collected off Buttonbush (*Cephalanthus occidentalis*). Renn Tumlison. N34.2204: W-93.1002.

Figure 13. Distribution of *Oncopeltus fasciatus* North of Mexico.

Figure 14. Field photo of *Oncopeltus fasciatus*

Miridae (Plant bugs): ***Collaria oculata***. The Alberta literature record was questioned by Maw et al (2000); we follow their listing (Fig. 15). Arkansas was within the known distribution. Two specimens (Fig. 16) were collected on 20 and 27 June 2008 from the Garland County site (see ***Cardiastethus assimilis***).

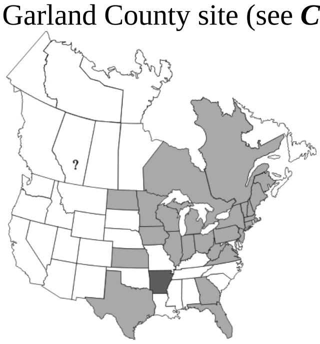

Figure 15. Distribution of *Collaria oculata* North of Mexico.

Figure 16. Dorsal view of *Collaria oculata*

Arkansas lies along the western edge (Fig. 17) of the known range of ***Diphleps unica*** (Fig. 18). This species is also figured in Henry and Froeschner (1988), page 256. A single male specimen was collected 20 June 2008 from the Garland County site (see ***Cardiastethus assimilis***).

Figure 17. Distribution of *Diphleps unica* North of Mexico.

Figure 18. Dorsal view of *Diphleps unica*

Eustictus necopinus necopinus (Figs. 19 & 20): A single specimen was collected 20 June 2008 from the Garland County site (see ***Cardiastethus assimilis***).

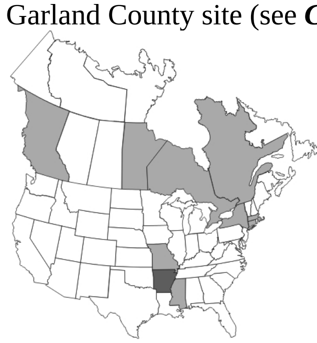

Figure 19. Distribution of *Eustictus necopinus necopinus* North of Mexico.

Figure 20. Dorsal view of *Eustictus necopinus necopinus*

Largely a northern species (Fig. 21), Arkansas is on the southern part of the range of ***Hyaliodes harti*** (Fig. 22). Two specimens were collected 20 June 2008 from the Garland County site (see ***Cardiastethus assimilis***).

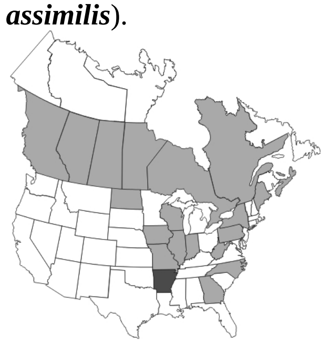

Figure 21. Distribution of *Hyaliodes harti* North of Mexico.

Figure 22. Dorsal view of *Hyaliodes harti*

Arkansas lies along the western edge of the known distribution of ***Lopidea robinae*** (Fig. 23). A single male specimen (Fig. 24a) of this species was collected on 1-7 July 2005 from the Johnson county location (see *Alydus pilosulus*). An image of the distinctive male right clasper is shown in Fig. 24b.

Figure 23. Distribution of *Lopidea robinae* North of Mexico.

Figure 24 a & b.
a=Dorsal view of *Lopidea robinae.*
b=right clasper of same species

Phytocoris erectus occurs across eastern North America (Fig. 25) and was expected for Arkansas. One male specimen (keyed and matched with the male clasper illustrations in Knight (1941)) of this species (Fig. 26) was collected on 24 June 2005 from the Johnson county location (see *Alydus pilosulus*).

Figure 25. Distribution of *Phytocoris erectus* North of Mexico.

Figure 26. Dorsal view of *Phytocoris erectus*

Arkansas falls within the known range (Fig. 27) of ***Tropidosteptes cardinalis*** (Fig. 28). Two specimens (1♂, 1♀) of this species were hand collected off an ash sapling on 24 April 2005 from the Johnson county location (see *Alydus pilosulus*).

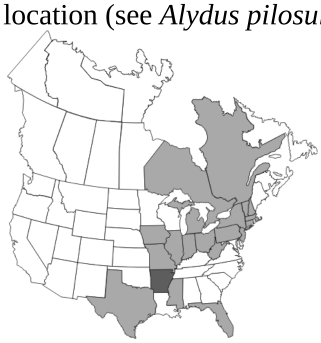

Figure 27. Distribution of *Tropidosteptes cardinalis* North of Mexico.

Figure 28. Dorsal view of *Tropidosteptes cardinalis*

Nabidae (Damsel bugs): The cosmopolitan (Fig. 29) ***Pagasa fusca*** (Fig. 30) was anticipated for Arkansas. A single specimen was collected on 10 December 2005, Columbia County, Magnolia, Henry W. Robison. Some records for this species may need to be confirmed and/or updated (see Scudder 2008).

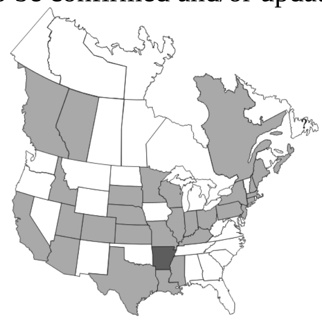

Figure 29. Distribution of *Pagasa fusca* North of Mexico.

Figure 30. Dorsal view of *Pagasa fusca*

Reduviidae (Assassin bugs): Distributed across the mid and eastern US (Fig. 31), ***Narvesus carolinensis*** (Fig. 32) was anticipated for Arkansas. Two individuals were collected, one each 1-9 June 2005 and 25-30 June 2005 from the Johnson county location (see *Alydus pilosulus*). Also from Hot Springs Co, Malvern, 15 June 1958, R.L. Fischer (*DS, Mich. St. U.).

Figure 31. Distribution of *Narvesus carolinensis* North of Mexico.

Figure 32. Dorsal view of *Narvesus carolinensis*

Oncerotrachelus acuminatus was anticipated for Arkansas (Fig. 33). One specimen (Fig. 34) was identified from the UAM material. Label data

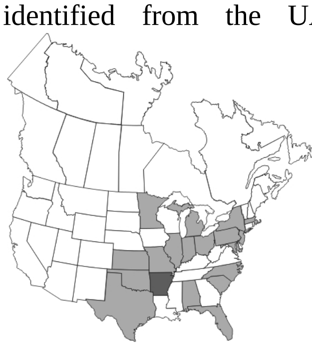

Figure 33. Distribution of *Oncerotrachelus acuminatus* North of Mexico.

Figure 34. Dorsal view of *Oncerotrachelus acuminatus*

Arkansas: Drew County, 5 October 1981, M. Weaver. We also include an historic specimen from [Crittenden Co.], 1278 Carlisle, January 1891, (*DS, Oh.St.U.).

Rhiginia cruciata is mainly an eastern bug (Fig. 35) and was anticipated for Arkansas and Ohio. One UAM specimen was identified. Label data **Arkansas:** Drew County, 6 October 1987, Foust. We collected one Ohio specimen (Fig. 36). Label data **Ohio**: Hocking County, Trib of Queer Creek, ≈3km East of S. Bloomingville, 2 June 1998, Malaise trap, N39.427: W-82.576. We also include six other Ohio records: [Gallia Co] Vinton, 5-12 June 1900, H.Osborn; [Scioto Co], Shawnee For., 9 June 1943, D.J./J.N. Knull (*DS, Oh.St.U.); Fairfield Co, 16 May 1945, F.W. Mead; Lawrence Co, Coal Grove, 11 October 1952; Hocking Co, Neotoma, 8 June 1952, C.A./D.M. Triplehorn (*DS, Fla.St.Col.Arth.); Ross Co, Bainbridge, 4 June 1960, G.C. Eickwort (*DS, Mich.St.U).

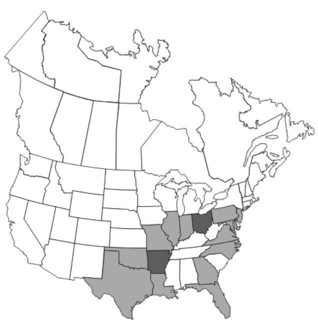

Figure 35. Distribution of *Rhiginia cruciata* North of Mexico.

Figure 36. Dorsal view of *Rhiginia cruciata*

Rhopalidae (scentless plant bugs): Arkansas falls within the known range (Fig. 37) of ***Harmostes fraterculus*** (Fig. 38). A single specimen was collected on 26 September 2005 from the Johnson county location (see *Alydus pilosulus*).

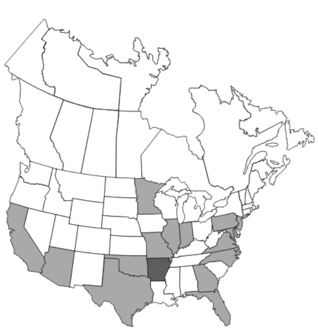

Figure 37. Distribution of *Harmostes fraterculus* North of Mexico.

Figure 38. Dorsal view of *Harmostes fraterculus*

Jadera haematoloma is primarily a southern bug (Figure 39) we anticipated for Arkansas. The common name is the red-shoulder bug, a distinctive feature (see Figure 40). One UAM specimen was identified. Label data **AR:** Drew County, 26 October 1980, D. McElroy. Another specimen was taken on 12 August 2003 from the Johnson county location (see *Alydus pilosulus*).

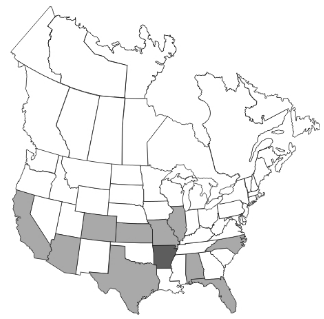

Figure 39. Distribution of *Jadera haematoloma* North of Mexico.

Figure 40. Dorsal view of *Jadera haematoloma*

Rhyparochromidae: Widespread species (Fig. 41), ***Atrazonotus umbrosus*** (Fig. 42) was expected. Collection data **Arkansas:** Faulkner County, 9 April 2010 in pocket gopher burrow, N35.071: W-92.523.

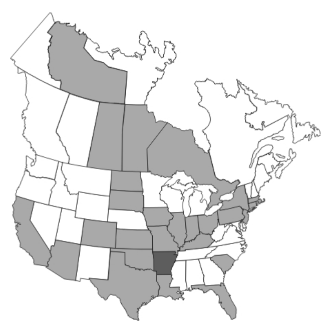

Figure 41. Distribution of *Atrazonotus umbrosus* North of Mexico.

Figure 42. Dorsal view of *Atrazonotus umbrosus*

Ozophora picturata was projected for Arkansas (Fig. 43). We collected two specimens of this species (Fig. 44) between 2 and 30 September 2005 in UV traps from the Johnson county location (see *Alydus pilosulus*).

Figure 43. Distribution of *Ozophora picturata* North of Mexico.

Figure 44. Dorsal view of *Ozophora picturata*

Paromius longulus is found through the southeast US (Figure 45). Two specimens were identified from UAM material. Label data **Arkansas:** Drew County, 12 September 1981, F. Durrwachjer; Drew County, 25 November 1986, F. Shepard. One other specimen was captured from a gopher burrow in Johnson County, Ludwig, 0.8km West of SR21-CR35/36 junction, 1 November 2008, Matt Connier.

Figure 45. Distribution of *Paromius longulus* North of Mexico.

Figure 46. Dorsal view of *Paromius longulus*

Acknowledgments

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New Records and Notes on the Natural History of Vertebrates from Arkansas

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This report documents new records of distribution and provides notes on the natural history of selected vertebrates from Arkansas. Field observations and collections were made by the authors and students at Henderson State University and Southern Arkansas University. All fish specimens documented below are housed in the Southern Arkansas University Vertebrate Collection (SAU) in Magnolia, Arkansas or in the Henderson State University Collection (HSU) in Arkadelphia, Arkansas. Specimens were collected with a 3.1 X 1.8 m seine with 3.175 mm mesh and 6.1 X 1.8 m seine with 3.175 mm mesh size. Mammal records were obtained by MBC by capture or observations of road hit animals and by additional investigation of mammal collections at institutions. Acronyms for specimen depositories are ASUMZ for the Arkansas State Museum of Zoology; HSU for the Henderson State University Collection; MSB for the Museum of Southwestern Biology; OMNH for the Sam Noble Oklahoma Museum of Natural History; SAU for the Southern Arkansas University Vertebrate Collection; and UCM for the University of Colorado Museum of Natural History.

Class Osteichthyes:

Ichthyomyzon castaneus Girard – Chestnut Lamprey. Lamprey records were initially provided for Arkansas by Robison and Buchanan (1988) and later updated by Robison et al. (2006) including some lamprey records from southern Arkansas. More recently, Tumlison and Robison (2010) reported several additional lamprey records from southern Arkansas. The following is a collection record of this rarely seen agnathan. A single specimen of *I. castaneus* was taken from a *Micropterus salmoides* specimen collected from the Sulphur River at US Hwy. 71 (Sec. 3, T19S, R27W), Miller County, AR, on 23 June 2005, by N. Dean and given to HWR. This represents the southwestern-most record of this lamprey species in the state.

Notropis maculatus (Hay) – Taillight Shiner. Robison (1978) reported Arkansas distributional records and described the habitat of this cyprinid species. The taillight shiner primarily inhabits the Coastal Plain lowlands and deltaic provinces of the southern and eastern regions of the state (Robison and Buchanan 1988). The following provides additional distribution records for this lowland shiner from south Arkansas. On 11 June 2001, 3 nuptial male specimens were collected from Calion Lake at Calion, AR (Sec. 22, T16S, R14W), Union County by HWR and the SAU Vertebrate Natural History class. Spawning in Arkansas is generally from April to mid-June (Robison and Buchanan 1988). A second collection taken from Lafayette County at Bayou Bodcau (Sec. 14, T15S, R24W) on 19 October 2002 by HWR yielded 2 specimens of *N. maculatus*.

Lepomis miniatus (Jordan) – Redspotted Sunfish. Robison and Buchanan (1988) mapped the occurrence of this sunfish in the state. McAllister et al. (2009) provided additional records of distribution for *L. miniatus* from Arkansas. On 7 June 1994 spawning *L. miniatus* were observed over solitary nests in a clear backwater area of Bayou Dorcheat at US Hwy. 82 (Sec. 7, T16S, R22W), Columbia County, AR by HWR. Subsequent seining yielded 4 individuals (1 nuptial male and 3 spawning females) of which 2 females were released at the site. Water temperature was 24.4ºC (76º F) and water depth was 1.2 m (3.8 ft). This represents the first observation of spawning of *L. miniatus* in Arkansas. An earlier collection from Lafayette County at Bayou Bodcau (Sec. 14, T15S, R24W) on 20 October 1989 by HWR and the SAU Vertebrate Natural History class yielded 2 specimens of *L. miniatus*.

Lepomis symmetricus Forbes – Bantam Sunfish. Robison and Buchanan (1988) reported localities for this uncommon sunfish from southern Arkansas. Two specimens were collected from Calion Lake at Calion, (Sec. 22, T16S, R24W), Union County, AR on 3 July 2001. An additional specimen was collected from

LaPere Creek at AR St. Hwy. 129, 3.2 km (2 mi.) South of Huttig, (Sec. 35, T19S, R11W), Union County, AR on 17 October 1992, by HWR and students.

Ouachita County now is represented by 2 collections of *L. symmetricus*. On 12 April 1997, 2 individuals (1 subadult and 1 juvenile, HSU 2055) were taken at Bragg Lake, 2.0 km (1.25 mi.) SE of Bragg City (Sec. 33, T12S, R18W). On 7 June 1997, 1 adult specimen (HSU 2184) was collected from Freeo Creek at AR St. Hwy. 9 (Sec. 36, T11S, R16W).

A record from Clark County (1 juvenile, HSU 2154) was obtained 20 April 1997 from McNeely Creek, ca. 6.5 km (4 mi.) S of Beirne, off AR St. Hwy. 61 (S31, T10S, R20W). A record for Pike County (1 adult, HSU 1557) was taken 6 April 1997 from a slough located 1.6 km (1.0 mi.) E of the jct. of AR St. Hwys. 195 and 301 (Sec. 13, T9S, R 24W). One adult and 3 juveniles (HSU 1343) were collected from Thompson Creek, ca. 11 km (7 mi.) NW Crossett, Ashley County, AR (Sec. 11, T17S, R9W), on 5 July 1996.

Etheostoma asprigene (Forbes) – Mud darter. Robison and Buchanan (1988) reported this species from Coastal Plain areas of Arkansas. The following represent additional distributional records of this darter. Three specimens were taken in an unnamed stream 9.7 km (6 mi.) W of Crossett (Sec. 13, T18S, R17W), Ashley County, AR, on 10 October 2000 by HWR. Also collected in Union County was a single specimen of *E. asprigene* taken from Calion Lake at Calion, AR (Sec. 22, T16S, R19W), on 18 June 1987, by HWR.

Etheostoma fusiforme (Girard) – Swamp Darter. This Coastal Plain darter is rarely collected in Arkansas (Robison and Buchanan 1988). The following represent additional records of this species. One female was collected from backwaters of Calion Lake in Calion (Sec. 22, T16S, R14W), Union County, AR, on 3 July 2001 by HWR. Another specimen (HSU 2132) was collected from Norris Creek, at the NE corner of Strong, Union County, AR (Sec. 33, T18S, R12W) on 22 March 1997.

An additional specimen of this lowland darter was taken from Bayou Bodcau, 1.6 km (1 mi.) N of Lewisville, Lafayette County, AR (Sec. 7, T15S, R23W) on 22 July 2001 by HWR. This represents the westernmost record of this darter in Arkansas.

Percina sciera (Swain) – Dusky Darter. Robison and Buchanan (1988) presented the distribution of this darter in Arkansas. The following represent additional records of this species. One specimen was collected in Big Brushy Creek, ca. 9.7 km (6 mi.) NW of Crossett, AR (Sec. 6, T18S, R9W), Ashley County, AR, on 15 September 1996, by HWR. Also collected in Union County were 2 specimens of *P. sciera* from Three Creeks at AR St. Hwy. 15 (Sec. 20, T19S, R17W) on 21 June 1995 by HWR. This darter is also herein reported from Lafayette County for the first time as a single specimen was taken from Bayou Bodcau at Sunray Rd. (Sec. 14, T15S, R24W) on 11 May 1997 by HWR.

Class Aves:

Petrochelidon pyrrhonota (Vieillot) – Cliff Swallow. Cliff Swallows historically bred in northwestern Arkansas (Howell, 1911, Baerg 1951), but the known breeding range expanded through the Ozarks by the 1960s and into central and southwestern Arkansas by the early 1980s (James and Neal 1986). Construction of concrete bridges during the mid-1900s created extralimital nesting habitat (Erskine 1979), that allowed the expansion and southern shift in breeding distribution. A recent survey of bridges for the durable, gourd-shaped nests revealed that nesting range had expanded eastward through most of southern Arkansas (Tumlison 2007), and observations of breeding birds supported the notion that the breeding population continued to use the nesting sites (Tumlison 2009). The absence of nests in 2006 but their presence in 2007 at the Saline River bridge on U.S. Hwy 278 documented the continuing eastward expansion of nesting into Bradley County (Tumlison, 2009).

During both earlier studies in southern Arkansas, the most southeastern observations of birds or nests were in Bradley County and on the Ouachita River bridge on U.S. Hwy 82 between Union and Ashley Counties. Searches had been conducted, however, through eastern Ashley County as well as Chicot County and up to the Mississippi River, with no evidence of cliff swallows being located until a few deteriorating nests were discovered on a bridge on Lake Chicot (Tumlison and Robison, 2010).

The old bridge connecting Lake Village, AR, and Greenville, MS was largely of steel construction, and recently was replaced by a new structure. The new bridge includes a long ramp over land, composed primarily of concrete, which is replaced by steel over the Mississippi River. On 2 July 2010, the bridge (which had not yet opened for traffic) was examined for the presence of nests. Nests were not present on the steel portions of the bridge, but were present under the concrete structure, with most nests having been built closest to the river on the first concrete sections. At that time, about 75 cliff swallows were observed foraging over the field and levee, sometimes returning to the nests.

On 28 August 2010, the bridge had been opened to traffic and the site was revisited. The breeding season was over, but cliff swallows still were occupying some of the nests, likely just as roosting sites, and small flocks of them were foraging over the fields and levee. House Sparrows (*Passer domesticus*) occupied three of the nests, which is common for this non-native bird (James and Neal 1986).

Counts of nests were made at this time. The concrete ramp portion of the bridge consisted of 10 supported sections, but only the first four (nearest the river) were used for nests: the first section had 126 nests, the second 21, the third 0, and the fourth 27. No nests were constructed along the outer portions of the bridge. The concrete architecture underneath the bridge formed box-like rectangles of concrete, and most nests were built in the corners of those boxes. Corners provide two surfaces upon which the mud construction of a nest can be adhered, and given the humidity of the area, apparently provided the best foundation for nests given their common use.

With the documentation of nesting at this site, the eastward expansion of the breeding range of cliff swallows now in known to include all of southern Arkansas from western to eastern border.

Tyrannus forficatus (Gmelin) – Scissor-tailed Flycatcher. The scissor-tailed flycatcher is a summer resident of western and central Arkansas, but it is present only in small numbers in the eastern lowlands - although by the 1970s there were May and June reports reaching the Mississippi River of southeastern Arkansas (James and Neal 1986). Records from Arkansas indicate that nesting begins in May and June, and fledglings are seen by late July (James and Neal 1986).

A search of more recent records of these birds, maintained in the Arkansas Audubon Society database (http://www.arbirds.org/searchspecies.asp), revealed that scissor-tails have been reported 10 times in the extreme southeastern counties of Drew, Desha, and Chicot. The Drew County observation of a single bird occurred in June 1996, during the breeding season, with the observer noting the bird was "uncommon this far east". Farther east, in Desha County, scissor-tails were reported first in October 2004 (a single bird), then a pair was seen in April 2006 (with a note expressing a hope that nesting might occur). In June of 2007, nesting pairs were reported at the towns of Back Gate and Dumas, and in 2009 spring and fall migrants were reported in March and October.

In Chicot County, a scissor-tail was reported in October 1991, then 2 sightings were made in October 1993 – both were considered to be of transients. Two other reports documented the presumed return of a single bird observed in July, 2008, then August 2009.

In southeastern Arkansas, breeding bird surveys (available from the Patuxent Wildlife Research Center, http://www.mbr-pwrc.usgs.gov/bbs/bbs.html) are conducted yearly along the Old Milo route in western Ashley County and the Eudora route in eastern Chicot County. Analysis of surveys from 1966 – 2007 (Sauer et al. 2008) revealed no observations of Scissor-tails in Ashley County, and single occurrences in Chicot County in 1975 and 1977.

On 11 July 2010, 4 scissor-tailed flycatchers were observed at the intersection of AR St. Hwy. 133S and the truck route on the southern side of Crossett, Ashley County, AR. The birds moved and foraged among the scattered trees near businesses along the truck route. This observation is the first report for Ashley County, and the fact that 2 of the birds were fledglings provides the first evidence of breeding in Ashley County, and represents the southeastern-most documented case for Arkansas.

Class Mammalia:

Scalopus aquaticus (Bangs) – Eastern mole. Searcy County: vic. Mull: This adult male was hand captured by MBC 3 km S Junction Ramblewood Trail/ AR St. Hwy. 14, 13 August 2010, (ASUMZ 28642). Sealander and Heidt (1990) reported the Eastern mole from Searcy County, but this is the first museum record for this county.

Marmota monax (Linnaeus) – Woodchuck. Marion County: Mull: This adult male was found as a recent roadkill by MBC on AR St. Hwy. 14, 18 July 2010, (ASUMZ 28641). Both Sealander and Heidt (1990) and Tumlison et al. (2007) reported that woodchucks had been seen in Marion County, but this is the first museum record.

Geomys breviceps Baird – Baird's pocket gopher. As part of a larger ecological study, 4 specimens were collected by MBC in an area within a linear distance of ~100 m in Jefferson County near Pine Bluff off Exit 37 on Interstate 530 on 10 April 2010. Two of the individuals displayed the normal pelage whereas the other 2 (adult scrotal male [ASUMZ 28632] and adult female [ASUMZ 28633]) displayed unique color mutations of the pelage (Fig. 1). The pelage of the male exhibited very prevalent white hairs on the posterior half of its dorsum whereas the female exhibited very dominant white hairs on the median third of its dorsum. As part of the same ecological study, 2 specimens (adult scrotal male [ASUMZ 28599] and adult female [ASUMZ 28598]) were collected by MBC in an area within a linear distance of ~50 m in Columbia County within the city limits of Magnolia at the Junction of AR St. Hwys. 79 and 82 on 29 October 2010. These 2 individuals exhibited a charcoal gray pelage over the entirety of the body, which is usually brown in color.

The pelage of pocket gophers generally matches the color of the inhabited soil (e.g. *Geomys bursarius*, Krupa and Geluso 2000) possibly to minimize predation. Baird's pocket gophers have pelage that is typically brown, but ranges from pale brown to black (Sulentich et al. 1991). Some individuals express complete pelage deviations, such as albinism. Yet, a small percentage of pocket gophers display aberrant pelage that occurs on a small percentage of its overall body. Examples of these pelage abnormalities generally are expressed as spotting or grizzling (McCarley 1951). The individuals that MBC collected did not exhibit the typical pelage of brown or the usual aberrant pelages that are reported.

Peromyscus maniculatus (Wagner) – Deer mouse. An adult specimen was trapped by MBC in a pitfall trap set (25 April - 9 May 2009) in a Baird's pocket gopher burrow system ~2 km E of Mansfield, 0.5 km S on Harp Rd. in Scott County. This deer mouse was a non-target species captured in a pitfall trap targeting pocket gopher insect inquilines, which was set in a burrow and completely sealed off from the surface. Other vertebrates (*i.e.*, reptiles [Connior et al. 2008]) have been captured in pocket gopher burrows and mounds in Arkansas, but this is the first documented record of a mammal being captured inside a pocket gopher burrow in Arkansas. Deer mice have been captured and are known to use burrows of other species of pocket gophers as retreats (Howard and Childs 1959, Vaughan 1961).

Figure 1. Unique color mutations of the pelage of Baird's pocket gopher (*Geomys breviceps*) collected from Pine Bluff, Jefferson County, Arkansas on 10 April 2010.

Connior (2010) provided updated distribution records of mammals in Arkansas based on original distributions from Sealander and Heidt (1990). Recently, Tumlison and Robison (2010) provided additional distributional records from Southern Arkansas. An examination of specimens of mammals housed in the teaching collections at South Arkansas Community College (El Dorado, Arkansas) and mammal divisions of institutional museums produced the following list of specimen localities that represent new county records.

Scalopus aquaticus (Bangs) – Eastern mole. Union County: Mt. Holly City Limits, 18 February 1988. This specimen was located in the teaching collection at South Arkansas Community College and was subsequently deposited in the Arkansas State University Museum of Zoology (ASUMZ 28597). Yell County: Mount Nebo State Park, 8 May 1962, (UCM 10983). Sealander and Heidt (1990) reported the Eastern mole from Union county, but these are the first museum records for these counties.

Oryzomys palustris (Harlan) – Marsh rice rat. Crawford County: Ft. Chaffee, Land Condition Trend Analysis (LCTA) Plot 33, 16.9 km (10.5 mi) N Greenwood, 1989, (OMNH 19559). Franklin County: Fort Chaffee Maneuvers Training Center, LCTA #122, UTM 15, 403149E, 3895420N, 2000, (OMNH 32865). Sebastian County: Fort Chaffee Maneuvers Training Center, LCTA #517, UTM 15 S, 396653E, 3903543N, 2000, (OMNH 32866). These are new county records (Sealander and Heidt 1990).

Reithrodontomys humulis (Audubon and Bachman) – Eastern harvest mouse. Sevier County: 6.5 km **(**4 mi.) W Dequeen, US Hwy 70, 0.4 km (0.25 mi) E Rolling Fork, 22 December 1965, (MSB 22487). This record is only the sixth county that this species has been collected from in Arkansas (Sealander and Heidt 1990).

Mus musculus (Linnaeus) – House mouse. Crawford County: Ft. Chaffee, LCTA Plot 33, 16.9 km (10.5 mi) N Greenwood, 1989, (OMNH 36290). Conway County: 11 km (6.8 mi) E Mather Lodge, Petit Jean St. Park, 1970, (OMNH 10455). Sebastian County: Ft. Chaffee Maneuver Training Center, LCTA Site A12, UTM 15S, 384155E, 3909801N, 2000, (OMNH 35960). Sevier County: 3.2 km (2 mi.) NW Dequeen, 27 December 1965, Museum of Southwestern Biology (MSB 22488). Union County: NE 1/4, NE 1/4, sec 18, T18S R16W, 17 January 1991, ASUMZ 28596. This specimen was located in the teaching collection at South Arkansas Community College and was subsequently deposited in the Arkansas State University Museum of Zoology. These are new county records (Selander and Heidt 1990).

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New Distributional Records of Ants in Arkansas for 2009 and 2010 with Comments on Previous Records

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We are continually updating the ant faunal list for the state (Warren and Rouse 1969) and report the results of our ant sampling in 2009-10. In 2009, we surveyed 5 prairies and several nearby wooded areas: 1) Railroad Prairie and woods, 2) Downs Prairie, 3) Konecny Prairie and woods, all in Prairie Co., 4) Roth Prairie in Arkansas Co. and 5) Locust Ridge Prairie in Union Co. In 2010, we surveyed pine stands at Warren Prairie in Drew Co., and found a new species for Arkansas Oak NA in Nevada Co. while documenting harvester ant colonies there.

In 2009, for the prairies we used pitfall trapping, and for the wooded areas we used intensive plot sampling techniques, namely, sifting of leaf litter and duff followed by Berlese extraction, breaking into rotten wood, beating of low vegetation, and hand collecting (General and Thompson 2007). In 2010, we used pitfall trapping in the pine forests. The most appropriate and latest taxonomic references were used to identify the ants to genus (Fisher and Cover 2007) then to species (Bolton 1994, 2000, 2003, Bolton et al. 2007, Johnson 1988, LaPolla et al. 2010, MacGown 2006, Snelling 1995, Trager 1984, Trager et al. 2007, Ward 1985, and Wilson 2003). Specimens were sent to the Museum of Comparative Zoology (MCZ) of Harvard University for verification by Mr. Stefan P. Cover. Vouchers of all new state records will eventually be deposited at the Arthropod Museum of the University of Arkansas, Fayetteville, AR and MCZ, Cambridge, MA.

Formica incerta is newly recorded from Arkansas, being very common in the prairies. In addition, we established 72 new county records for the 46 species collected (Table 1). We also recognize the first collection of *Pachycondyla gilva* (formerly *Cryptopone gilva*, sensu Mackay and Mackay 2010) by Mr. Cover from the Boston Mountains, Franklin County in 1996 (AntWeb 2002).

Finally, we amend the records reported in previous publications of our updating efforts. *Aphaenogaster texana* is listed in General and Thompson (2007, 2008, 2009). A fortuitous visit to MCZ in 2009 by DMG revealed that these ants are properly named *Aphaenogaster rudis*. New county distributional records for *Dorymyrmex bureni* and *Pyramica reflexa* are revised to new state distributional records for 2008 (General and Thompson 2009). In the process of creating a relational database of Arkansas ant records, we discovered that records of these 2 species had not been previously published.

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Table 1. List of new distributional records for Arkansas in 2009 and 2010.

	County				
Species	Arkansas	Drew	Nevada	Prairie	Union
Amblyopone pallipes		√			
Aphaenogaster fulva		√		√	
Aphaenogaster lamellidens		√			
Aphaenogaster rudis		√		√	√
Aphaenogaster treatae		√			
Brachymyrmex depilis		√		√	√
Camponotus castaneus					√
Camponotus pylartes		√			
Crematogaster atkinsoni		√			
Crematogaster cerasi				√	
Crematogaster lineolata				√	
Crematogaster minutissima					√
Dolichoderus mariae			√		
Forelius pruinosus		√		√	√
Formica incerta	X	X		X	X
Formica pallidefulva				√	
Hypoponera opaciceps		√			√
Hypoponera opacior				√	
Lasius alienus		√		√	
Lasius neoniger				√	
Monomorium minimum				√	√
Myrmecina americana				√	√
Nylanderia terricola				√	√
Pheidole bicarinata		√		√	√
Pheidole dentata		√			
Prenolepis imparis		√			
Proceratium croceum		√			
Proceratium pergandei		√			
Protomognathus americanus		√			
Pseudomyrmex pallidus		√			
Pyramica clypeata					√
Pyramica dietrichi		√		√	√
Pyramica membranifera					√
Pyramica ohioensis		√		√	
Pyramica ornata				√	√
Pyramica pilinasis		√			
Pyramica rostrata		√			√
Solenopsis invicta				√	√
Solenopsis molesta				√	√
Stenamma brevicorne		√			
Stenamma impar		√			
Strumigenys louisianae				√	√
Tapinoma sessile		√			
Temnothorax curvispinosus				√	
Temnothorax pergandei		√		√	
Trachymyrmex septentrionalis				√	

Key to Table 1. X = New AR record of species; √ = New county record of species

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Foraging Behavior of Three Sympatric and Congeneric Tyrannid Flycatchers (*Tyrannus* spp.) in Western Arkansas

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With the recent establishment of the Western Kingbird (*Tyrannus verticalis*; WEKI) in Arkansas (Ellis and Kannan 2004), the northwestern part of the state now has during summer 3 sympatric kingbirds: the Eastern Kingbird (*T. tyrannus*; EAKI), the Scissor-tailed Flycatcher (*T. forficata*; STFL), and WEKI. This offers an opportunity to examine the phenomenon of competition and co-existence in these equal-sized congeneric Tyrannids. Because closely related species have similar ecological needs, there is the potential for competition for resources (Gause 1934) and resulting partitioning of ecological niches (MacArthur 1958). Although many studies have examined the resource use and niche partitioning in sympatric tyrant flycatchers none duplicate the specific 3 species design of our study. One study compared 2 of the species (EAKI and WEKI) we investigated (Mackenzie and Sealey 1981). Three papers included WEKI but in comparison to a western *Tyrannus* that was not a part of our effort (Hespenheide 1964, Ohlendorf 1974, and Blancher and Robinson 1984), and 2 investigators studied EAKI comparing it to several eastern USA flycatchers (Hespenheide 1971, Via 1979). We conducted our study because arrival of a new species can shift foraging niches of native species as a consequence of competition for resources (Morse 1971, 1980, 1989). Therefore, quantitative data on foraging niches of the new and the original species can provide insights on how they can coexist and whether the new species has the potential to displace existing species. Assuming that food is in limited supply, partitioning of the foraging niche in response to any competition between these 3 Tyrannids can be accomplished by foraging in different microhabitats on similar arthropod prey, or by capturing different kinds of arthropod prey (size and taxa) in the same microhabitat (MacArthur 1958, Schoener 1965, MacArthur and Pianka 1966, Beaver and Baldwin 1975).

We studied foraging behavior in the 3 sympatric kingbirds in and around Fort Smith (Sebastian Co.), Arkansas, in May-June of 2006. Our goal was to determine how WEKI coexists with the 2 indigenous species and to examine for any niche partitioning. There were 2 study areas; one on the campus of the University of Arkansas in Fort Smith, the other area was in downtown Fort Smith near an electrical power substation. The campus site comprised a largely open lawn area near the clock tower containing two concrete water fountains and several tall trees. Both STFL and EAKI occurred regularly there and were numerous. The downtown area near the electrical substation was surrounded by chain-link fences and scattered trees. WEKI nested on the substation structures. All 3 species occurred there but STFL was infrequently observed. WEKI was initially discovered there in 2002 (Ellis and Kannan 2004) at which time it was already well established nesting (Bernard W. Beall, *pers. comm.*).

Observations were performed early mornings (0700-0900) and late afternoons (1800-2100), which were the convenient times for field work, but the time for each observation was not recorded. From vantage points, foraging birds were observed and the following variables noted for each foraging observation: perch height from which the sally was launched; perch type (whether fence, wire, building, tree, etc.); sally distance; sally time; maximum height flown; height at which prey was captured; prey size (whether half the size of bill, same as bill, or double the bill size); and whether the bird returned to same perch (recorded as a 1) or different perch (recorded as a 2). (Measurements in feet were later converted to metric.) Size of prey in millimeters was estimated by multiplying the final ratios of prey size to bird bill size times the actual bill lengths of the respective bird species, which average approximately 18mm for male STFL and WEKI (Regosin 1998, Gamble and Bergin 1996) and 14mm for male EAKI (Murphy 1996). We recorded 474 observations: 214 for STFL, 132 for WEKI, and 128 for EAKI; for prey size sample sizes were 154 for STFL, 119 for WEKI, and 122 for EAKI totaling 395 observations. The reduced number is due to observations made in which prey size could not be determined. No more than three successive foraging bouts were recorded for an individual bird before finding another bird. Because the birds were not marked, it was uncertain that on visits to the study areas specific birds were not sampled more than once producing an element of pseudo-replication in the data. The existence of ample populations of birds at the study sites contributed to lessening this effect. Also the absence of WEKI on campus confounded the comparison between species. (We did not note nature of capture substrate during foraging bouts, whether in air, on vegetation, or on ground.) Statistical analyses of the foraging parameters, consisting of analysis of variance employing Duncan's multiple range procedure, was performed using SAS-9.2 (SAS 2008).

The birds selected a wide variety of perches during their foraging activities (Table 1). Even though the 2 study areas did exhibit common perch opportunities, there still were differences. For example, the clock tower only existed at the campus location and the metal structures of the electrical substation only occurred at the other site. However, both sites had trees and other common structures but in differing proportions. Considering these differences and also that both sites did not contain all the species of kingbirds, striking differences in perch selection were evident (Table 1). EAKI showed a distinct preference for trees from data at both study areas. STFL, which predominated at the campus study area, favored perching on the clock tower and secondarily on trees. WEKI was present only at the off-campus site, and there they most commonly selected the openness of fence and utility pole wires, while none used trees. In the same off-campus area EAKI was not detected using wires but instead used the tree perches that may provide more protective cover. WEKI nested on the superstructure of the power substation and occasionally performed foraging flights from the metal beams.

All three species differed significantly from each other in perch height, height flown, and prey capture height, *P*=0.0001*)* with STFL preferring the highest and EAKI the lowest (Table 2). Also, STFL returned to a different perch (*P*=0.0001) compared to EAKI and

Table 1. Perch selection by the three species of sympatric kingbirds during foraging forays (STFL=Scissor-tailed Flycatcher, WEKI=Western Kingbird, EAKI=Eastern Kingbird). Data are shown as percentage perch occupancy, with number of observations in parentheses.

Species	Clock tower	Building	Tree	Fence wire	Fence post	Utility wire	Utility pole	Trash can	Metal beam	Fountain
STFL	67% (144)	8% (16)	14% (30)	3% (8)	4% (9)	1% (2)	2% (4)	1% (1)	0	0
WEKI	0	2% (3)	0	27% (36)	0	52% (68)	12% (16)	0	7% (9)	0
EAKI	4% (5)	3% (4)	77% (99)	0	0	0	9% (11)	6% (7)	0	1% (2)

Table 2. Analysis of seven variables in the foraging behavior of three sympatric Kingbirds in western Arkansas (STFL=Scissor-tailed Flycatcher, WEKI=Western Kingbird, EAKI=Eastern Kingbird).

Species	Perch height (m)		Height flown (m)		Same perch =1; different perch =2		Prey length (mm)		Prey capture height (m)		Sally distance (m)		Sally time (s)	
	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N
STFL	19.4[a]	214	19.8[a]	214	1.37[a]	214	24.8[a]	154	14.8[a]	214	8.8[a]	214	3.5[a]	214
WEKI	11.5[b]	132	11.8[b]	132	1.21[b]	132	23.3[a]	119	8.2[b]	132	8.0[a]	132	3.2[a]	132
EAKI	4.0[c]	128	5.0[c]	128	1.14[b]	128	20.2[a]	122	3.6[c]	128	9.0[a]	128	3.5[a]	128

[a,b,c]Means with the same letter are not significantly different (alpha=0.05); Duncan's Multiple Range test.

WEKI, which tended to return to the same perch after capturing prey (Table 2). The 3 species did not differ significantly from each other in prey size, sally time, or sally distance (Table 2). It should be noted that EAKI bill length averaged 4mm shorter than WEKI and STFL and that mean prey length for EAKI was 4.6mm shorter than for STFL and 3.1mm shorter than WEKI, but these prey length differences were not significant (Table 2, *P*=0.2181). The different heights exhibited in foraging behavior by the 3 kingbirds shown by our results (Table 2) supports the part of Schoener's (1965) hypothesis that states that congeneric bird species of similar size could feed on similar sized prey but in different microhabitats to coexist and avoid competition. Therefore, we conclude that these three species will continue to coexist in the Fort Smith region of Arkansas.

A study in Kansas (Dick and Rising 1965) found that WEKI and EAKI overlapped considerably in arthropods consumed but differed greatly from each other in different localities suggesting to the authors that the birds were coexisting by foraging "in significantly different parts of the available habitat" therefore supporting our conclusion. However, we do not have data for EAKI or STFL in our area before colonization by WEKI needed to detect for a shift in foraging niche space after the advent of the WEKI. Data for WEKI from a previous study conducted in an open riparian habitat in southeastern Arizona (Blancher and Robertson 1984), found that the mean foraging height (9.3m) is similar to that observed in the present study (8.2m; Table 2), but both foraging time and distance flown were approximately twice that found in our study. Sally time was 3s for EAKI (Murphy 1996), which is close to our finding for all three species (Table 2), but Gamble and Bergin (1996) report 8s for WEKI. A study in southwestern Virginia (Via 1979) showed that foraging flights for EAKI were mostly from tops of herbaceous vegetation, a category that we did not recognize. Our study showed EAKI flew mainly from trees (Table 1) which was second in frequency, nearly equal to foraging from fence and utility wires, in Virginia. In our study foraging flights from wires were commonly exhibited by WEKI and no flights from these structures where shown by EAKI (Table 1). Regosin (1998) and Murphy (1996) respectively for STFL and EAKI stated that both commonly used wires as perches, quite different from our findings (Table 1). For WEKI, Gamble and Bergin (1996) agree with our finding that power lines and fences are important. MacKenzie and Sealy (1981) found that WEKI selected larger trees for nesting than EAKI, and WEKI nest height was higher than EAKI, which corresponds to the higher foraging zone in WEKI when compared to EAKI that we found. Hespenheide (1971) analyzed beetles occurring in stomachs of EAKI and found the mean size was 9.078 mm in length, ranging from 3 to 20 mm, which is much smaller than the mean of 23.3 mm we found (Table 2) in actively foraging Kingbirds catching insects. Regosin (1998) and Murphy (1996) stated that small prey was consumed in flight while large prey was returned to usually the foraging perch of origin. We analyzed only the large prey.

Descriptions of habitats of the 3 Kingbirds are similar consisting of open country with some trees, open savannahs including agricultural lands and desert scrub (Gamble and Bergin 1996, Murphy 1996, Regosin 1998). Those that have evaluated differences in habitats find WEKI occurs in the most open habitats (Hespenheide 1964, Ohlendorf 1974, Blancher and Robertson 1984). Although we did not investigate habitat differences in the species it can be seen in Table 1 that EAKI foraged from trees the most and that WEKI never foraged from tree perches, and STFL was intermediate in tree usage. WEKI in performing foraging flights mainly from fence and utility wires was operating in a very open treeless environment. The tall clock tower on campus was by far the favored foraging perch for STFL and was seldom used by EAKI (Table 1) even though it was available. This disparity highlights the demonstrated differences in foraging zones in which STFL foraged higher than EAKI.

In summary, the three same sized species of co-occurring Kingbirds foraging on equal sized arthropod prey avoided competition by performing aerial foraging activities at different heights. This agrees with the part of Schoener's hypothesis that states that closely related co-existing birds consuming similar food items will occupy different microhabitats, in this case foraging at different heights in the air space.

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The Efficacy of Thermal Imaging Technology for Documenting American Woodcock on Pine Stands

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Abstract

Thermal imaging technology provides a useful tool to understand nocturnal activity of wildlife. We used thermal imaging to document American woodcock use of pine stands in Arkansas. A thermal imaging camera was used along logging roads on sampling dates ranging from December 2009 – February 2010 and in February 2011. We located 4 woodcock in 2010 in 20.27 hours of sampling within all stand types. For 11.55 h we only sampled pine seedling/clearcut stands due to vegetation structure inhibiting our ability to identify woodcock with the camera. In 2011 we found 2 woodcock in 7.42 hours of sampling on pine seedling/clearcut stands. Detection was highest during the peak in woodcock courtship and it increased by 75% when only pine seedling/clearcut stands were sampled in 2010. We detected almost 2 times as many woodcock per hour in 2010 than 2011. We feel that thermal imaging is a viable tool for documenting woodcock. However, we suggest that a handheld thermal camera be used as this would likely increase woodcock detection.

Introduction

Thermal imaging technology provides wildlife researchers with an opportunity to study nocturnal species and document their activity. Most research regarding the efficacy of thermal imaging in wildlife population monitoring has focused on its use in studying mammals (e.g. deer). Less has been done to document the practicality of using this technique for birds. Research has shown mixed reviews regarding the utility of thermal imaging for locating birds, particularly with small bird species (Boonstra et al. 1995, Galligan et al. 2003, Locke et al. 2006) although studies completed documenting birds in flight during migration have been successful (Gauthreaux and Livingston 2006). As few studies on this have been completed, more needs to be done to understand thermal imaging and its use in surveying avian populations as it provides a non-invasive tool for wildlife researchers.

We used thermal imaging technology to document nocturnal habitat use of the American woodcock (*Scolopax minor*) on pine clearcuts in south-central Arkansas. The woodcock is a mid-sized gamebird whose cryptic coloration makes it difficult to locate (Keppie and Whiting 1994). During the nocturnal periods they will often use fields or clearcuts for feeding and roosting activities (Keppie and Whiting 1994). Thus, thermal imaging may provide a useful tool in detecting their nocturnal activity in lieu of other techniques which are more invasive (e.g. spot-lighting).

The goal of our study was to determine the feasibility of using thermal imaging technology in documenting woodcock use of pine plantations. In the future thermal imaging may provide a viable method for assessing woodcock use of vegetation, in censusing of their populations across their range, and in locating individuals for banding and telemetry studies particularly in areas with limited vegetation structure.

Materials and Methods

Our study site was located on privately owned land within the West Gulf Coastal Plain in Cleveland and Bradley Counties, Arkansas. The site (approximately 23,500 ha) was bordered on the east by the Saline River, 8 km north of Warren, Arkansas, in a portion of Arkansas deemed as a high-priority management area for woodcock (Myatt and Krementz 2007). The study area was comprised of approximately 35% bottomland hardwoods and 33 % loblolly pine (*Pinus taeda*) plantations. The remaining 32% was comprised of pines and mixed hardwood-pine stands.

We conducted thermal imaging along logging roads on 10 occasions between December 16, 2009 and February 6, 2010 and 7 occasions between February 7 and 22, 2011. We began thermal imaging approximately 1 hr after sunset and completed surveys by 2300. No set routes were followed but the individual clearcuts were surveyed > 2 nights apart to account for variation in detection due to migration. All stand types were surveyed on 16 December 2009 and 5 – 6 January 2010. Due to low visibility in mature forested vegetation, only new clearcuts and pine seedling stands were surveyed for the remaining surveys in 2010 and 2011.

We surveyed each route using a Mitsubishi IR-M700 thermal infrared imager (Mitsubishi Electric Corporation, Canada) equipped with a 50 mm lens. The camera was held by an observer on the edge of the field truck and the angle was adjusted relative to clearcut topography. Output was sent to a digital video cassette recorder (Sony DCR-TRV900) being monitored by a 2nd observer. When a potential woodcock was located, a 3rd observer used a spotlight and walked to the location to validate woodcock presence.

The number of woodcock/h was calculated when all stand types were sampled in 2010, only new clearcuts and pine seedling stands were sampled when no woodcock were courting, when woodcock were courting, and during the peak in woodcock courting. The peak in woodcock courting was based on woodcock counts from crepuscular surveys completed from January – February 2010 and 2011 during a concurrent study completed on the study site on woodcock migration.

Results

Four woodcock were located in pine seedling and clearcut stands from December 16th, 2009 – February 6th 2010 during 20.27 hours of sampling in all stand types. For 11.55 hours, only pine seedling and clearcut stands (0.35 woodcock/h) with less dense vegetation structure were sampled, and encounter rate was 75% greater than when all stands were sampled (0.2 woodcock/hr). Woodcock were courting for 9.88 of the 11.55 hours sampled and no woodcock were found when woodcock were not courting. Over twice as many woodcock were located during the peak in woodcock courting in early-February (Table 1).

In 2011, 2 woodcock were located in 7.42 hours. Number of woodcock located per hour was 0.27/h. There was a 50 % decrease in woodcock encounter rate in 2011 compared to 2010 (Table 1).

Discussion

Although our results show limited utility of thermal technology for making population inferences, we found that thermal imaging may provide a viable tool in locating woodcock during their peak use on new clearcuts and pine-seedling stands. We were able to document woodcock with comparable rates to capture rates associated with studies completed in Maine, New York, Pennsylvania, West Virginia, and Michigan (0.39 – 0.65 woodcock/man hour) (Hale and Gregg 1976). Moreover, our encounter rate exceeded capture rates in 2010 during the period of peak woodcock use. However, as probability of capture is not 100 percent, the encounter rate would need to exceed these capture rates to justify the use of thermal imaging due to the high cost differential.

Table 1. The number of woodcock found per hour using thermal imaging in new clearcuts/pine seedling stands when woodcock were not courting, during woodcock courting, and during the peak in woodcock courting in Warren, AR from January - February 2010 and 2011.

	Woodcock/h	
Sampling	2010	2011
Non-courting	0.00	-
Woodcock courting	0.41	0.27
Peak woodcock courting	1.14	-

Interestingly our detection rates in 2011 were much lower than in 2010. Berdeen and Krementz (1998) suggested that woodcock may be forced into less suitable habitat in the Southeastern United States due to the increased propensity of wintertime flooding of bottomland hardwoods, the woodcock's preferred diurnal grounds during winter (Keppie and Whiting 1994). As 2009 was a flood prone year and much of our study site was flooded, it is likely that woodcock in 2010 may have had less area available to them in 2010 causing their numbers to increase in other stands. Thus, detecting less woodcock with thermal imaging may be explained by flooding as we followed the same routes both years and sampled the same stands.

Several factors limited our ability to detect woodcock using thermal imaging. First, we found that thermal imaging was not useful in finding woodcock in stands greater than 1 year old due to the increased density of vegetation. Similarly, the topography of the clearcuts were so varied that this likely limited the range in which we could detect woodcock. Due to this and our survey methodology, we were limited to encountering woodcock along roads. If woodcock are less likely to use areas near roads, this may have affected our encounter rate. Moreover, we were often confused by logs and other debris within the clearcut due to the woodcock's thermal signature not having a high enough contrast to distinguish between them and other debris (Figure 1).

We feel that the use of a handheld thermal imaging camera for documenting woodcock should be explored. This method would provide more versatility as it would account for variability in topography by allowing the individual to adjust the thermal camera more accurately than from a vehicle. Furthermore, a handheld thermal camera would allow for all woodcock to be sampled, not just individuals along the roads as the individual could walk through the stands. Using a handheld thermal camera would likely increase encounter rate making this technology useful in censusing woodcock populations and for woodcock banding and telemetry studies.

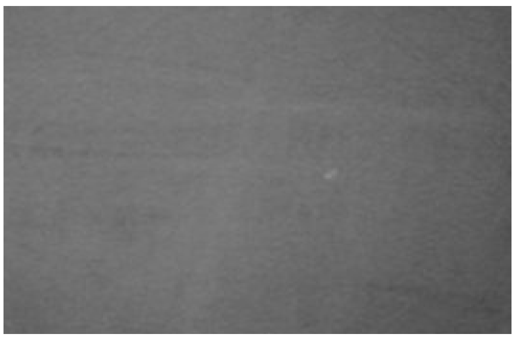

Figure 1. The thermal signature of a woodcock found in a pine seedling stand in Warren, AR in February 2011.

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Caryospora duszynskii (Apicomplexa: Eimeriidae) from the Speckled Kingsnake, *Lampropeltis holbrooki* (Reptilia: Ophidia), in Arkansas, with a Summary of Previous Reports

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The speckled kingsnake, *Lampropeltis holbrooki* Stejneger (=*L. getula holbrooki*) is a medium sized colubrid that ranges from southern Iowa south through Missouri, Arkansas, western Tennessee, eastern Oklahoma, eastern Texas, Mississippi, and Louisiana to the Gulf of Mexico (Conant and Collins 1998). In Arkansas, *L. holbrooki* can be found statewide where it inhabits forested woodlands and rocky hillsides in the Interior Highlands (Ozark and Ouachita mountains) to floodplains and swampy wetlands in the Gulf Coastal Plain (Trauth et al. 2004).

Much is known about the ecology of this snake (see Trauth et al. 2004); however, less is known about its coccidian parasites. Fully sporulated oocysts and free sporocysts of *Sarcocystis montanaensis* Dubey were reported in a naturally infected *L. holbrooki* from Benton County, Arkansas by Lindsay et al. (1992) where they determined this snake species was the definitive host in a previously unknown speckled kingsnake-prairie vole (*Microtus ochrogaster*) life cycle. However, after carefully examining the same isolate, Duszynski and Upton (2009) found minor differences in sporocyst size and in the primary sarcocyst wall and named it as a new species, *Sarcocystis lampropeltii*. In addition, *Eimeria zamenis* Phisalix has been reported from *L. holbrooki* in Illinois and Iowa (see Duszynski and Upton 2009). Herein, we document a new host record for another coccidian parasite of *L. holbrooki* as well as a summary of hosts of this coccidian.

Between March 2010-August 2011, 11 adult colubrid snakes, including 2 southern black racers, *Coluber constrictor priapus* from Polk County, 2 western ratsnakes, *Scotophis obsoletus* from Pike and Sevier counties, 1 prairie kingsnake, *Lampropeltis calligaster calligaster* from Hot Spring County, 2 *L. holbrooki* from Franklin and Pope counties, 1 Great Plains ratsnake, *Pantherophis* (=*Elaphe*) *emoryi* from Pope County, Arkansas, 1 Great Plains rat snake, *Pantherophis emoryi* from McCurtain County, Oklahoma, and 2 Texas patchnose snakes, *Salvadora grahamiae lineata* from Johnson County, Texas were collected by hand and examined for coccidian parasites. Snakes were killed with an overdose of sodium pentobarbital (Nembutal®) and a mid-ventral incision was made to expose fecal contents. Feces was collected and placed in individual vials containing 2.5% (w/v) aqueous potassium dichromate ($K_2Cr_2O_7$) and examined by light microscopy following flotation in Sheather's sugar solution (specific gravity = 1.30). Negative samples were discarded and a single positive sample with unsporulated oocysts was allowed 1 week of sporulation at room temperature (ca. 23°C) in a Petri dish containing a thin layer of 2.5% $K_2Cr_2O_7$. This sample was shipped to R.S. Seville and oocysts were concentrated with Sheather's sugar solution (sp. gr. 1.30) and examined using a compound microscope equipped with Nomarski interference-contrast (DIC) optics. Thirty-six oocysts were photographed and measured using Olympus Microsuite© software. Measurements are reported in micrometers (µm) with means followed by the ranges in parentheses. Oocysts were ca. 71 days old when measured and photographed. Standardized abbreviations for characteristics of oocysts and sporocysts are per Wilber et al. (1998) as follows: oocyst length (L) and width (W), their ranges and ratios (L/W), micropyle (M), oocyst residuum (OR), polar granules (PG), sporocyst length (L) and width (W), their ranges and ratio (L/W), Stieda body (SB), substieda body (SSB), parastieda body (PSB), and sporocyst residuum (SR). A photovoucher of a sporulated oocyst (Fig. 1) was accessioned into the United States National Parasite Collection, Beltsville, Maryland as USNPC 104376. A host voucher specimen was deposited in the Henderson State University Herpetology Collection (HSU), Arkadelphia, Arkansas as HSU 1517. Host taxonomy follows Collins and Taggart (2008, 2009), Pyron and Burbrink (2009) or the Reptile Database (Uetz 2011).

One of 11 (9%) of the snakes was infected with coccidia. A single *L. holbrooki* (female, 472 mm snout-vent length) collected on 23 April 2010 from 3.2 km S of Cass off St. Hwy 23, Franklin County (35.587387°N, 92.852596°W) was found to be passing oocysts of a coccidian fitting the description of *Caryospora duszynskii* Upton, Current and Barnard, 1984 (Fig. 1). Oocysts were spheroidal to subspheroidal, L × W = 24.9 × 23.3 (22.0-27.5 × 21.2-25.6), L/W ratio 1.1 (1.0-1.1), PG present, oocyst wall bilayered, ~ 1.9 (1.7-2.2), rough outer 2/3 thickness with no OR or M; sporocysts were ovoidal, L × W = 17.7 × 12.9 (15.4-19.2 × 11.5-13.9), L/W ratio 1.4 (1.3-1.5), SB and SSB prominent, PSB absent, SR composed of numerous spheroidal granules dispersed into small and large granules. No gross pathology was observed in this host.

Caryospora duszynskii was originally described from the eastern corn snake, *Pantherophis* (=*Elaphe*) *guttatus* from Georgia (Upton et al. 1984). Since then the species has been found in other North American colubrid snakes, including those in the genera *Lampropeltis*, *Masticophis*, *Pantherophis* and *Scotophis* (Table 1; Arkansas State University Museum of Zoology = ASUMZ). Upton et al. (1984) provided the first published photomicrograph and line drawing of an oocyst of *C. duszynskii*, which compare favorably to oocysts we describe herein (Figs. 1-2). We did observe some minor differences in measurements between the two isolates (Table 2), but all other morphological features were essentially the same. Perhaps the use of molecular tools, rather than relying on morphology alone, could help elucidate whether coccidians found are truly the same species or represent cryptic species in separate host species (Williams et al. 2010).

Modrý et al. (2005) recently demonstrated that mice (*Mus musculus*) are capable of indirectly transmitting infections of *C. duszynskii* to uninfected snakes (*P. guttatus* and *S. obsoletus*). Since speckled kingsnakes and other hosts of *C. duszynskii* primarily eat rodents (Green 1997), this finding may be an integral part of the natural history of these hosts. In addition, Modrý et al. (2005) demonstrated the direct transmission of *C. duszynskii* from *P. guttatus* to *P. obsoletus*. Interestingly, *L. holbrooki* in Arkansas has been shown to eat other reptiles (including hosts of *C. duszynskii*) and their eggs (Trauth and McAllister 1995). Additional studies are suggested to investigate this ecological phenomenon in other Arkansas snakes.

Table 1. Seven known hosts of *Caryospora duszynskii*.

Host	State	Prevalence[1]	Reference
Pantherophis guttatus	Georgia	1/1 (100%)	Upton et al. (1984)
	Florida	2/3 (67%)	Modrý et al. (2005)
P. emoryi	Oklahoma[2]; Texas[3]	2/2 (100%); 2/8 (25%)	McAllister (1989); McAllister et al. (1995) ; McAllister and Upton (pers. obs.)
Scotophis obsoletus	Missouri	1/1 (100%)	Upton et al. (1984)
	Texas	1/4 (25%)	McAllister (1989); McAllister et al. (1995)
Lampropeltis calligaster calligaster	Arkansas[4]; Oklahoma	2/2 (100%); 1/1(100%)	McAllister et al. (1995) McAllister and Upton (pers. obs.)
L. holbrooki[5]	Arkansas	1/2 (50%)	This report
L. triangulum syspila[5]	Arkansas[6]	1/6 (17%)	McAllister and Upton (pers. obs.)
Masticophis flagellum flagellum	Arkansas	1/3 (33%)	Upton et al. (1994)

[1]Prevalence in collected samples = number infected/number examined (percent); prevalence values may not represent reality as larger sample sizes may yield more relevant prevalence.
[2]Collected on 29 September 1992 from Greer County, Oklahoma (ASUMZ 18601).
[3]Collected on 26 April 1991 from Jim Hogg County, Texas (host released).
[4]Collected on 29 June 1993 from Conway County, Arkansas (ASUMZ 19104).
[5]New host record.
[6]Collected on 30 June 1992 from Lee County, Arkansas (ASUMZ 18524); mixed infection with *Caryospora lampropeltis*.

Table 2. Selected comparative measurements for 3 isolates of *C. duszynskii*.

Host	Oocysts[1] L × W (range) µm	Sporocysts[2] L × W (range) µm	Reference
Pantherophis guttatus	25.7 × 24.3 (23.0-28.5 × 22.0-28.0)	18.3 × 14.8 (17.0-21.5 × 13.5-16.5)	Upton et al. (1984)
Scotophis obsoletus	27.7 × 26.0 (25.6-29.6 × 24.8-28.0)	19.3 × 14.3 (18.4-20.8 × 13.6-15.0)	McAllister (1989)
Lampropeltis holbrooki	24.9 × 23.3 (22.0-27.5 × 21.2-25.6)	17.7 × 12.9 (15.4-19.2 × 11.5-13.9)	This report

[1]Oocyst L/W ratios = 1.1 (1.0-1.1) vs. 1.1 (1.0-1.1) vs. 1.1 (1.0-1.1).
[2]Sporocyst L/W ratios = 1.2 (1.1-1.3) vs. 1.4 (1.3-1.4) vs. 1.4 (1.3-1.5).

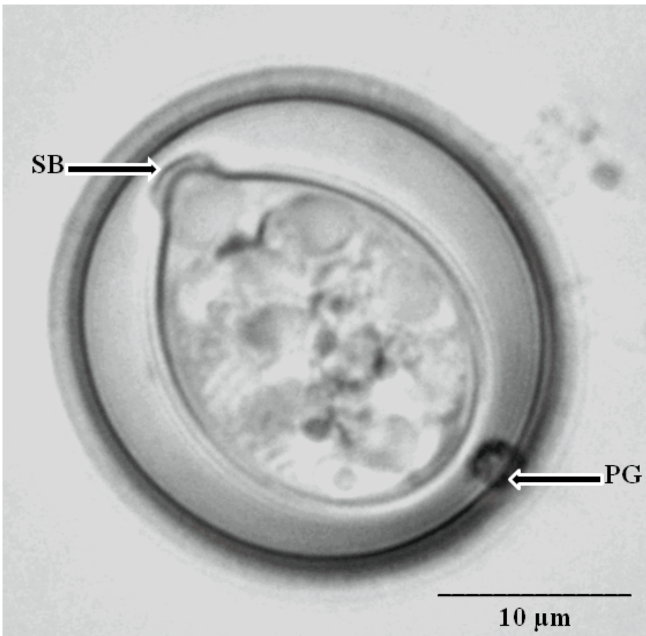

Figure 1. Sporulated oocyst of *Caryospora duszynskii* from *Lampropeltis holbrooki* collected in Franklin County, Arkansas. PG = polar granule; SB = Stieda body.

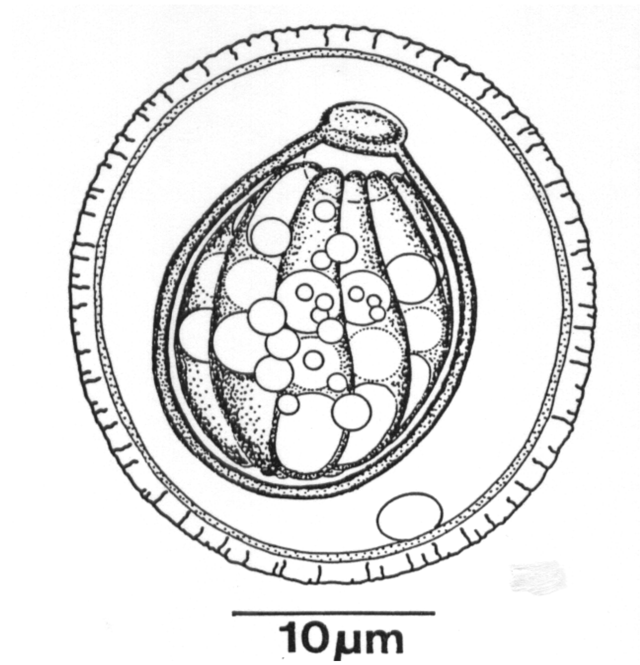

Figure 2. Line drawing of *Caryospora duszynskii* from *Pantherophis* spp. (Redrawn from Upton et al. 1984; see McAllister 1989, Fig. 16).

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Distribution, Conservation and Current Status of the Little Brown Bat (*Myotis lucifugus*) in Arkansas

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The little brown bat (*Myotis lucifugus*) is a common insectivorous bat found across much of North America with the exception of parts of Kansas, Nebraska, and the southern tier of states from Louisiana to southern California. Arkansas represents the southwestern edge of its range in the eastern United States.

The Natural Heritage Program state ranking for this species is S3 (Vulnerable) and it is considered an Arkansas Species of Greatest Conservation Need (Anderson 2006). In the northeastern United States, there have been significant declines in little brown bat populations from White Nose Syndrome in this and other bats that hibernate in caves (Frick et al. 2010). Prompted by the threat of White Nose Syndrome, this paper reviews little brown bat distribution, summer ecology, populations, and conservation measures taken to protect winter hibernacula in Arkansas.

Recent maps of the distribution of this species indicate it has been found in 29 counties, primarily in the Ouachita and Ozark Mountains (Fokidis et al. 2005, Medlin et al. 2006, Sasse and Saugey 2008, Sealander and Heidt 1990).

New records are reported from four counties. Thirty bats were observed in Bennett Cave in Carroll County on May 17, 2005. Two bats were seen in Bat Cave in Marion County on January 16, 2002, though none were present in this cave on surveys of 2007-08 and 2009-10. Three bats were counted in Chalk Mine in Montgomery County on February 25, 2010 but were absent during a survey conducted in the winter of 2010-11. Twenty bats were seen at Coldwater Creek Cave in Baxter County on March 21, 2001 (Figure 1).

Additionally, Sealander and Heidt (1990) and subsequent authors overlooked previously published records of museum specimens from Prairie (Sealander 1956), Searcy (McDaniel and Gardner 1977), Sebastian (Sealander 1956), and Sharp Counties (McDaniel and Gardner 1977)(Figure 1).

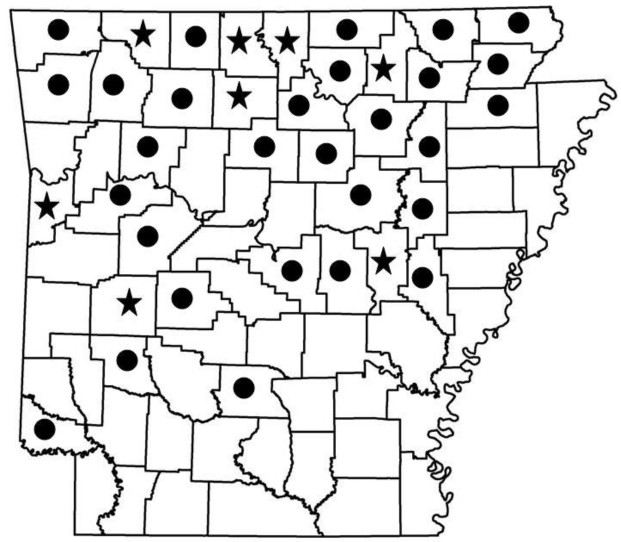

Figure 1. Distribution of the little brown bat in Arkansas. "Stars" indicate new county records or previously published records that were not included in recent analyses of statewide distribution. "Solid circles" indicate historical records from Fokidis et al. 2005, Medlin et al. 2006, Sasse and Saugey 2008, Sealander and Heidt 1990.

Although widely distributed across Arkansas in summer months, little brown bats are rarely captured during mist net surveys, even in areas with heavy concentrations of winter hibernacula. During 80 nights of netting from 1996-1999 in Stone County near some of the most important Arkansas hibernacula, only 1 of 1,087 captured bats was a little brown bat (Harvey et al. 1999, Wilhide et al 1998). In Newton County, only one little brown bat was captured during 32 nights of netting in 2008-09 (Sasse, *unpublished data*). Fokidis et al (2005) and Medlin et al. (2006) captured a few specimens in bottomland hardwood forests in the Mississippi Delta and Gulf Coastal Plain, but they were not common.

Although this species is known to form summer colonies in buildings where they would likely encounter humans, only 21 specimens were submitted for rabies testing by the Arkansas Department of Health from 1983-2010 (Sasse and Saugey 2008, Saugey *unpublished data*). Nineteen specimens were submitted during the months of March through September, although single males from Independence County were submitted during December, 1985 and 1996. The paucity of rabies submissions compared to their higher relative frequency in samples taken near their core range in the northeastern United States (Wang et al. 2010) suggests that they are rare in Arkansas. However, Fletcher et al. (1991) found that they can occur in large numbers at some urban sites.

Fletcher et al. (1991) studied maternity colonies consisting of 300-500 bats in houses in Jackson County where they stayed as late as early November. Banded bats from these colonies were later recovered at hibernacula in Stone County (JD Wilhide, personal communication).

Little brown bats currently use 34 known caves and mines. Largest numbers of hibernacula are in Stone (13), Newton (6), Independence (3), Searcy (2), and Sharp (2) counties. Single hibernacula were found in Baxter, Garland, Izard, Logan, Madison, Marion, and Montgomery counties. Additionally, Bennett Cave in Carroll County is most likely a stopover point during migration because they have only been observed in this site once in May.

Because little brown bats hibernate in sites with characteristics favorable to the endangered Indiana bat (*Myotis sodalis*), they are most often found while conducting surveys for that species. Unfortunately, population estimates were not regularly recorded at many sites prior to 2000 because they were not the target species. Many hibernacula sites have been surveyed once or only a few times in the last 35 years and it is not possible to determine reliable population trends.

At 18 hibernacula, the maximum number of bats observed was less than 25; from 25-99 bats were recorded from 6 sites, and 100-1,200 bats at 5 sites. At five other sites, their presence was noted but no counts were made. These limited data suggest that there may only be a few thousand little brown bats wintering in Arkansas.

All 5 sites with a history of more than 100 bats were located on the Ozark National Forest in Stone County. Prior to 2007, maximum populations were 145 at Amphitheatre Cave, 200 at Biology Cave, 115 at Gustafson Cave, 445 at Hidden Springs Cave, and 1,000 at Rowland Cave.

These caves were all surveyed multiple times in the last 5 winters, but only 2 (Hidden Springs and Rowland Caves) harbored populations greater than 100 bats, and the largest winter population estimate for this species in Arkansas (1,200 bats) was at Hidden Springs Cave during winter, 2009-10.

Population estimates at Amphitheatre, Gustafson, and Rowland Caves are confounded by high ceilings that make it difficult to distinguish this species from Indiana bats. Both species often cluster in the same areas, but several recent surveys did not separate these species while making population estimates.

Although known to be rare in Arkansas (Anderson 2006), this species has no formal legal protection other than that offered to all nongame species, which prohibits them from being killed except to protect human health or personal property. Fortunately, 19 caves are owned by the federal government, 2 by the state government and only 13 are in private ownership. Because they often use the same caves as the endangered Indiana bat, they have benefited from conservation actions taken to protect that species. Seven caves are gated, 3 are fenced, and 5 have closure signs designed to prevent human disturbance while caves are occupied by bats. With one exception these caves are closed to public access on federal and state lands in Arkansas due to concerns relating to potential human spread of the fungus associated with White Nose Syndrome. Blanchard Springs Caverns in Stone County is managed as a tourist attraction by the U.S. Forest Service and is open to the public during year-round. The portion of the cave used by hibernating bats is closed during winter.

Other than human disturbance, there are few threats to caves used by little brown bats in Arkansas. Rowland Cave is subject to occasional flooding of the entrance, which could trap bats inside the cave for extended periods of time. One mine in Garland County that was known to be used by little brown bats was flooded by the construction of Blakely Dam for Lake Ouachita in the 1950s (Davis et al. 1955, Sealander and Young 1955).

Existing conservation actions may be adequate to maintain the current population of little brown bats in Arkansas. However, extirpation is a possibility if White Nose Syndrome spreads into the state.

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Occurrence of Two Rare Prairie Insects, *Tetraloniella albata (*Cresson*)* and *Microstylum morosum* (Loew), at Terre Noire Natural Area, Clark County, Arkansas

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In southwestern Arkansas, remnant prairies occur in a few scattered patches. The “blackland” prairie is a region of calcareous clay soils that lie mostly in the West Gulf Coastal Plain in the southwestern portion of the state (Foti 1974). Although the English geologist George Featherstonhaugh (1844) superficially described these prairies, detailed studies of the distribution, geology, and vegetation of the remnants were not conducted for about another 150 years (Foti 1989). A detailed study of one prairie (Saratoga Landing Blackland Prairie in Hempstead and Howard Counties) revealed characteristics of disturbance that are typical of the remnants – eroded gullies and invasion by woody plants – therefore the use of prescribed fire was suggested as an effective technique for prairie restoration (Foti 1990).

The Arkansas Natural Heritage Commission (ANHC) and The Nature Conservancy (TNC) own remnant prairie patches in Clark County, known and managed as Terre Noire Natural Area (TNNA, Fig. 1).

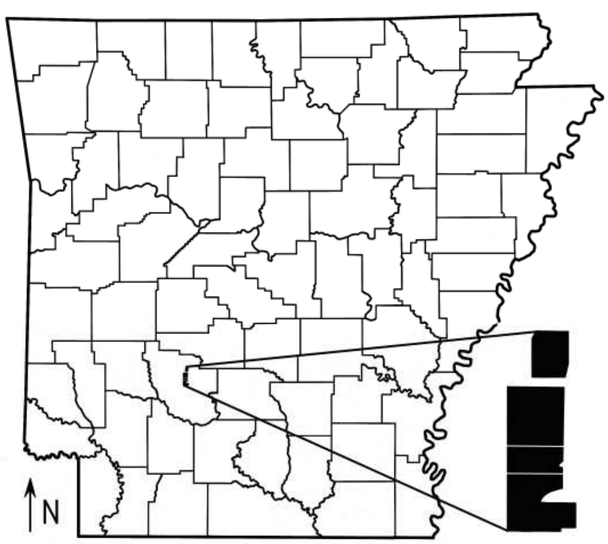

Figure 1. Location of Terre Noire Natural Area, Clark County, AR. Enlargement indicates the 4 units of the TNNA.

The TNNA is one of the highest quality blackland prairies remaining in Arkansas (http://www.naturalheritage.com/natural-area/terre-noire). Located in north-central Clark County, TNNA was established in 1991 and has grown by land acquisition to include 200 hectares (493 acres). The ANHC has been adding to the protected Natural Area as lands have become available, and presently there are 4 units under management (controlled burns and removal of eastern red cedar, *Juniperus virginiana* L.) to maintain or restore prairie conditions. The more northern 2 units are comprised of restored remnant prairie with interspersed patches of trees, and the southern 2 units currently are undergoing extensive restorative treatment due to overgrowth of red cedar.

The TNNA is home to several species of plants and animals considered to be “species of special concern” in Arkansas. The present study was conducted to determine the presence of 2 rare insect species of concern. The long-horned bee *Tetraloniella albata* (Cresson), a member of the family Apidae (subfamily Eucerinae – see Laberge, 2001), is associated with prairies, and has been reported in the southeastern U.S. (in Mississippi) only once (MacGown and Schiefer 1992), although it has been collected previously at TNNA (Warriner, *in litt.*). This bee is characterized as a small, fuzzy, white bee with long antennae present in males (Figure 2). It is oligolectic (from Greek words, meaning “few selected”) and specifically uses purple prairie clover (*Dalea purpurea* Vent.) at TNNA (8 species of *Dalea* occur in Arkansas but only 2, including *D. purpurea*, are not considered to be species of special concern (Arkansas Vascular Flora Committee 2006). This plant-specific trait allowed the survey strategy to be focused on the presence and blooming chronology of the flowers.

Microstylum morosum (Loew), the giant prairie robberfly, is another rare insect of special concern, which is also associated with prairies and previously found at TNNA (Warriner 2004). *Microstylum morosum* (Figure 2) is the largest member of the Asilidae (Back 1909) reaching a length of 50 mm (Bromley 1934). Males are shiny black and have brown to black wings. Females are larger than males, but are most easily distinguished by their reddish legs. Both have distinctive emerald-green eyes.

The species was believed to be endemic to Texas (Martin 1960) until Beckemeyer and Charlton (2000) documented it in Kansas, Oklahoma, Arizona, New Mexico, and Colorado. More recently, *M. morosum* was documented at TNNA – about 320 km distant from the nearest eastern occurrence then known in Texas. This first documented Arkansas record was discovered on 19 July and a voucher specimen was collected 20 July (Warriner 2004). In Texas, the species has been collected between 28 June and 26 August (Bromley 1934).

Figure 2. Images of males of *Tetraloniella albata* (top) and *Microstylum morosum* (bottom) taken at Terre Noire Natural Area (TNNA) during 2010.

Tetraloniella albata

To search for *Tetraloniella albata* during the summer of 2010, we visited TNNA and conducted random walks to survey each of the 4 units for the presence of these bees. Twelve sites were selected for examination, representing the range from high-quality prairie to degraded prairie encroached by dense stands of cedar. Because the presence of *T. albata* is associated with the onset of flowering of purple prairie clover, we monitored floral development and began our surveys after the plants were in bloom. During peak activity periods between 10:00 – 14:00 hrs (M. Warriner, *in litt.*), we meandered among patches of purple prairie clover and recorded the number of *T. albata* seen during the visit to each site (chance observations at other times also were recorded). Besides the distinctive appearance of this white bee serving to "catch the eye", location of individuals was further enhanced by hearing the unusual high-pitched buzz of the bee in flight. The site being a protected natural area owned by state agencies, we collected only one voucher specimen (deposited in the collections at Henderson State University), and numerous "voucher" photographs were taken of other individuals.

In Arkansas, *T. albata* has been collected from 20 May to 25 June (M. Warriner, *in litt.*). During our study, *Dalea purpurea* was coming into bloom on 21 May 2010, but *T. albata* was not found until 25 May 2010. On that date, at 13:06 hr, about 10 individuals were seen foraging among prairie clover on the northern-most part of TNNA, but only 1 individual was seen on each of the next 2 units southward during that day. We made 6 additional trips to TNNA between 27 May and 9 June 2010 to search for *T. albata* on other parts of the Natural Area. Visual qualitative assessments of the 4 units at TNNA revealed that the abundance of purple prairie clover decreased from the most northern (best prairie) to the most southern (most overgrown with cedar) unit, and the abundance of *T. albata* was functionally consistent with the observed abundance of *D. purpurea*.

The earliest observation of *T. albata* was at 8:45 h and the latest was at 13:30 h (the bees likely were active well after that time, but surveys had been terminated due to the heat). A maximum of 26 bees was found during a survey of the northern-most unit on 7 June, resulting in an average of 1 bee per 2 minutes of the survey. Twelve bees were seen at each of 2 other sites, 1 at a separate location on the north unit (8 June) and 1 on the second unit south (2 June), resulting in an average of 1 bee per 5 minutes of the survey. On the third unit south, 8 *T. albata* were found on 9 June, averaging 1 bee per 10 minutes of survey. Only 1 *T. albata* was encountered on the heavily treated fourth unit south (where there are few and scattered *D. purpurea*) at 13:11 h on 27 May.

It appears that this rare bee is well established in the northern 2 units of TNNA. Management to restore prairie habitat in the southern 2 units should allow further re-establishment of already-present *D. purpurea* and lead to increase in populations of *T. albata* throughout TNNA.

Microstylum morosum

Although the first documented record of *M. morosum* from Arkansas was collected in Clark County during 2002 (Warriner 2004), apparently the first specimen from Arkansas was collected in 1994 from Howard County (Barnes et al. 2007). Several recent photographic records, listed here, were compiled by Hershel Raney on his Arkansas Robberfly website (http:www.hr-rna.com/RNA/Robber%20main%20page .htm). On 5 August 2005 at 9:05 h, Charles Mills photographed a male *M. morosum* in Howard County at Okay levee near Millwood Lake, and on 7 September 2007 Greg Lasley photographed a female within a mile of Mills' location at the levee (images available at http://www.greglasley.net/nonBirds/ microstylummorosum.html). This specimen (43 mm total length) was collected and preserved in the collection of Mike Thomas in Connecticut. Dan Scheiman photographed a female on 1 July 2006 in Hempstead County at Grandview Prairie Wildlife Management Area, and Norm and Cheryl Lavers later imaged a female also at Grandview Prairie, on 19 July 2008.

All of these records were from southwestern Arkansas, but more recently Norm Lavers deposited a specimen in the University of Arkansas Arthropod Museum, collected in Baxter County, AR, near the Missouri border. *Microstylum morosum* also has been collected recently (2009) near the Arkansas border in the White River Hills of extreme southwestern Missouri (detailed in Ted McRae's website, http://beetlesinthebush.wordpress.com/2009/09/17/north-americas-largest-robber-fly).

Based on all previous dates of observations and collection, it was clear that the species does not appear until summer. We had watched for *M. morosum* during the earlier surveys targeting *T. albata* but did not encounter any individuals until 29 June 2010 (about 3 weeks earlier than the initial discovery at TNNA on 19 July (Warriner 2004).

We initially attempted to make counts of this robberfly during timed random walks, but its relative rarity made the timed approach uninformative. Instead, we selected prairie patches and conducted non-timed random walks merely to locate and document the presence of the species.

Four of our 5 observations of *M. morosum* occurred on the best prairie, i.e., the most northern unit. On 29 June 2010, we located a male *M. morosum* at 11:00 h at the ecotone of the prairie on the west-central edge of the northern-most unit. Within a few minutes, a female joined the male on woody vegetation at the edge of the grassy prairie. Near the northern side of the unit, and close to the location of Warriner's (2004) observation, we found another female *M. morosum* near the forest edge at 11:45 h. More centrally in the unit, a female was located on 21 July 2010 at 11:32 h. On 28 July, at 11:22 h, a female was found at the southern edge of the unit.

All other units were searched for *M. morosum* on 1, 15, 16, 19, 26, and 30 July, and 21 and 26 August, with findings only on 30 July, when a female was observed at 11:53 h on the second unit south. She perched on grasses near woody vegetation near the northern border of that unit. Prairie edges that appeared to be appropriate habitat were present in the third unit south, but repeated searches did not reveal the species in that unit. Further prairie restoration increasing connectivity between the units likely will result in the occurrence of *M. morosum* farther into TNNA.

Other large robberflies encountered and photographed during the search for *M. morosum* included *Efferia aestuans* (L.), *E. nemoralis (*Hine*)*, *Promachus hinei* (Bromley), *P. bastardii* (Macquart), and *Triorla interrupta* (Macquart). None of these are easily confused with *M. morosum*.

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The editorial staff also extends our heartfelt appreciation for the expertise, assistance and valuable time provided by our colleagues who acted as reviewers for the Journal. Expert reviewers were recruited from within Arkansas, other States of the U.S.A, Europe and Asia. Only through the diligent efforts of all those involved that gave freely of their time, can we continue to produce a high quality scientific publication.

Title of a Paper Prepared for the Arkansas Academy of Science Journal (14 point, bold, centered)

A.E. Firstauthor[1], B.F. Second[1], C.G. Third[2], and D.H. Lastauthor[1] (12 point font, normal, centered)

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[2]Arkansas Game and Fish Commission, 915 E. Sevier Street, Benton, AR 72015 (10 point font, italic, centered)

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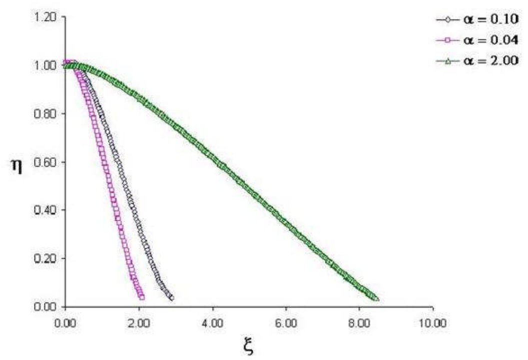

Figure 1. Electric field, η, as a function of position, ξ, within the sheath region for three different wave speeds, α.

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<u>**Specific examples**</u>:
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Davis DH. 1993. Rhythmic activity in the short-tailed vole, *Microtus*. Journal of Animal Ecology 2:232-8
<u>Cited in text as:</u> (Davis 1993)

Steiner U, **JE Klein** and **LJ Fletters**. 1992. Complete wetting from polymer mixtures. Science 258(5080):1122-9.
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Zheng YF and **JYS Luh**. 1989. Optimal load distribution for two industrial robots handling a single object. ASME Journal of Dynamic System, Measurment, and Control 111:232-7.
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<u>**In press articles**</u>

Author(s). Expected publication Year. Article Title. Journal title *in press*.
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Kulawiec M, **A Safina**, **MM Desouki**, **IH Still**, **S-I Matsui**, **A Bakin** and **KK Singh**. 2008. Tumorigenic transformation of human breast epithelial cells induced by mitochondrial DNA depletion. Cancer Biology & Therapy *in press.*

<u>**Electronic Journal Articles and Electronic Books**</u> should be cited as standard journal articles and books except add an availability statement and date of accession following the page(s).

653 p. Available at: www.usfw.gov/ozarkstreams. Accessed 2004 Nov 29.

<u>**Books, Pamphlets, and Brochures**</u>

Box GEP, **WG Hunter** and **JS Hunter**. 1978. Statistics for experiments. J Wiley (NY). 653 p.

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Gilman AG, **TW Rall**, **AS Nies** and **P Taylor, editors**. 1990. The pharmacological basis of therapeutics. 8th ed. Pergamon (NY). 1811 p.
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Book Chapter or Other Part with Separate Title but Same Author(s) – General format is given first.

Author(s) or editor(s). Year. Title of book. Publisher's name (Place of publication). Kind of part and its numeration, title of part; pages of part.

Hebel R and **MW Stromberg**. 1987. Anatomy of the laboratory cat. Williams & Wilkins (Baltimore) . Part D, Nervous system; p 55-65.

Singleton S and **BC Bennett**. 1997. Handbook of microbiology. 2nd ed. Emmaus (Rodale, PA). Chapter 5, Engineering plasmids; p 285-96.

Book Chapter or Other Part with Different Authors – General format is given first.

Author(s) of the part. Year. Title of the part. *In* author(s) or editor(s) of the book. Title of the book. Publisher (Place of publication). Pages of the part.

Weins JA. 1996. Wildlife in patchy environments: Metapopulations, mosaics, and management. *In*: McCullough DR, editor. Metapopulations and wildlife conservation. Island Press (Washington, DC). p 506.

Johnson RC and **RL Smith**. 1985. Evaluation of techniques for assessment of mammal populations in Wisconsin. *In* Scott Jr NJ, editor. Mammal communities. 2nd ed. Pergamon (New York). p 122-30.

Dissertations and Theses – General format is given first.

Author. Date of degree. Title [type of publication – dissertation or thesis]. Place of institution: name of institution granting the degree. Total number of pages. Availability statement.

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Stevens WB. 2004. An ecotoxilogical analysis of stream water in Arkansas [dissertation]. State University (AR): Arkansas State University. 159 p.

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Stevens WB. 2004. An ecotoxilogical analysis of stream water in Arkansas [dissertation]. State University (AR): Arkansas State University. 159 p.

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Harris JL and **ME Gordon** (Department of Biological Sciences, University of Mississippi, Oxford MS). 1988. Status survey of *Lampsilis powelli* (Lea, 1852). Final report 1 Aug 86 – 31 Dec 87. Jackson (MS): US Fish and Wildlife Service, Office of Endangered Species. Report nr USFW-OES-88-0228. Contract nr USFW-86-0228. 44+ p.

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Published Conference Proceedings – General format is given first.

Author(s)/Editor(s). Date of publication. Title of publication or conference. Name of conference (if not given in the 2nd element); inclusive dates of the

conference; place of the conference. Place of publication: publisher. Total number of pages.

Vivian VL, **editor**. 1995. Symposium on Nonhuman Primate Models for AIDS; 1994 June 10-15; San Diego, CA. Sacramento (CA): Grune & Stratton. 216 p.

Multiple Citations are Cited in text as:

(Harris and Gordon 1988, Steiner et al. 1992, Johnson 2006).

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