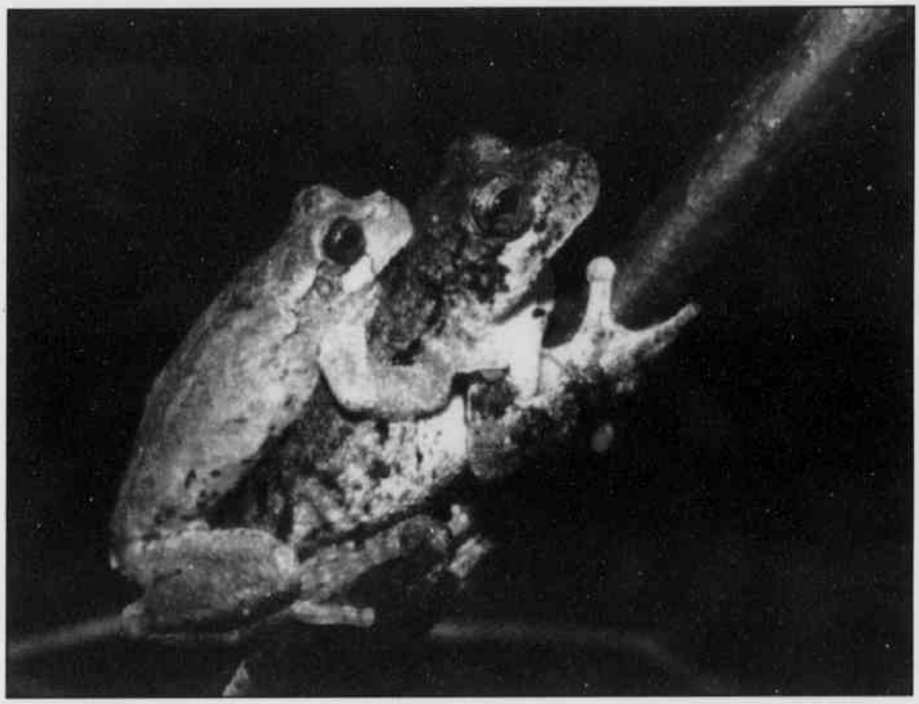
Journal of the

CODEN: AKASO
ISBN: 0097-4374

ARKANSAS ACADEMY OF SCIENCE

VOLUME 53
1999



ARKANSAS ACADEMY OF SCIENCE
DEPT. OF NATURAL SCIENCE
MONTICELLO, ARKANSAS 71655

PAST PRESIDENTS OF THE ARKANSAS ACADEMY OF SCIENCE

Charles Brookover, 1917
Dwight M. Moore, 1932-33, 64
Flora Haas, 1934
H. H. Hyman, 1935
L. B. Ham, 1936
W. C. Munn, 1937
M. J. McHenry, 1938
T. L. Smith, 1939
P. G. Horton, 1940
I. A. Willis, 1941-42
L. B. Roberts, 1943-44
Jeff Banks, 1945
H. L. Winburn, 1946-47
E. A. Provine, 1948
G. V. Robinette, 1949
John R. Totter, 1950
R. H. Austin, 1951
E. A. Spessard, 1952
Delbert Swartz, 1953
Z. V. Harvalik, 1954
M. Ruth Armstrong, 1955
W. W. Nedrow, 1956
Jack W. Sears, 1957
J. R. Mundie, 1958
C. E. Hoffman, 1959
N. D. Buffaloe, 1960
H. L. Bogan, 1961
Trumann McEver, 1962
Robert Shideler, 1963
L. F. Bailey, 1965
James H. Fribourgh, 1966
Howard Moore, 1967
John J. Chapman, 1968
Arthur Fry, 1969
M. L. Lawson, 1970
R. T. Kirkwood, 1971
George E. Templeton, 1972
E. B. Wittlake, 1973
Clark McCarty, 1974
Edward Dale, 1975
Joe Guenter, 1976
Jewel Moore, 1977
Joe Nix, 1978
P. Max Johnston, 1979
E. Leon Richards, 1980
Henry W. Robison, 1981
John K. Beadles, 1982
Robbin C. Anderson, 1983
Paul Sharrah, 1984
William L. Evans, 1985
Gary Heidt, 1986
Edmond Bacon, 1987
Gary Tucker, 1988
David Chittenden, 1989
Richard K. Speairs, Jr. 1990
Robert Watson, 1991
Michael W. Rapp, 1992
Arthur A. Johnson, 1993
George Harp, 1994
James Peck, 1995
Peggy R. Dorris, 1996
Richard Kluender, 1997
James Daly, 1998

INSTITUTIONAL MEMBERS

The Arkansas Academy of Science recognizes the support of the following institutions through their Institutional Membership in the Academy.

ARKANSAS STATE UNIVERSITY, State University
ARKANSAS TECH UNIVERSTIY, Russellville
HARDING UNIVERSITY, Searcy
HENDERSON STATE UNIVERSITY, Arkadelphia
HENDRIX COLLEGE, Conway
JOHN BROWN UNIVERSITY, Siloam Springs
MISSISSIPPI COUNTY COMMUNITY COLLEGE, Blytheville
OUACHITA BAPTIST UNIVERSITY, Arkadelphia
SOUTHERN ARKANSAS UNIVERSITY, Magnolia
UNIVERSITY OF ARKANSAS AT FAYETTEVILLE
UNIVERSITY OF ARKANSAS AT LITTLE ROCK
UNIVERSITY OF ARKANSAS FOR MEDICAL SCIENCES, Little Rock
UNIVERSITY OF ARKANSAS AT MONTICELLO
UNIVERSITY OF ARKANSAS AT PINE BLUFF
UNIVERSITY OF CENTRAL ARKANSAS, Conway
UNIVERSITY OF THE OZARKS, Clarksville
WESTARK COLLEGE, Fort Smith

EDITORIAL STAFF

COVER: Amplexus in the bird-voiced treefrog (*Hyla avivoca*) from Calion Lake, Union County, Arkansas. Photo by Stan Trauth

Arkansas Academy of Science 1999

April 2-3, 1999
83rd Annual Meeting

Arkansas Tech University
Russellville

JOURNAL
ARKANSAS ACADEMY OF SCIENCE

ANNUAL MEETING 2-3 APRIL 1999
ARKANSAS TECH UNIVERSITY

Rose McConnell
President

Mostafa Hemmati
President-Elect

John D. Rickett
Secretary

Joyce Hardin
Treasurer

NAAS Delegate

Henry Robison
Historian

Secretary's Report

MINUTES OF THE 83RD MEETING

FIRST BUSINESS MEETING
2 APRIL 1999

Number present: 15

1. Rose called the meeting to order at 1125 hrs. with a welcome, then recognized the following individuals/committees for reports:

2. Local Arrangements Committee Chair (Mostafa Hemmati):
   (a) the registration table has been set up in the lobby of McEver Hall;
   (b) pre-registration packets are ready (165 pre-registrations were received, including 80 requests for banquet ticket);
   (c) the journal distribution table is nearby;
   (d) the banquet speak will be Dr. Dawn Bonnell (U. Penn.) (the Office of Academic Affairs [Dr. Larry Robinson] is paying her transportation expenses and honorarium);
   (e) 84 abstracts were received;
   (f) a tour of the new library will be offered at 4:00 Friday;
   (g) a mixer will occur at 5:00 at the Holiday Inn (shuttles will be available);
   (h) the banquet is set for 6:00 in the cafeteria;
   (i) refreshments will be available at break times during paper sessions;
   (j) the judging panel has been named.

3. John Rickett, Secretary:
   (a) presented the minutes of 1998 Busienss Meetings for review and correction (the minutes were approved by the Executive Committee at its Fall 1998 meeting in order to publish them in the journal);
   (b) membership report: Rickett asked for a motion to approve minutes (Hemmati moved; 2nd: Wiley).

4. Joyce Hardin, Treasurer: referring to a handout of expenses and income, reviewed the past year's financial operations. Some discussion for clarification and additional information followed.

FUNDS

	1997	1998
Beginning Balance - 1 January	**$20,512.95**	**$22,740.91**
Net Gain	2,227.96	2,425.37
CLOSING BALANCE - DECEMBER 31	**$22.740.91**	**$25,166.28**
DISTRIBUTION OF FUNDS		
Checking Account (Mercantile Bank, Conway, AR)	$ 2,949.86	$ 4,379.19
Certificates of Deposit		
Dwight Moore Endowment (Mercantile Bank,Conway, AR) No. 175192 - 5.0% Int.	$ 3,646.15	$ 3,963.83
Life Membership Endowment (Mercantile Bank, Conway, AR) No. 175193 - 5.0% Int.	$12,144.90	$13,203.06
CD Unrestricted (Mercantile Bank,Conway, AR)	$ 4,000.00	$ 3,620.20
TOTAL	**$22,740.91**	**$25,166.28**

Respectfully Submitted,

Dr. Joyce M. Hardin, AAS Treasurer

Financial Statement, Arkansas Academy of Science

INCOME:	1997	1998
1. ANNUAL MEETING	**$ 2,711.15**	**-0-**
2. ENDOWMENT		
AAS Endowment Unrestricted		$4,135.30
		$4,135.30
	$ 5,245.29	**$ 4,135.30**

3. ENDOWMENT DONATIONS		
a. AAS Unrestricted	$ 125.00	
b. Dwight Moore	$ 25.00	
	$ 150.00	
	-0-	$ 150.00
4. INTEREST (Checking Account)	$ 99.14	-0-
5. INDIVIDUAL MEMBERSHIPS		
a. Associate/Student	330.00	
b. Regular (Individual)	3,425.00	
c. Sustaining	245.00	
d. Life	525.00	
	$4,525.00	
	$ 3,615.00	$ 4,525.00
6. INSTITUTIONAL MEMBERSHIPS	$ 1,500.00	$ 1,700.00
7. MISCELLANEOUS	-0-	$ 159.00
8. PROCEEDINGS		
a. Miscellaneous Sales	55.00	
b. Page Charges	6,720.00	
c. Subscriptions	895.00	
	$ 7,670.00	
	$10,321.30	$ 7,670.00
9. T-SHIRT (General Endowment)		$ 714.00
TOTAL INCOME	**$23,491.88**	**$19,053.30**

Financial Statement, Arkansas Academy of Science

EXPENSES:

	1997	1998
1. ANNUAL MEETING	$ 1,795.25	$ 163.64
Plaques - Dick Kluender (#606)		
2. AWARDS		
a. Conway Trophy & Awards, Plaques for Arkansas Science Talent Search (#617)	244.09	
b. Arkansas Science Fair Association (#614)	250.00	
c. Arkansas Junior Academy of Science (#615	250.00	
d. Student awards	250.00	
Justin Scarbrough (#611) James Sheets (#609)		
Robin Roggio (#616) Kathy Herrin (#610)		
e. David Saugey Teachers Workshop (#621)	250.00	
	$ 1,444.09	
	$ 1,018.00	$1,444.09
3. BANK CHARGES		
Mercantile Bank - New checks and deposit slips	$ 1,018.00	$1,444.09
4. DUES		
National Association of Acdamies of Science (#608)	$ 62.50	$ 62.50
5. MISCELLANEOUS		
a. Ed Griffin Travel to AAS Conference (#612)	$188.00	
b. Stan Trauth Page Charge Refund (#607)	40.00	
6. NEWSLETTERS		
a. Kwik Print - Spring 1998 Newsletter (#604)	$314.01	
b. UALR - Postage Spring 1997 Newsletter (#619)	403.72	
	$ 403.54	$ 717.73
7. OFFICE EXPENSES	$ 531.43	-0-
8. PROCEEDINGS		
a. Stan Trauth - Editorial Consultation and Travel Volume 51 (#605)	200.00	
b. Pinpoint Color Volume 51 (#618)	14,308.01	
c. Joy Trauth - Editorial Consultant Volume 52 (#620)	500.00	
	15,008.01	
	$12,640.75	**$15,008.01**
9. BANK SERVICE CHARGES	**$ 19.90**	-0-
10. TRANSFER TO CD (Unrestricted)	**$4,000.00**	-0-
TOTAL EXPENSES	**$20,542.02**	**$17,623.97**

5. *Journal* Editor: Stan Trauth presented Volume 52; it is about 75 pages smaller; the approximate cost is about $11,000. Trauth pointed out a few errors caused by a new typesetter (from lack of knowledge of scientific terminology and notation). A motion to accept the report was made by Daly (2nd: Draganjac).

6. *Newsletter* Editor: David Saugey...he is leaving the office, but moved that $750 be set aside for the preparation of one issue of next year's newsletter (2nd: Daly). Rose issued a plea for an on-the-spot nomination for a new Newsletter editor.

7. Historian: Henry Robison announced this is the 83rd Annual Meeting of the Arkansas Academy of Science and the fifth time to meet on the Arkansas Tech University campus. Previous years of meeting here were 1960, 1970, 1977 and 1988.

8. Committee Reports:
   a. Biota Committee: Doug James has a new list of snails of Arkansas (copies will be available); he is in the process of scanning the previous lists onto disk and plans to return those lists to their authors for accuracy checks and upgrading. As of a month ago, the UA Press has not appointed a new director, and James isn't pushing for professional publication until then. James expressed desire for a website and asked our opinion of that form of information dispersal. The Arkansas Species Viability group has a list of bird species of special concern and is working on a list of plants (Kim Smith will report on it at the Second Business Meeting).
   b. Editorial staff revision: Stan Trauth explained the proposed reformatting of titles and duties–the Editor-in-Chief will be primarily responsible for formatting the journal and working with the printer, whereas the Managing Editor will be primarily

responsible for getting the manuscripts reviewed and revised. Stan moved (2nd: Speairs) the approval of this change.

c. Constitution Revision Committee: Rickett presented and explained proposed changes–(1) journal title changes, (2) restructuring of the editorial staff and makeup of the Publications Committee, and (3) cleaning up some language in the descriptions of the Publicity and Science Education Committees. M. Hemmati moved to accept (2nd: Daly).

d. Nominations Committee: Jim Daly announced that John Rickett (UALR) and Tim Kral (UAF) have been nominated for Vice President; Stan Trauth has been nominated for Editor-in-Chief (pending membership approval of the proposed restructuring); and no nominee for Newsletter Editor has been obtained. Daly suggested if we get more than two nominees for any office, we have a runoff to get a definite majority (instead of a plurality).

e. WebPage progress: Rose presented a progress report, explaining some of the anatomy of the new website and the information categories, links, etc. Inquiries should be directed to Walt Godwin (UAM).

f. Junior Academy of Science and Science Fairs: Rickett referred to a report (Appendix A) received from Mike Rapp listing the regional fair directors, student participation and monetary requests ($450 for Science Fairs and $250 for Junior Academy for the next year's operations). Moved by Dan Magoulick; 2nd: Wiley.

g. Science Talent Search: Dan Magoulick reported the usual activities and successes of the Science Talent Search (no written version was submitted) and requested $244.09 to cover award expenses. S. Trauth moved; 2nd: D. James.

h. Auditing Committee: President McConnell asked for volunteers. Bob Wiley volunteered to chair it and will find someone else to help.

i. Resolutions Committee appointment: Rose asked for volunteers and when none came, appointed Mark Draganjac to chair it, and M. Hemmati volunteered to help.

9. Old Business: None came.

10. New Business:
Richard Speairs announced there will be an organizational meeting in room 204 McEver for the Ouachita Mountains Biological Station Board of Governors and Advisory Board.

11. Presidential announcements:

a. The Sigma Xi breakfast will be at the Holiday Inn Saturday morning.

b. Authors are to submit manuscripts for publication to section chairs or editor, and section chairs should make efforts to stay on time.

c. The banquet will start at 6:30, and Dr. Dawn Bonnell will be the featured speaker.

d. A tour of the new library will be offered at 4:00 Friday.

12. President McConnell adjourned the meeting at 12:37.

SECOND BUSINESS MEETING
3 APRIL 1999

Number present: 51

1. President McConnell called the meeting to order at 1200 hrs. and recognized the following individuals/committees for review and/or action:

2. Secretary Rickett presented the minutes of the 1998 Business Meetings by noting copies were available at the entry doors. No corrections were received, so Rickett moved their acceptance (2nd: M. Hemmati). Passed

3. Nominations Committee Chair Daly announced the candidates for Vice President are John Rickett (UALR) and Tim Kral (UAF). President McConnell called for nominations from the floor, but none came. Godwin moved (2nd: Robison) that nominations cease. Passed. Daly announced that Mike Soulsby has been nominated for Secretary. President McConnell asked for nominations from floor, but none came. Doug James moved (2nd: Hemmati) that nominations cease and Soulsby be elected by acclamation. Passed. Hemmati nominated Jeff Robertson for Newsletter Editor. Robison moved (2nd: Hemmati) that nominations cease and Robertson be elected by acclamation. Passed. Ballots for the election of Vice President were passed out and collected.

4. Treasurer Hardin alerted attendees to copies of a financial statement available at the doors and briefly reviewed the items of income and expenses. The journal is our single largest expense, but early payment of page charges is assisting greatly in the management of accounts. No discussion followed, and President McConnell recognized Robert Wiley (Chair, Auditing Committee) who reported that the Treasurer's books are in good order. Hemmati moved (2nd: Robison) to accept the financial report. Passed.

5. Biota Committee: Doug James reported that five lists

have been recently submitted (four groups of insects and snails). The list of vascular flora of Arkansas is on a website at UAF. He also offered to provide individual copies of currently held lists to anyone willing to pay copying costs. The Arkansas Species Viability group has compiled a list of birds and is preparing a list of plants in reference to sensitive habitat areas. (Kim Smith didn't report).

6. Historian: Henry Robison reported that this is the 83rd annual meeting of the Academy; the fifth time to meet at Arkansas Tech University. Other years the meeting occurred here were 1960, 1970, 1977 and 1988.

7. *Journal* Editor: Stan Trauth announced members' copies are available at the table if not already obtained. This issue is smaller. A few errors were noted. Trauth requested that institutional representatives take back appropriate copies to their home campuses. Stan asked for $500 for editorial assistance and $200 for the Editor's stipend. Moved by Hemmati (2nd: Braithwaite). George Harp pointed out that the total page charges collected averages out to slightly more than $31 per page which means approximately 25 percent of pages aren't accounted for in the per-copy/per-page cost analysis. Hardin agreed to check it out.

8. Newsletter Editor: David Saugey briefly reviewed the Newsletter preparation process and noted the cost is quite heavy (probably would be less if we could offer it "on line"). He asked for $750 to support the cost of preparing one issue in 1999-2000. Hemmati moved; (2nd: Robison).

9. President McConnell re-introduced the proposed changes in the editorial staff--the Editor-in-Chief will work with the printer, while the Managing Editor will work mostly with manuscripts and the reviewing and revising process. This restructuring includes a new expense of $300 stipend for the Managing Editor. McConnell opened the floor for discussion. A little came but none that caused any revision of the proposal. Motion (from First Business Meeting) was re-introduced and passed. Stan Trauth was nominated for the new office of Editor-in-Chief. Watson moved (2nd: _?_) that nominations cease and Trauth be elected by acclamation. Passed.

10. Constitution Revision Committee: Rickett reviewed proposed changes (details presented in First Business Meeting). Doug James moved. (2nd: Hemmati). Passed.

11. Science Talent Search (Magoulick not present); request for $244.09 was restated.

12. Science Fairs/Junior Academy: Rickett referred to a report sent in by Mike Rapp (basic contents and monies requested) (Appendix A).

13. President McConnell revisited all the motions requesting monies ($500 for editorial assistance; $300 for Managing Editor; $200 for Editor-in-Chief; $450 for Science Fairs; $250 for Junior Academy; $244.09 for Science Talent Search; and $750 for Newsletter and a motion to approve disbursal (First Business Meeting). Motion passed.

14. Resolutions Committee: Mark Draganjac read resolutions (Appendix B). Braithwaite moved (2nd: _?_) their acceptance. Passed.

15. Student awards: A member of the judges panel announced student paper winners in their respective categories (Appendix C) and thanked the Arkansas Environmental Federation and Sigma Xi for sponsoring the undergraduate and graduate awards, respectively.

16. McConnell recognized M. Hemmati for a meeting review–over 200 people registered for the meeting, 85 attended the banquet, and 84 papers were presented.

17. McConnell announced the Academy's web page is "http://cotton.uamont.edu/~aas/". Rose then described the anatomy of its setup. There may be a few glitches so be patient; many thanks to Walt Godwin.

18. McConnell then asked for other old business, but none came.

19. McConnell then referred to new items of business:
    a. John Rickett is the new Vice President.
    b. We are setting up an e-mail list–all members will be initially put on the list, and the first message will include instructions on how to get off the list if anyone doesn't want to be on the list. Send any questions or suggestions to Walt Godwin at "godwin@uamont.edu". Saugey suggested we give Godwin a vigorous round of applause as thanks–so done.
    c. J. D. Wilhide suggested we purchase a couple of tablecovers with our name and logo. Rose commissioned Joyce Hardin to investigate the cost of such items and report at the Fall ExCom meeting.
    d. A representative for the Arkansas Environmental Competition took the floor and explained the activities of the organization. Permission was requested

(and granted) to send us some information, and the Executive Committee can consider it at their next meeting.

20. Announcements (McConnell):
    a. individuals from different campuses pick up journals for colleagues who are not here and take them back
    b. turn in manuscripts to Trauth or Saugey.
    c. thanks to Mostafa Hemmati for chairing the Local Arrangements Committee and to Dr. Larry Robinson (ATU Office of Academic Affairs) for supporting the banquet speaker.
    d. the 2000 meeting will be in Hot Springs, co-sponsored by the U.S. Forest Service and the Arkansas School for Math & Sciences.

21. Recognitions:
    a. Stan Trauth, for his work as Journal Editor (with plaque).
    b. John Rickett, for 10 years of service as Secretary (with plaque).

22. Rose introduced Mostafa Hemmati as the incoming President and turned the gavel over to him. Hemmati offered his thanks to all attendees, bade all adieu from the meeting, and adjourned the meeting at 1325 hrs.

Respectfully submitted,

John Rickett, Secretary
May-June 1999

APPENDIX A

STATE SCIENCE FAIR ASSOCIATION

Thank you for the support the Academy has provided for the past 16 years for AAS members serving as judges and for financial support. Following is a report of the Science Fairs and Junior Academy of Science Meetings held in Arkansas during 1999:

Central (held at UAMS, Feb 27): Gary Earleywine, fair director, and Marian Douglas, Jr. Acad. director; participants: 323.

Northcentral (held at Lyon College, Batesville, Feb 19): Beverly Meinzer, fair director, and Kathy Campbell, Jr. Acad. director; participants: 172.

Northeast (held at AR State Univ., Jonesboro, Feb 19-20): Larry Mink, fair director, and Ron Johnson, Jr., Jr. Acad. director; participants: 125.

Northwest (held at Univ. of AR, Fayetteville, Mar 5): Lynne Hehr, director of fair and Jr. Acad.; participants: 469.

Southcentral (held at Henderson State Univ., Arkadelphia, Feb 19) Jules Mollere, fair director, and David Brooks, Jr., Jr. Acad. director; participants: 153.

Southeast (held at Univ. of AR, Monticello, Mar 5): Bill Nicholson, fair director; participants: 280.

Southwest (held at Southern AR Univ., Magnolia, Feb 26): Tim Daniels, fair director; participants: 611.

Westcentral (held at AR Sch. for Math & Sci., Hot Springs, Feb 24-26: Shane Willbanks, fair and Jr. Acad. director, participants: 110.

Approximately 280 students are expected to register for the state science fair, and 70 students for the state Junior Academy of Science meeting, to be held March 19-20 in Conway at Univ. of Central Arkansas. Mike Rapp is the director of the state science fair, and Bob and Raynell Skinner are (state) co-directors of the Junior Academy of Science.

With this report, we are requesting the Academy continue its funding for this year's science fair activities ($450 to help cover expenses for students being sent to the Intel International Science & Engineering Fair (ISEF) and state Junior Academy of Science meeting ($250 to help send students to the American Junior Academy of Science meeting).

Last year, the AJAS sent three students and a teacher to the American Junior Academy of Science meeting in Anaheim. Over 50 students and teachers attended the ISEF in May in Fort Worth, Texas. For your information, an Arkansas student, Geoff Schmidt from Little Rock Central High School, won one of the two overall grand prizes at the 1998 ISEF. Geoff was chosen from 1100 students from over 35 countries, and this is the fourth time in the past 20 years that an Arkansas student has won one of the two grand prizes. Geoff received about $60,000 in unrestricted scholarships and prizes, plus several trips, including one to the Nobel Prize ceremony in Stockholm.

Please offer a resolution of thanks for the work of the individuals indicated above, which could be included in the minutes published in the *Journal*, and please bring the request for funding to the members:

Request for funding for 1999 Arkansas Science Fair Association and Junior Academy of Science:

"The Arkansas Science Fair Association requests the Arkansas Academy of Science to continue its support of $50 to each of the nine science fairs in Arkansas that will send students and teachers to the International Science and Engineering Fair, to he held in May, 1999, in Philadelphia. The total contribution being requested is $450. The Arkansas Junior Academy of Science requests the Arkansas Academy of Science to continue its support of $250 for 1999."

Should the membership approve this request, please have the first check made payable to "Arkansas Science Fair Association" and mail it to Dr. Michael W. Rapp, Department of Chemistry, University of Central Arkansas, Conway, AR 72035. Please have the second check made payable to "Arkansas Junior Academy of Science" and mail it to Dr. Bob Skinner, Department of Anatomy, UAMS Slot 510, 4301 W. Markham, Little Rock, AR 72205.

Mike Rapp
15 March 1999

APPENDIX B

RESOLUTIONS

BE IT RESOLVED that we, the membership of the Arkansas of Science, offer our sincere thanks to Arkansas Tech University for hosting the 1999 meeting of the Arkansas Academy of Science. In particular, we thank the Local Arrangements Committee, Mostafa Hemmati, Chair, Charles Gagen, John Graham, Franklin Hardcastle, Christopher Kellner, Robert Maruca, Jeff Robertson, Darla Sparacino, Dwight Stoltzfus, Frances Terry, Ken Trantham and Tsunemi Yamashita, and all the student workers and staff who collectively contributed to a very successful meeting. Appreciation is expressed for the use of the excellent facilities and the hospitality shown to us by all Arkansas Tech University personnel. We truly appreciate Dr. Dawn Bonnell and her excellent presentation of "Scanning Probe Microscopy of Nanometer Scale Phenomena in Oxides".

The Academy recognizes the important role played by the various Section chairpersons and expresses sincere appreciation to Wilfred Braithwaite (Physics and Geology/Microelectronics and Engineering), Scott Kirkconnell (Biomedical Science), Chris Kellner (Terrestrial Ecology), Gerald Walsh (Invertebrate Zoology), Franklin Hardcastle and Michael Panigot (Chemistry), Joe Stoeckel (Aquatic Ecology), Tom Nupp (Vertebrate Zoology), and Gary Tucker (Plant Ecology and Botany).

A special thank's is owed to the individuals devoting considerable time and energy to judging student papers: Chris Kellner, Dwight Stoltzfus, Scott Kirkconnell, Melinda Wilkins, Tom Nupp, Doug James, Joyce Hardin, K.C. Larson, Joe Stoeckel, Richard Grippo. Dan Magoulick, Steve Gann, John Graham, Wilfred Braithwaite, Jeff Robertson, Robert Maruca, Michael Panigot and Ron Nelson.

The Academy appreciates Arkansas Tech University for sponsoring the Friday evening social, the Arkansas Environmental Federation for the funding of the undergraduate presentation awards and Sigma Xi for funding the graduate presentation awards.

We express gratitude to the various directors of the science and youth activities which are supported and/or supervised by the Academy: Jim Edson (Chair of the Science Education Committee), Mike Rapp (Director of the Arkansas State Science Fair Association). Tom Palko Director of the Junior Science and Humanities Symposium), Dan Magoulick (Director of the Intel/Arkansas Science Talent Search) and Robert Skinner (Director of the Junior Academy of Science). (Sec. note: Ms. Raynell Skinner co-directs the Junior Academy of Science).

We wish to thank all those who served as directors at the regional science fairs and junior Academy meetings (see Appendix A).

The continued success of the Academy is due to its strong leadership. We offer sincere thanks to our officers for another successful year: Rose McConnell (President), Mostafa Hemmati (President-Elect), Mark Draganjac (Vice President), John Rickett. (Secretary), Joyce Hardin (Treasurer), James Daly (Past President). Stan Trauth (*Journal* Editor), David Saugey (*Newsletter* Editor) and Henry Robison (Historian). In addition. the Academy expresses appreciation to all who contributed time and effort on various committees of the Academy. The Academy appreciates the time and effort of Walt Godwin for setting up and maintaining the Academy's webpage.

Finally, we congratulate all who presented papers and posters at this meeting. Student participants are especially recognized since their continued efforts and contributions will be directly responsible for the future success of the Academy and its programs for the continuing improvement and advancement of science education and research in Arkansas.

Respectfully submitted,
Mark Draganjac, Chair
Resolutions Committee

APPENDIX C

STUDENT AWARDS

Undergraduate, Environmental Science:

First: Elisa Horsch, "Trophic cascade initiated by cursorial spiders, in an early successional field", Hendrix College.

Second: Eric Anderson, "Effects of ANO effluent on Lake Dardanelle microflora", Arkansas Tech University. (no third place)

Undergraduate, Life Science:

First (tie): Jonathan Whitlock, "Regulation of neural determination and differentiation genes of the bHLH family", UT Southwestern Medical Center

First (tie): Shonda Harris, "Life history and population characteristics of the Carolina mantid, *Stagmomantis carolina*, Saussure (Mantodea: Mantidae)", Hendrix College

Third: Josie Dickens, "Survey of medium and large mammals in an urban park (Murray Park, Little Rock, AR)", University of Arkansas at Little Rock.

Undergraduate, Physical Science:

First: C. Edrington, "Improvements in photoconductance of evaporated indium (III) sulfide films by annealing" Arkansas State University.

Second: R. Tut Campbell, "A supernova patrol program", Arkansas Tech University.

Third: Lex Mitchell, "Interpreting the raman spectra of iron oxide corrosion products", Arkansas Tech University.

Graduate, Life/Environmental Science:

First: C.V. Ashburn, "Identification of the SVV glycoprotein L(gL)", University of Arkansas for Medical Science.

Second (tie): Camille Flinders, "Habitat partitioning in a lotic crayfish community in the Ozark plateaus: the role of environmental variables", University of Central Arkansas.

Second (tie): Jeff Briggler, "Demographics of a ringed salamander (*Ambystoma annulatum*) breeding population during migration", University of Arkansas at Fayetteville.

Graduate, Physical Science:

First: Steve Farmer, "Implementing the hart communications protocol in control valve applications", University of Arkansas at Little Rock.

(no other awards)

CONSTITUTION

ARKANSAS ACADEMY OF SCIENCE

(Revised at the April 1999 Annual Meeting)

ARTICLE I. NAME

The name of this organization shall be "The Arkansas Academy of Science."

ARTICLE II. OBJECTIVES

The objectives of this organization shall be the promotion and diffusion of knowledge of the fields of Science and unification of these interests in the State.

ARTICLE III. MEMBERSHIP

Section 1. Persons and organizations interested in the objectives of this Academy may join by the payment of dues.

Section 2. There shall be two general classes of membership in the Academy: Members (consisting of Regular, Sustaining, Sponsoring, Life, and Undergraduate Student) and Institutional Members.

ARTICLE IV. OFFICERS

The officers of the Academy shall be a President, a President-elect, a Vice President, a Secretary, a Treasurer, a Historian, a *Journal* Editor-in-Chief, a *Journal* Managing Editor, and a *Newsletter* Editor who shall perform the duties usually pertaining to their respective offices. All officers of the Academy except the President, President-elect and Managing Editor of the *Journal* shall be chosen by ballot by the membership-at-large in the annual meeting. The President, President-elect and Vice President shall hold office for one year. The Secretary, Treasurer, Historian, *Journal* Editor-in-Chief, *Journal* Managing Editor, and *Newsletter* Editor shall hold office for five years. The office of President shall be filled by the preceding year's President-elect. The office of President-elect shall be filled by the preceding year's Vice President. The Managing Editor shall be appointed by the Executive Committee. These officers and the immediate past President shall constitute the Executive Committee of the organization.

ARTICLE V. MEETINGS

The annual meeting of the Academy shall be held at such times and places as will be designated by the Executive Committee.

ARTICLE VI. PUBLICATIONS

The publications of the Academy shall include the Journal of the Academy and such papers as are deemed suitable by the Executive Committee.

ARTICLE VII. AMENDMENTS

This constitution may be altered or amended at any annual meeting by a three-fourths majority of the attending members of at least one year's standing. Final action on any alteration or amendment shall be taken at a session subsequent to the one at which it is presented.

BY-LAWS

(Revised at the April 1999 Annual Meeting)

1. These by-laws may be altered or amended in the same manner as the constitution.
2. The following standing committees shall be established: Auditing, Awards, Biota, Constitution, Development, Local Arrangements, Nominations, Publications, Publicity, Resolutions, and Science Education. *Ad hoc* committees may be appointed by the President. The make-up, duties and duration of service for members of each standing committee shall be determined by the Executive Committee with members for vacancies to be appointed by the President.
3. Whenever the number of papers to be presented in any field becomes sufficiently large, an additional section may be created at the discretion of the Local Arrangements Committee.
4. Persons presenting papers with the intent of having them published in the *Journal* shall present an original and two copies of the paper to the Chairman of the appropriate section or either of the *Journal* Editors at the annual meeting. The Editors shall be under no obligation to consider papers submitted after this date.
5. Members who shall allow their dues to remain unpaid for two years, having been annually notified of their arrearage by the Secretary, shall lose their status of membership.
6. Expenditures in excess of $200 which have not been specifically authorized by the Academy at a prior annual business meeting require written approval by the President before payment can be made.
7. The fiscal year and the membership year shall begin January 1 and end December 31. A person joining the Academy during the year is entitled to membership privileges for the remainder of that fiscal year.
8. All officers elected at the annual meeting assume their duties at the end of the last business session of that meeting.
9. In the event an officer, except President, Past President, President-elect, and Vice President, is unable to complete a term, the Executive Committee shall appoint a successor to complete that term, or open a new five-year term with an election at the next general meeting.
10. Dues for all categories of members shall be set by the Executive Committee of the Academy and submitted to the membership for approval. Approval by the membership shall be by majority vote of those present. Any change of dues approved by the membership shall be effective January 1 of the year following that in which the change was approved.
11. The price of the *Journal* in sales to non-members of the Academy shall be determined by the Executive Committee.
12. The Academy shall sponsor such activities as it deems necessary to further its objectives. All activities sponsored by the Academy shall be reviewed annually by the Executive Committee.
13. The Academy shall set aside $1,000 or more as a reserve fund which may be withdrawn and used upon expressed consent of the Executive Committee.
14. Notwithstanding any provision of the Constitution or By-laws which might be susceptible to a contrary construction,
    (a) the Academy shall be organized and operated exclusively for scientific and educational purposes;
    (b) with the exception of established awards, no part of the net earnings of the Academy shall or may under any circumstances inure to the benefit of any private individual;
    (c) no substantial part of the activities of the Academy shall consist of carrying on propaganda, or otherwise attempting to influence legislation;
    (d) the Academy shall not participate in, or intervene in (including the publishing or distributing of statements) any political campaign on behalf of any candidate for public office;
    (e) the Academy shall not be organized or operated for profit;
    (f) the Academy shall not:
        (1) lend any part of its income or corpus, without the receipt of adequate security and a reasonable rate of interest, to;
        (2) pay any compensation in excess of a reasonable allowance for salaries or other compensation for personal services actually rendered to;
        (3) make any part of its services available on a preferential basis to;
        (4) make any purchase of securities or any other property for more than adequate consideration in money or money's worth from;
        (5) sell any securities or other property for less than adequate consideration in money's worth to;
        (6) engage in any other transactions which result in substantial diversion of its income or corpus to any officer of the Executive Committee or substantial contributor to the Academy

    The prohibitions contained in this subsection (f) do not mean to imply that the Academy may make such loans, payments, sales or purchases to anyone else, unless such authority be given or implied by other provisions of the Constitution or By-laws.

Upon dissolution of the Academy, the Executive Committee shall distribute the assets and accrued income to one or more organizations as determined by the Executive Committee, but which organizations shall meet the limitations prescribed in subsections (a) through (f), inclusive, immediately preceding.

14. The Arkansas Academy of Science is the parent organization of the Arkansas Junior Academy of Science. The appointment of the Director of the Arkansas Junior Academy of Science is made by the President of the Arkansas Academy of Science for a period of three years. The Director will operate with the advice of a Board of Regional Directors appointed by the President of the Arkansas Academy of Science. The Regional Directors will serve at the pleasure of the President.

APPENDIX A

AAS CONSTITUTIONAL COMMITTEES

EXECUTIVE COMMITTEE: The Executive Committee shall consist of the President, Past President, President-elect, Vice President, Secretary, Treasurer, Historian, *Journal* Editor-in-Chief, *Journal* Managing Editor, and Newsletter Editor. The Executive Committee shall make recommendations concerning the policies and activities of the Academy in accordance with the Constitution and By-laws of the Academy. The Committee shall meet prior to the first annual business meeting to discuss any motions to be presented at the annual business meeting or any other matters that pertain to the Academy. Other Executive Committee meetings may be held, with the general consensus of its members, depending on the need to discuss Academy issues and interests.

AAS STANDING COMMITTEES ESTABLISHED BY THE BY-LAWS

1. AUDITING COMMITTEE: The Auditing Committee shall consist of a Chair and three additional members. The President shall appoint the Committee prior to or at the first annual business meeting, and it shall function only for that annual meeting. The Committee shall examine the financial records of the Academy, provided by the Treasurer, and report its findings to the Academy at the second business meeting.
2. AWARDS COMMITTEE: The Awards Committee shall be named by the Local Arrangements Committee for the upcoming annual meeting. The Committee shall consist of a Chair and as many additional members as the Chair and/or Local Arrangements Committee deem necessary. The Awards Committee shall evaluate undergraduate and graduate paper presentations during the annual meeting and make recommendations for the various awards established by the Executive Committee.
3. BIOTA COMMITTEE: The Biota Committee shall consist of a Chair and five additional members, and shall be appointed by the President for undefined terms of service. A term of service may be terminated by the President, the committee Chair, or the member. The Biota Committee shall collect, organize, and disseminate taxonomic information on the flora and fauna of Arkansas. Reports shall be made available to the members of the Academy and any other interested party when sufficient information exists.
4. CONSTITUTION COMMITTEE: The Constitution Committee shall be appointed by the President whenever a need for constitutional examination exists and consist of the President-elect, Vice President, and one other member. The President-elect shall serve as the Chair. The Committee shall make recommendations on changes in the Constitution and By-laws whenever such changes are deemed necessary.
5. DEVELOPMENT COMMITTEE: The Development Committee shall consist of a Chair and two additional members and be appointed by the President to undefined terms. The President, the committee Chair, or the member may terminate the appointment. The Development Committee shall promote the growth and development of the Academy by contacting private industries to secure endowment funding to support activities of the Academy.
6. LOCAL ARRANGEMENTS COMMITTEE: The Local Arrangements Committee shall consist of a Chair, appointed by the President, and a minimum of two additional members, selected by the Chair. The Local Arrangements Committee shall make the arrangements necessary to host the annual meeting in accordance with the established guidelines for hosting a meeting adopted by the Executive Committee.
7. NOMINATIONS COMMITTEE: The Nominations Committee shall consist of a Chair and two additional members. Each member shall serve a three-year term with staggered expiration dates. The member serving his/her third year shall be the Chair, and the President shall appoint one new member each year prior to the annual meeting. The Nominations Committee shall recommend candidates to the members of the Academy for election. A minimum of two candidates shall be proposed for Vice President, and a minimum of one candidate shall be proposed for each of the other offices (Secretary, Treasurer, Historian, and Editors) as their

terms expire.

8. PUBLICATIONS COMMITTEE: The Publications Committee shall consist of the Editor-in-Chief and Managing Editor of the *Journal* and two additional members. The Editor-in-Chief shall be elected by the membership of the Academy to a five-year term and serve as the Chair. The Managing Editor shall be appointed by the Executive Committee and serve a five-year term. The two additional members shall be appointed by the President for undefined terms. The Committee Chair, President, or the member may terminate a member's appointment. The Chair may select as many Associate Editors as deemed necessary to accomplish the task of manuscript review. The Editor-in-Chief, Managing Editor and Associate Editors shall review manuscripts submitted for publication in the *Journal* and any other publications deemed desirable by the Executive Committee. Manuscripts may also be submitted to selected specialists for review. The Editors, jointly or singly, shall have the primary jurisdiction, but the Committee may be consulted, for decisions regarding acceptance, rejection or revision of all manuscripts.
9. PUBLICITY COMMITTEE: The Publicity Committee shall consist of a Chair and two additional members. The Committee shall be appointed by the President for undefined terms, and the President, committee Chair or the member may terminate the member's appointment. The Publicity Committee shall promote the public image of the Academy with news releases on activities and accomplishments of the Academy. All news releases shall be reviewed and approved by the Executive Committee prior to release to the news media.
10. RESOLUTIONS COMMITTEE: The Resolutions Committee shall consist of a Chair and two additional members. The Committee shall be appointed by the President prior to or at the first annual business meeting and serve only for that annual meeting. The Resolutions Committee shall present appropriate resolutions expressing the appreciation of the Academy to all individuals and organizations involved in activities sponsored by the Academy during the year.
11. SCIENCE EDUCATION COMMITTEE: The Science Education Committee shall consist of a Chair and additional members as deemed necessary by the Chair of the committee. The President shall appoint the Chair and, in consultation with the Chair, additional members for undefined terms. The President, the committee Chair or the member may terminate the member's appointment. The Science Education Committee shall provide information to the Academy on current programs and activities in science education in the state, promote programs, including the Junior Academy, Science/Engineering Fairs, and Science Talent Search(es) and cooperate with state agencies and other educational organizations in the study and development of innovative ideas or activities to improve science education at all levels in the state.

APPENDIX B

DUTIES OF ELECTED OFFICERS

A. President –
   1. Calls to order and presides over all Executive and General Business meetings
   2. Handles official Academy correspondence as pertains to the office of President, and/or delegates correspondence pertaining to other offices to those officers as appropriate
   3. Asks any other officers and directors of subunits, as appropriate, for advice and assistance

B. President-elect –
   1. Serves in the capacity of President should the President be unable to perform his/her duties
   2. Assists and advises the President when called on to do so

C. Vice President –
   Assists and advises the President and/or President-elect when called on to do so

D. Past President –
   By virtue of his/her service and experience, the Past President assists and advises the President when called on to do so

E. Treasurer –
   1. Keeps all financial records of the Academy
   2. Receives payments of dues, *Journal* subscriptions, and all other sources of income
   3. Manages investments of the Academy with the approval of the Executive Committee
   4. Disburses funds for payment of Academy operating expenses and gifts awarded

F. Secretary –
   1. Keeps all clerical records of the Academy: memberships by approved categories, *Journal* subscriptions, exchange and abstracting service lists, and other records as deemed necessary and appropriate by the Executive Committee
   2. Sends out copies of the *Journal* to members (as needed) and as requested by subscription, exchange, and abstracting service lists
   3. Corresponds with members and libraries as appropriate regarding payment of dues and payment

Arkansas Academy of Science

of invoices for the *Journal*

4. Furnishes mailing labels to other Executive Committee members and Local Arrangements Committee Chair as appropriate
5. Furnishes membership information, as appropriate, to anyone requesting
6. Corresponds with AAAS (American Association for the Advancement of Science) to receive or provide information as needed and appropriate

G. *Journal* Editors –

1. Receive manuscripts submitted for publication and cooperate with Associate Editors in the review, revision and acceptance process
2. The Managing Editor coordinates the manuscript review process with the Associate Editors and selected reviewers
3. Both Editors prepare the next issue of the *Journal* by assembling the final copies of manuscripts accepted for publication
4. The Editor-in-Chief primarily works with the printer in the technical preparation of the *Journal*
5. Arrange for the distribution of copies of the *Journal* at the next annual meeting

H. *Newsletter* Editor –

1. Receives and compiles news items regarding Academy operations, Executive Committee decisions, and general Academy activities and involvements
2. Prepares two (or as many or few as the Executive Committee deems appropriate) issues of the *Newsletter* per year, the contents of which are subject to approval and revision by the Executive Committee –
   a. the "Fall" issue shall contain general news about the Academy activities and general information about the next annual meeting
   b. The "Spring" issue shall contain more specific information about the next annual meeting, an abstract form, meeting reservation/registration form(s), and specific news about achievements of Academy members
3. Distributes copies to all Academy members and prospective members, as directed by the Executive Committee

I. Historian –

1. Keeps historical records of Academy meetings and other activities
2. Reports on past activities at the annual meeting, as the presiding officer directs, and as the Executive Committee requests

MEMBERS 1999

FIRST MI	LAST NAME	INSTITUTION
Al	Adams	University of Arkansas at Little Rock
Max L.	Baker	University of Arkansas for Medical Sciences
Gene Lee	Bangs	University of Arkansas at Little Rock
Gwen	Barber	Arkansas Tech University
Victor	Blunt	University of Arkansas at Pine Bluff
Frank	Bowers	University of Wisconsin-Stevens Point
Jimmy D.	Bragg	Henderson State University
Edwin S.	Braithwaite	Cedarville College
William D.	Brown	University of Arkansas at Fayetteville
Thomas	Buchanan	Westark Community College
John	Bush	University of Arkansas at Little Rock
Michael E.	Cartwright	Arkansas Game & Fish Commission
Stanley L.	Chapman	University of Arkansas at Fayetteville
Vincent A.	Cobb	Ouachita Baptist University
Lynita	Cooksey	Arkansas State University
Marc	Corrigan	University of Arkansas at Monticello
Betty	Crump	U.S.D.A., Forest Service
Donald	Culwell	University of Central Arkansas
James T.	Daniels	Southern Arkansas University
Perry A.	Daniels	Arkansas State University
Jerry A.	Darsey	University of Arkansas at Little Rock
Chris	Davidson	
Patrick	Desrochers	University of Central Arkansas
Peggy Rae	Dorris	Henderson State University
Rudolph J.	Eichenberger	Southern Arkansas University
David	Eller	University of Arkansas for Medical Sciences
Robert	Engelken	Arkansas State University
Don	England	Harding University
James	Engman	Henderson State University
E. P. (Perk)	Floyd	U.S. Public Health Service
Thomas L.	Foti	Natural Heritage Commission
Charlie	Gagen	Arkansas Tech University
Wayne	Gildseth	Southern Arkansas University
Crissy Patterson	Goss	Hampton High School
John P.	Graham	Arkansas Tech University
Wayne L.	Gray	University of Arkansas for Medical Sciences
Reid	Green	U.S. Geological Survey
Brian	Greuel	John Brown University
Richard S.	Grippo	Arkansas State University
Anne A.	Grippo	Arkansas State University
Paul V.	Hamilton	University of Central Arkansas
Earl L.	Hanebrink	Arkansas State University-retired
Franklin D.	Hardcastle	Arkansas Tech University
John L.	Harris	Arkansas Highway & Transportation Dept.
Michael J.	Harvey	Tennessee Tech University
Roger M.	Hawk	University of Arkansas at Little Rock
Marsha	Hendricks	Harding University
Kristine	Herbert	Westpark Community College
Larry R.	Hilburn	Black River Technical College
Jim	Huey	University of Arkansas at Monticello
Philip E.	Hyatt	USDA, Forest Service
M. D.	Jalaluddin	University of Arkansas at Pine Bluff
David	Jamieson	Arkansas State University-Beebe/Newport
James E.	Johnson	University of Arkansas at Fayetteville
Michael I.	Johnson	Nettleton High School
Hugh	Johnson	Southern Arkansas University
Thurman O.	Jordan	Arkansas Audubon Society
Jay	Justice	Arkansas Dept. Pollution Control & Ecology
Mark	Karnes	The Ross Foundation
Philip L.	Kehler	University of Arkansas at Little Rock
Scott W.	Kirkconnell	Arkansas Tech University
Maurice G.	Kleve	University of Arkansas at Little Rock
Richard	Kluender	University of Arkansas at Monticello
Roger E., II	Koeppe	University of Arkansas at Fayetteville
Randall A.	Kopper	Hendrix College
Timothy	Kral	University of Arkansas at Fayetteville
Norman	Lavers	Arkansas State University
Stephen A.	Leslie	University of Arkansas at Little Rock
Hal O.	Liechty	University of Arkansas at Monticello
Brian	Lockhart	University of Arkansas at Monticello
Dan	Magoulick	University of Central Arkansas
Daniel L.	Marsh	Henderson State University
John E.	Marshall	Biotechnical Services Inc.
Robert	Maruca	Arkansas Tech University
H. Michael	Mathews	Henderson State University
Russell B.	McAllister	Arkansas Dept. Pollution Control & Ecology
V. Rick	McDaniel	Arkansas State University
Richard	Meyer	University of Arkansas at Fayetteville
Muhammad A.	Miah	University of Arkansas at Pine Bluff
Cristin	Milam	Arkansas State University
Lawrence A.	Mink	Arkansas State University
Paul	Mixon	Arkansas State University
Warren	Montague	U.S. Forest Service
Cindy	Moore	Westark Community College
Matthew	Moran	Hendrix College
Leland F.	Morgans	University of Arkansas at Little Rock
Tom	Nelson	Eastern Illinois University
Ronald E.	Nelson	Arkansas Tech University
Russell	Nordeen	University of Arkansas at Monticello
Thomas	Nupp	Arkansas Tech University
Joseph O.	Owasoyo	University of Arkansas at Pine Bluff
Don R.	Owens	University of Arkansas at Little Rock
Michael J.	Panigot	Arkansas State University
Mark A.	Paulissen	McNeese State University
Michael V.	Plummer	Harding University
William R., II	Posey	Department Pollution Control & Ecology
Donna G.	Quimby	University of Arkansas at Little Rock
James A.	Rasmussen	Southern Arkansas University
Darryl K.	Reach	University of Arkansas at Little Rock
Scott W.	Reeve	Arkansas State University
Dennis J.	Richardson	Quinnipiac College
Jeff W.	Robertson	Arkansas Tech University
Joe	Rosen	University of Central Arkansas
Karen	Rowe	Arkansas Game & Fish Commission
Steven W.	Runge	University of Central Arkansas
Charles J.	Scifres	University of Arkansas at Fayetteville
Frank L.	Setliff	University of Arkansas at Little Rock
Larry	Seward	John Brown University
Elwood B.	Shade	University of Arkansas at Monticello
Ali U.	Shaikh	University of Arkansas at Little Rock
William M.	Shepherd	Arkansas Natural Heritage Commission
Robert A.	Sims	University of Arkansas at Little Rock
Robert	Skinner	University of Arkansas for Medical Sciences
Kimberly G.	Smith	University of Arkansas at Fayetteville
Richard D.	Smith	Pulaski Tech College
Roy J.	Smith, Jr.	U.S.D.A./University of Arkansas
Thomas	Soerens	University of Arkansas at Fayetteville
Frederick W.	Speigel	University of Arkansas at Fayetteville
Richard W.	Standage	U.S. Forest Service
Joseph N.	Stoeckel	Arkansas Tech University
Eric	Sundell	University of Arkansas at Monticello
Phil	Tappe	University of Arkansas at Monticello
William R.	Teague	University of Arkansas at Fayetteville
Wayne E.	Throgmartin	Southern Illinois University
D. S.	Tomer	University of Central Arkansas
Staria	Vanderpool	Arkansas State University
Brian	Wagner	Arkansas Game & Fish Commission
Richard B.	Walker	University of Arkansas at Pine Bluff
Stephen A.	Walker	
Gerald	Walsh	
Robert L.	Watson	University of Arkansas at Little Rock
James O.	Wear	V.A. Medical Center
Jerry	Webb	University of Arkansas at Monticello
Rayona	Webster	Cossatot Technical College
Robert	Weih	University of Arkansas at Monticello
Delores	Wennerstrom	Pulaski Academy
David	Wennerstrom	University of Arkansas for Medical Sciences
Todd	Wiebers	Henderson State University
J. D.	Wilhide	Arkansas State University
Edmond W.	Wilson, Jr.	Harding University
Donald C.	Wold	University of Arkansas at Little Rock
Heather L.	Woolverton	University of Central Arkansas
Andrew	Wright	University of Arkansas at Little Rock
Tsunemi	Yamashita	Arkansas Tech University
J. Lyndal	York	University of Arkansas for Medical Sciences

SUSTAINING MEMBERS

Malcolm K.	Cleaveland	University of Arkansas at Fayetteville
Edward E.	Dale, Jr.	University of Arkansas at Fayetteville
David L.	Davies	University of Arkansas for Medical Sciences
Edmond E.	Griffin	University of Central Arkansas
Paul M.	Nave	Arkansas State University
Alex R.	Nisbet	Ouachita Baptist University

FIRST MI	LAST NAME	INSTITUTION
Clifton	Orr	University of Arkansas/Pine Bluff
Joseph R.	Penor	University of Arkansas at Little Rock
Paul C.	Sharrah	University of Arkansas at Fayetteville
Samuel	Siegel	University of Arkansas at Fayetteville
Felix K.	Tendeku	University of Arkansas at Pine Bluff
Rudy	Timmerman	Rich Mountain Community College
William M.	Willingham	University of Arkansas at Pine Bluff
Steve	Zimmer	Arkansas Tech University

SPONSORING MEMBERS

Thomas J.	Lynch	University of Arkansas at Little Rock
Rose	McConnell	University of Arkansas at Monticello
Marsha	Rowe	Stamps High School
Michael E.	Soulsby	University of Arkansas for Medical Sciences

LIFE MEMBERS

Robbin C.	Anderson	University of Arkansas at Fayetteville
Edmond J.	Bacon	University of Arkansas at Monticello
Vernon	Bates	Ouachita Mtns. Biological Station
Wilfred J.	Braithwaite	University of Arkansas at Little Rock
David	Chittenden	Arkansas State University
Calvin	Cotton	Geographics Silk Screening Co.
Fred	Dalske	University of Central Arkansas
James J.	Daly	University of Arkansas for Medical Sciences
Leo Carson	Davis	Southern Arkansas University
Robert H.	Dilday	University of Arkansas at Fayetteville
Mark	Draganjac	Arkansas State University
Jim	Edson	University of Arkansas at Monticello
Daniel R.	England	Southern Arkansas University
William L.	Evans	University of Arkansas at Fayetteville
Kim	Fifer	University of Arkansas for Medical Sciences
James H.	Fribourgh	University of Arkansas at Little Rock
Arthur	Fry	University of Arkansas at Fayetteville
Collis R.	Geren	University of Arkansas at Fayetteville
John	Giese	Ark. Dept. of Pollution Control & Ecol.
Walter E.	Godwin	University of Arkansas at Monticello
Joe M.	Guenter	University of Arkansas at Monticello
Joyce M.	Hardin	Hendrix College
George L.	Harp	Arkansas State University
Phoebe A.	Harp	Arkansas State University
Gary A.	Heidt	University of Arkansas at Little Rock
Ronnie	Helms	University of Arkansas at Fayetteville
Mostafra	Hemmati	Arkansas Tech University
Carol A.	Jacobs	
Douglas	James	University of Arkansas at Fayetteville
Arthur A.	Johnson	Hendrix College
Cindy	Kane	University of Arkansas for Medical Sciences
Donald R.	Mattison	University of Pittsburgh
Roland E.	McDaniel	FTN Associates, Ltd.
Herbert	Monoson	Ark. Science &Technology Authority
Clementine	Moore	
Gaylord M.	Northrop	University of Arkansas at Little Rock
Tom	Palko	Arkansas Tech University
James H.	Peck	University of Arkansas at Little Rock
Michael W.	Rapp	University of Central Arkansas
John D.	Rickett	University of Arkansas at Little Rock
Henry W.	Robison	Southern Arkansas University
David A.	Saugey	U.S. Forest Service
Betty M.	Speairs	Ouachita Mtns. Biological Station
Richard K.	Speairs	Ouachita Mtns. Biological Station
George E.	Templeton	University of Arkansas at Fayetteville
Stanley E.	Trauth	Arkansas State University
Gary	Tucker	FTN Associates
Renn	Tumlison	Henderson State University
James L.	Wickliff	University of Arkansas at Fayetteville
Robert W.	Wiley	University of Arkansas at Monticello

STUDENT MEMBERS

FIRST MI	LAST NAME	INSTITUTION
Jennifer	Abbott	Henderson State University
James R.	Anderson	Henderson State University
Brady	Baker	Arkansas State University
Jeremy W.	Bowers	Arkansas State University
Mohanjeet Singh	Brar	University of Arkansas at Fayetteville
Jeff	Briggler	University of Arkansas at Fayetteville
Daniel	Bullock	Arkansas Tech University
Melissa	Camp	Henderson State University
Shawn	Cochran	Arkansas State University
Mathues S.	Doss	Arkansas Tech University
Andrew	Edwards	University of Arkansas at Little Rock
Steve P.	Fillip	Henderson State University
Eric L.	George	Arkansas Tech University
Timothy A.	Golden	Henderson State University
Cynthia	Goshen	Henderson State University
Chad	Hargrave	University of Arkansas
David C.	Hearn	University of Arkansas at Fayetteville
Richard B.	Homard	University of Arkansas at Little Rock
Laura	Hudson	Westark Community College
Kristy	Jones	John Brown University
Sailesh	Kumar	University of Arkansas at Little Rock
Jared	Kyzer	Henderson State University
Mary Lynn	Lambert	Eastern Illinois University
Diana	Lindquist	University of Arkansas at Little Rock
Lisa	Maddox	University of Arkansas for Medical Sciences
David L.	McDaniel	Henderson State University
Donna	Moore	University of Arkansas at Fayetteville
Dan C.	Phan	University of Arkansas for Medical Sciences
Christine	Pope	Henderson State University
Robin	Roggio	University of Arkansas at Fayetteville
Lori	Sale	Arkansas Tech University
Demetra	Salisbury	University of Arkansas at Fayetteville
Garrett	Sanford	University of Arkansas at Fayetteville
Stephen R.	Skinner	University of Arkansas at Fayetteville
Frances	Terry	Arkansas Tech University
Charles	Verghese	Arkansas Tech University
Jeremy	Warford	Hendrix College
Hilary	Warley	Arkansas State University
Theo	Witsell	University of Arkansas at Little Rock
Timothy W.	Wofford	University of Arkansas at Little Rock
Hilary J.	Worley	Arkansas State University
Jedediah J.	Young	University of Arkansas at Fayetteville

PROGRAM

Arkansas Academy of Science
83rd Annual Meeting
April 2-3, 1999
Arkansas Tech University

SCHEDULE OF EVENTS

Friday, April 2, 1999

9:00 am. - 11:00 p.m.	Executive Committee Meeting	Doc Brian Student Services Bldg. 104
11:00 a.m. - 4:00 p.m.	Registration	McEver Entrance
11:00 a.m. - 12:00 p.m.	First Business Meeting	Doc Brian Student Services Bldg. 104
1:00 p.m. - 5:00 p.m.	Poster Sessions	McEver Hallway
1:00 p.m. - 4:00 p.m.	Oral Presentations	
	Physics & Geology	McEver 202
	Biomedical Science	McEver 162
	Terrestrial Ecology	McEver 206
	Invertebrate Zoology	McEver 210
	Chemistry I	McEver 204
2:00 p.m. - 2:30 p.m.	Refreshments	McEver Entrance
4:00 p.m. - 5:00 p.m.	Library & Technology Center Tour	Meet at Registration Desk
4:00p.m. - 5:00p.m.	Board of Governors Meeting of the Ouachita Biological Station	McEver 204
5:00 p.m. - 6:15 p.m.	Social Mixer*	Holiday Inn, Nebo Room
6:30 p.m. - 87:30 p.m.	Dinner	Chambers Cafeteria East Entrance
	Welcome by Dr. Charles Robert Brown, President	
7:30 p.m. - 9:00 p.m.	Invited Guest Speaker	Chambers Cafeteria
	Dr. Dawn Bonnell, University of Pennsylvania	
9:00 p.m. - 9:30 p.m.	Good Evening!*	

Saturday, 3 April 1999

7:30 a.m. - 10:00 am.	Registration	McEver Entrance
7:30 a.m. - 10:00 am.	Refreshments	McEver Entrance
8:00 a.m. - 11:00 am.	Oral Presentations	
	Microelectronics & Eng.	McEver 202
	Aquatic Ecology	McEver 162
	Vertebrate Zoology	McEver 206
	Plant Ecology & Botany	McEver 210
	Chemistry II	McEver 204
11:00 a.m. - 11:30 a.m.	Judges Meeting	McEver 202
12:00 p.m. - 1:00 p.m.	Second Business Meeting & Award Presentations	McEver 162

*A shuttle bus will operate between McEver Hall and the Holiday Inn during these indicated times.

SECTION PROGRAMS

* Undergraduate **Graduate

ORAL PRESENTATIONS

Friday, April 2, 1999
Physics and Geology
Location: McEver Hall, Room 202

Chairperson: Dr. Wilfred J. Braithwaite, University of Arkansas at Little Rock

Time	Topic
1:00	Karen Abruckle and Leo Carson Davis. Department of Biological Sciences, Southern Arkansas University, Magnolia Arkansas, 71753, and Department of Physical Sciences, Southern Arkansas University, Magnolia, Arkansas, 71753. **PALEOZOIC FOSSILS FROM THE GULF COASTAL PLAIN OF ARKANSAS**
1:15	Ben Waggoner, Department of Biology, University of Central Arkansas, Conway, AR 72035-0001. **MAZON CREEK-TYPE FOSSILS FROM THE MCALESTER FORMATION (PENNSYLVANIAN: DESMOINESIAN), JOHNSON COUNTY, ARKANSAS**

1:30 Felix Tendeku, Department of Mathematical Sciences & Technology, Box 4987, University of Arkansas at Pine Bluff, Pine Bluff, AR 71611. **STATISTICAL ANALYSIS OF CLIMATIC VARIABLES IN THE ARKANSAS-RED RIVER BASIN**

1:45 William Tyler, S. Khan, V. Blunt, V. Litman, W.M. Willingham & A.H. Chowdhury, Research Center, University of Arkansas, Pine Bluff, AR 71611. **CALIBRATION OF ZAHN CUP**

2:00 Christine A. Byrd, W. J. Braithwaite, Physics and Astronomy, University of Arkansas, Little Rock, AR 72204, E. S. Braithwaite, Science and Mathematics, Cedarville College, Cedarville, OH 45314, and J. G. Cramer, Department of Physics, University of Washington, Seattle, WA 98195. **IMPACT ON HBT OF TOTAL SEPARATION OF KAONS AND PIONS IN STAR'S TPC**

2:15 Frances Terry and M. Hemmati, Physical Science Department, Arkansas Tech University, Russellville, AR 72801. **ELECTRON SHOCK WAVES**

2:30 Break

2:45 Christine A. Byrd, W. J. Braithwaite, Physics and Astronomy, University of Arkansas, Little Rock, AR 72204, and E. S. Braithwaite, Science and Mathematics, Cedarville College, Cedarville, OH 45314. **ONLINE ACCEPTANCE AND EFFICIENCY MONITORING OF STAR'S MAIN TPC**

3:00 Mostafa Hemmati and Heath Spillers, Physical Science Department, Arkansas Tech University, Russellville, AR 72801. **EFFECTS OF SCIENCE CRUSADE IN ARKANSAS**

3:15 Eric George, Mostafa Hemmati, and Frances Terry, Physical Science Department, Arkansas Tech University, Russellville, AR 72801. **SPEED RANGE FOR BREAKDOWN WAVES**

3:30 Robert Fithen, Ronald E. Nelson, Arkansas Tech University, Russellville, AR, 72801. **WAVELETS FROM FINITE IMPULSE RESPONSE FILTERS**

3:45 R. Tut Campbell and Jeff Robertson, Physical Science Department, Arkansas Tech University, Russellville, AR, 72801. **A SUPERNOVA PATROL PROGRAM**

Biomedical Science
Location: McEver Hall, Room 162

Chairperson: Dr. Scott Kirkconnell, Arkansas Tech University

Time	Topic
1:00	Garrett B. Sanford[1], Thomas J. Lynch[1], James W. Hardin[2], and John Theus[3]. [1]Dept. of Biology, University of Arkansas at Little Rock; Little Rock, AR 72204, [2]John Wayne Cancer Center, Santa Monica, CA 90404, [3]University of Arkansas for Medical Sciences, Little Rock, AR 72204. **STUDIES ON NFκB IN CULTURED MULTIPLE MYELOMA CELLS**
1:15	C.V. Ashburn and W.L. Gray Dept. of Microbiology and Immunology. University of Arkansas for Medical Sciences, Little Rock, AR 72205. **IDENTIFICATION OF THE SVV GLYCOPROTEIN L(gL)**
1:30	Jonathan Whitlock, Center for Basic Neuroscience, UT Southwestern Medical Center, 5323 Harry Hines Blvd, Dallas, TX 75235-0111, Hendrix College, undergraduate affiliation Jane Johnson, Ph.D. - mentor (UT Southwestern) Joyce Hardin, Ph.D. - advisor (Hendrix College). **REGULATION OF NEURAL DETERMINATION AND DIFFERENTIATION GENES OF THE bHLH FAMILY**
1:45	Leah Annulis, Heng Wang, Jianhu Du, and Dennis D. Black Department of Pediatrics, Arkansas Children's Hospital, Little Rock, AR 72202. **APOLIPOPROTEIN GENE EXPRESSION IN NEONATAL PIGLETS**
2:00	R. L. Jordan and W. L. Gray, Dept. of Microbiology and Immunology, University of Arkansas for Medical Sciences, Little Rock, AR 72205. **ANALYSIS OF CHANNEL CATFISH HERPESVIRUS TRANSCRIPTION**
2:15	Break
2:30	Michael White and Wayne L. Gray, Department of Microbiology and Immunology, University of Arkansas for Medical Sciences, Little Rock, AR 72205. **DNA SEQUENCE ANALYSIS OF THE SIMIAN VARICELLA VIRUS GENOME**
2:45	Donna Quimby, University of Arkansas at Little Rock, L.R., AR 72204; Kathy Hall, University of Arkansas, Fayetteville, AR 72703. **THE EFFECTS OF VARIED INTENSITY RESISTANCE TRAINING IN COMBINATION WITH WEIGHT-BEARING EXERCISE ON BONE ADAPTATIONS IN OVARIECTOMIZED AND SHAM OPERATED SPRAGUE DAWLEY RATS**
3:00	Paul D. Mixon, Ph.D., P.E., Department of Engineering, Arkansas State University. **HUMAN BIOLOGICAL EFFECTS RESULTING FROM EXPOSURE TO 60 Hz POWER LINES AND OTHER ELECTRICAL FACILITIES**
3:15	Tosha Belford, John Taylor, and S. Kirkconnell Biology Department, Arkansas Tech University, Russellville, AR 72801. **MICORBES IN DAY CARE CENTERS**

TERRESTRIAL ECOLOGY
Location: McEver Hall, Room 206

Chairperson: Dr. Chris Kellner, Arkansas Tech University

Time	Topic
1:00	Stanley E. Trauth, Walter E. Meshaka, Jr., and Robert L. Cox, Department of Biological Sciences, Arkansas State University, P.O. Box 599, State University, Arkansas; Museum, Everglades National Park, 40001 SR 9336, Homestead, Florida 33034-6733; RLC (deceased). **POPULATION STRUCTURE AND REPRODUCTION IN THE EASTERN NARROWMOUTH TOAD, *GASTROPHRYNE CAROLINENSIS* (ANURA: MICROHYLIDAE), IN NORTHEASTERN ARKANSAS**
1:15	Mary Katherine Razer and Matthew D. Moran, Department of Biology, Hendrix College, 1600 Washington Avenue, Conway, AR 72032. **BEHAVIORAL AND NUMERICAL RESPONSE TO RESOURCE MANIPULATION IN ARTHROPOD COMMUNITIES**
1:30	Elisa A. Horsch and Matthew D. Moran, Hendrix College, Conway, AR 72032. **TROPHIC CASCADE INITIATED BY CURSORIAL SPIDERS IN AN EARLY SUCCESSIONAL FIELD**

1:45 Jeffrey T. Briggler, James E. Johnson, and Dwayne D. Rambo, Department of Biological Sciences, University of Arkansas, Fayetteville, AR 72701. **DEMOGRAPHICS OF A RINGED SALAMANDER (*AMBYSTOMA ANNULATUM*) BREEDING POPULATION DURING MIGRATION**

2:00 Thomas Nelson, Department of Biological Sciences, Eastern Illinois University, Charleston, IL 61920. **EVALUATION OF THREE TYPES OF FOREST OPENINGS FOR WILD TURKEYS**

2:15 Break

2:30 Shawn M. Cochran, J. D. Wilhide and V. R. McDaniel, Department of Biological Sciences, Arkansas State University, State University, 72467. **ROOSTING AND HABITAT USE OF RAFINESQUE'S BIG EARED BAT IN A BOTTOMLAND HARDWOOD FOREST ECOSYSTEM**

2:45 Paul T. Hoover, Janet Lanza, Brian Wells, Samuel Nelson, Biology Department, University of Arkansas at Little Rock, 2801 South University, Little Rock, Arkansas 72204. **THE EFFECTS OF VARYING AMINO ACID CONCENTRATIONS ON REPRODUCTIVE SUCCESS BY CABBAGE WHITE BUTTERFLIES**

3:00 Janet Lanza, Biology Department, University of Arkansas at Little Rock, 2801 South University, Little Rock, Arkansas 72204. **OPEN-ENDED INQUIRY-BASED LABORATORIES IN FIRST-YEAR BIOLOGY**

3:15 Jimmy D. Winter and Janet Lanza. Graduate Institute of Technology, University of Arkansas at Little Rock, 2801 South University, Little Rock, Arkansas 72204. **EXPERIENCING RESEARCH AND LEARNING INQUIRY-BASED TEACHING METHODS THROUGH THE ARKANSAS STRIVE PROGRAM**

INVERTEBRATE ZOOLOGY
Location: McEver Hall, Room 210

Chairperson: Dr. Gerald E. Walsh, 9 Yocum Road, Rogers, AR 72756

Time	Topic
1:00	Heidi Dukat and Dan Magoulick, Department of Biology, University of Central Arkansas, Conway, Arkansas 72035. **EFFECTS OF PREDATION ON HABITAT SELECTION BY TWO SPECIES OF STREAM-DWELLING CRAYFISH, *Orconectes marchandi* AND *Cambarus hubbsi***
1:15	*Michael Buck, Dr. Robert Engelken, C. Workman, A Thapa, and C. Edrington, Department of Engineering, Arkansas State University, State University (Jonesboro), AR 72467. **INDIUM-TELLURIUM COMPOUNDS ELECTROPLATED FROM MOLTEN SALT BATHS.**
1:30	Camille Flinders Sand Dan Magoulick, Department of Biology, University of Central Arkansas, Conway, Arkansas 72035. **HABITAT PARTITIONING IN A LOTIC CRAYFISH COMMUNITY IN THE OZARK PLATEAUS: THE ROLE OF ENVIRONMENTAL VARIABLES**
1:45	Gianetta L. Adams, James E. Johnson, and John V. Brahana, U.S. Geological Survey, Department of Biological Sciences and Department of Geology, University of Arkansas, Fayetteville, AR 72701. **ARKANSAS RANGE EXTENSION FOR THE BRISTLY CAVE CRAYFISH, *CAMBARUS SETOSUS* FAXON (DECAPODA, CAMBARIDAE)**
2:00	George L. Harp, Dept. of Biological Sciences, Arkansas State University, State University, AR 72467. **ADDITIONS TO THE ODONATE (DRAGONFLY) LISTS FOR SAN LUIS POTOSI AND TAMAULIPAS STATES, MEXICO**
2:15	Break
2:30	J. M. Turbeville and Jeffrey T. Briggler, Department of Biological Sciences, University of Arkansas, Fayetteville, AR 72701. **THE FIRST RECORD OF THE LEECH *MACROBDELLA DIPLOTERTIA* (MEYER, 1975) (ANNELIDA: CLITELLATA) IN ARKANSAS AND PRELIMINARY OBSERVATIONS ON ITS NATURAL HISTORY**
2:45	Brian F. Coles and Gerald E. Walsh, 4202 Scottie Smith Drive, Jefferson, AR 72079 and 9 Yocum Road, Rogers, AR 72756. **A REVISED LIST OF ARKANSAS LAND MOLLUSCA WITH NOTES ON THE GEOGRAPHIC DISTRIBUTION OF SPECIES**

CHEMISTRY I
Location: McEver Hall, Room 204

Chairperson: Dr. Franklin D. Hardcastle, Arkansas Tech University

Time	Topic
1:00	Victor M. Blunt, A. H. Chowdhury, S. Khan, V. Litman and W. M. Willingham, Department of Chemistry & Physics, University of Arkansas at Pine Bluff, Pine Bluff, AR 71601. **CHEMICAL ANALYSIS OF SMOKE BOMB MIXTURES**
1:15	Dedric Hayes and Victor M. Blunt, Department of Chemistry & Physics, University of Arkansas at Pine Bluff, Pine Bluff, AR 71601. **QUANTITATIVE AND QUALITATIVE ANALYSIS OF LACTOSE AND POTASSIUM CHLORATE IN SMOKE BOMB MIXTURES**
1:30	Franklin D. Hardcastle, Department of Physical Science, McEver Hall, Arkansas Tech University, Russellville, Arkansas 72801. **MOLECULAR STRUCTURES OF TITANATES BY RAMAN SPECTROSCOPY**
1:45	Muhammad H. Zaman, John P. Graham and Franklin D. Hardcastle, Department of Physical Science, McEver Hall, Arkansas Tech University, Russellville, Arkansas 72801. **RAMAN SPECTROSCOPY OF PHOSPHATES**
2:00	Lex Mitchell and Franklin D. Hardcastle, Department of Physical Science, McEver Hall, Arkansas Tech University, Russellville, Arkansas 72801. **INTERPRETING THE RAMAN SPECTRA OF IRON OXIDE CORROSION PRODUCTS**
2:15	Break
2:45	John P. Graham, Department of Physical Science, McEver Hall, Arkansas Tech University, Russellville, Arkansas 72801. **STRUCTURE AND BONDING OF A NOVEL CHELATING CARBENE COMPLEX**
3:00	D. Gipson, Dr. R. Engelken, M. Buck, C. Edrington, and A. Thapa, Department of Engineering, Arkansas State University, P.O. Box 1740, State University, Arkansas 72467. **MINIMALLY HAZARDOUS AND ENVIRONMENTALLY IMPACTIVE METALLIC ALLOY AND SEMI-**

CONDUCTING OXIDE FILMS OF Mo, W, Fe, AND/OR Ni ELECTROPLATED FROM AQUEOUS ELECTROLYGES

3:15 A. Thapa, Dr. R. Engelken, C. Edrington, M. Buck and D. Gipson, Department of Engineering, Arkansas State University, P.O. Box 1740, State University, Arkansas 72467. **CHEMICAL PRECIPITATION DEPOSITION OF INDIUM SULFIDE AND OTHER METAL SULFIDE FILMS FROM A NEW LOW pH AQUEOUS, THIOUREA/THIOACETAMIDE-FREE BATH WITH REDUCED HAZARDS AND ENVIRONMENTAL IMPACT**

3:30 C. Edrington, Dr. R. Engelken, M. Buck, A. Thapa and D. Gipson, Department of Engineering, Arkansas State University, P.O. Box 1740, State University, Arkansas 72467. **IMPROVEMENTS IN PHOTOCONDUCTANCE OF EVAPORATED INDIUM (III) SULFIDE FILMS BY ANNEALING**

ORAL PRESENTATIONS

Saturday, April 3, 1999

MICROELECTRONICS AND ENGINEERING

Location: McEver Hall, Room 202

Chairperson: Dr. Wilfred J. Braithwaite, University of Arkansas at Little Rock

Time	Topic
8:15	Aslam H. Chowdhury, S. Khan, V. Blunt, V. Litman and W. M. Willingham, Research Center, University of Arkansas, Pine Bluff, AR 71611. **SETTLING RATE BY OPTICAL METHOD**
8:30	Clayton Workman,* Dr. Phillipe Ballet, Dr. Jay Smathers, Dr. Greg Salamo and Dr. Hameed Naseem. **A COMPARISON OF THE ATOMIC FORCE MICROSCOPY (AFM) AND SCANNING TUNNELING MICROSCOPY (STM) OF SELF-ASSEMBLED InAs QUANTUM DOTS ON GaAs AND AIAs**
8:45	D. W. Bullock, H. Yang, V. P. LaBella, Z. Ding and P. M. Thibado, Physics Department, University of Arkansas, Fayetteville, AR 72701. **ATOMIC CONTROL OF SEMI-CONDUCTOR STRUCTURES**
9:00	Jedediah J. Young, Nick Rosser, and Ajay P. Malshe, MRL, Department of Mechanical Engineering, University of Arkansas, Fayetteville, AR 72701. **MICROELECTRONICALLY INTEGRATED MULTIFUNCTIONAL INFLATABLE MICROCOMMUNICATIONS (MIMICs): THE NEXT GENERATION OF INFLATABLES FOR SPACE APPLICATIONS**
9:15	Break
9:45	Kaneez E. Banu, Biao Huang, and Simon S. Ang, University of Arkansas, High-Density Electronics Center, 600 W. 20th, Fayetteville, AR 72701. **MICROMACHINED HEAT SINK FOR INTEGRATED CIRCUITS COOLING**
10:00	Chris Hearn, Biao Huang, and Simon S. Ang, University of Arkansas, High-Density Electronics Center, 600 W. 20th, Fayetteville, AR 72701. **MICROELECTROMECHANICAL SYSTEMS FABRICATION TECHNIQUES**
10:15	Dr. Andrew B. Wright, University of Arkansas at Little Rock, Department of Applied Science, 2801 South University, Little Rock, AR 72204. **EQUATIONS OF MOTION FOR 4 DEGREE OF FREEDOM LEG FOR WALKING ROBOT**
10:30	Steve Farmer and Dr. Bob Sims P.E., University of Arkansas at Little Rock (UALR), Department of Applied Science, Little Rock, AR 72204. **IMPLEMENTING THE HART COMMUNICATIONS PROTOCOL IN CONTROL VALVE APPLICATIONS**
10:45	W. K. Chok and R. A. Sims, Applied Science Department, University of Arkansas at Little Rock, 2801 S. University Ave., Little Rock, AR 72204. **ION CURRENT IN THE ELECTROSTATIC APPLICATION OF AUTOMOTIVE CLEAR COAT POWDER**

AQUATIC ECOLOGY

Location: McEver Hall, Room 162

Chairperson: Dr. Joe Stoeckel, Arkansas Tech University

Time	Topic
8:00	Denver Dunn and George L. Harp (Arkansas State University Dept. of Biological Sciences, State University, Arkansas 72467). **DEGREE OF *COTTUS* PREDATION ON TROUT EGGS/FRY IN THE BULL SHOALS LAKE COLD TAILWATERS**
8:15	Shawn W. Hodges, Charles J. Gagen, Fisheries and Wildlife Biology Program, Arkansas Tech University, Russellville, AR 72801. **EFFECT OF LOW SUMMER STREAMFLOW ON SMALLMOUTH BASS MOVEMENTS IN CROOKED CREEK**
8:30	Daniel Ward, Denver Dunn, Hilary Worley, Martin Ruane, Vernon Hoffman, Grace Troutman, and Stanley Trauth (Arkansas State University Dept. of Biological Sciences, State University, Arkansas 72467). **THE FIRST REPORT OF *LAMPETRA APPENDIX* (DEKAY) FROM THE BLACK RIVER DRAINAGE SYSTEM OF ARKANSAS**
8:45	Thomas M. Buchanan and Josh Nichols, Department of Biology, Westark College, Fort Smith, AR 72913, Don Turman, Colton Dennis, Stuart Wooldridge, and Brett Hobbs, Arkansas Game & Fish Commission, 2 Natural Resources Drives, Little Rock, AR 72205. **OCCURRENCE AND REPRODUCTION OF THE ALABAMA SHAD, *ALOSA ALABAMAE*, IN THE OUACHITA RIVER SYSTEM OF ARKANSAS**
9:00	Richard Grippo, Bobby Bennett, Department of Biological Sciences, and Randel Cox, Department of Chemistry and Physics, Arkansas State University, State University, AR 72467. **COMPARISON OF ENVIRONMENTAL ASSESSMENTS OF HARBOR EXPANSIONS ON THE MISSISSIPPI RIVER**
9:15	Break
9:30	John D. Rickett, Biology Department, U. A. L. R., 2801 S. University, Little Rock, AR 72204. E.P. (Perk) Floyd, 2423 E. Woodson Lateral, No. 35, Hensley, AR 72065. **MORPHOMETRY, WATERSHED CHARACTERISTICS AND WATER QUALITY OF FERGUSON LAKE, SALINE COUNTY, ARKANSAS**

9:45 Andi Dickens and Scott Kirkconnell Biology Department, Arkansas Tech University, Russellville, AR 72801. **COLIFORM EVALUATION OF RIVER VALLEY WATERWAYS**

10:00 Eric Anderson and Scott Kirkconnell, Biology Department, Arkansas Tech University, Russellville, AR 72801. **EFFECTS OF ANO EFFLUENT ON LAKE DARDANELLE MICROFLORA**

10:15 Jennifer Smith, Ana Ghanem, Missy Elzey and Thomas S. Soerens,* Department of Civil Engineering, University of Arkansas, 4190 Bell Engineering Center, Fayetteville, AR 72701. **LOCATING NAPL's IN GROUND WATER USING PARTITIONING FLUORESCENT DYES**

10:30 Yian-Mei Lo, Thomas S. Soerens,* Marc A. Nelson, Department of Civil Engineering, Univeristy of Arkansas, 4190 Bell Engineering Center, Fayetteville, AR 72701. **OPTIMUM STORM SAMPLING OF CALCULATION OF NUTRIENT LOADS IN MOORE'S CREEK AND THE ILLINOIS RIVER**

VERTEBRATE ZOOLOGY
Location: McEver Hall, Room 206

Chairperson: Dr. Tom Nupp, Arkansas Tech University

Time	Topic
8:00	Stanley E. Trauth and J. D. Wilhide, Department of Biological Sciences, Arkansas State University, P.O. Box 599, State University, AR 72467-0599. **STATUS OF THREE PLETHODONTID SALAMANDERS (GENUS *PLETHODON*) FROM THE OUACHITA NATIONAL FOREST OF SOUTHWESTERN ARKANSAS**
8:15	Douglas A. James[1] and Christopher J. Kellner[2]. [1]Department of Biological Sciences, University of Arkansas, Fayetteville, AR 72701 and [2]Department of Biology, Arkansas Tech University, Russellville, AR 72801. **STATUS OF THE CERULEAN WARBLER IN ARKANSAS IN THE 1990s**
8:30	Peta Elsken-Lacy, Amy M. Wilson, James H. Peck and Gary A. Heidt, Dept. of Biology, UALR, Little Rock, AR 72204. **ARKANSAS GRAY FOX FUR PRICE-HARVEST MODEL REVISITED**
8:45	Wayne E. Thogmartin, James E. Johnson, Bradley A. Schaeffer, and Camille C. Ciriano Arkansas Cooperative Fish and Wildlife Research Unit, U.S. Geological Survey, Biological Resources Division, Department of Biological Sciences, University of Arkansas, Fayetteville, AR 72701. **SURVEY OF DISEASES IN WILD TURKEYS IN ARKANSAS**
9:00	Josie H. Dickins, David W. Clark, Steffany White, and Gary A. Heidt, Department of Biology, UALR, Little Rock, AR 72204. **SURVEY OF MEDIUM AND LARGE MAMMALS IN AN URBAN PARK (MURRAY PARK, LITTLE ROCK, AR)**
9:15	Break
9:30	Theo Witsell, Gary A. Heidt, and Parker L. Dozhier, Dept. of Biology, UALR, Little Rock, AR 72204, and Hot Springs, AR (PLD). **DOCUMENTED OCCURRENCE OF THE MOUNTAIN LION *(FELIS CONCOLOR)* IN ARKANSAS**
9:45	Keith Sutton[1] and David Jamieson[2] [1]Arkansas Game and Fish Commission, 2 Natural Resources Drive, Little Rock, AR 72205. [2]Arkansas State University-Newport, Department of Biological Science, 7648 Victory Boulevard, Newport, AR 72112. **RESULTS OF AN ARKANSAS WILDLIFE MAGAZINE READER SURVEY CONCERNING REINTRODUCTION OF THE FLORIDA PANTHER *(FELIS CONCOLOR CORYI)* IN ARKANSAS**
10:00	Kimberly G. Smith, Department of Biological Sciences, University ofArkansas, Fayetteville, AR 77201, Cindy Osborne, Arkansas Natural Heritage Commission, Little Rock, AR 72201. **1999 REPORT OF THE ARKANSAS AVIAN VIABLEILITY ASSESSMENT COMMITTEE**

PLANT ECOLOGY & BOTANY
Location: McEver Hall, Room 210

Chairperson: Dr. Gary Tucker

Time	Topic
8:00	Timothy A. Golden and Daniel L. Marsh, Department of Biology, Henderson State University, Arkadelphia, AR 71923. **VARIATIONS IN *SPHAEROCARPOS* (MARCHANTIOPSIDA) IN ARKANSAS**
8:15	Jared W. Kyzer and Daniel L. Marsh, Department of Biology, Henderson State University, Arkadelphia, AR 71923. **OCCURRENCES OF *PETALOPHYLLUM* FOSSOMBRONIACEAE IN THE INTERIOR HIGHLANDS OF ARKANSAS**
8:30	Casey Jones and Renn Tumlison, Department of Biology, Henderson State University, Arkadelphia, AR 71923. **WOODY VEGETATION OF A HILLTOP ISLAND IN DEGRAY LAKE**
8:45	Anne A. Grippo[1], Yan Xie[2], Benjamin L. Rougeau[2], William V. Wyatt2, Departmetns of [1]Biological Sciences and [2]Chemistry & Physics, Arkansas State University, State University, AR 72467. **ANALYSIS OF PHYTOESTROGENS BY HIGH PRESSURE LIQUID CHROMATOGRAPHY**
9:00	Larson, Katherine C. University of Central Arkansas, Conway, AR 72035. **FORAGING BEHAVIOR OF HONEYSUCKLE VINES: CONTRAST BETWEEN THE INVASIVE *LONICERA JAPONICA* AND ITS NATIVE CONGENER *L. SEMPERVIRENS***
9:15	Break
9:30	Linh V. Hoang[1]. [1]Department of Biological Sciences, Arkansas State University, P.O. Box 599, State University, AR 72467-0599. **THE POPULATION STRUCTURE OF SOLIDAGO RIDDELL II (RIDDELL'S GOLDENROD: ASTERACEAE) AT ROCK CREEK NATURAL AREA IN ARKANSAS AND THROUGHOUT ITS RANGE IN NORTH AMERICA**

CHEMISTRY II
Location: McEver Hall, Room 204

Chairperson: Dr. Michael J. Panigot

Time	Topic
9:00	Stanley L. Chapman and William Teague, University of Arkansas, P.O. Box 391, Little Rock, AR 72203. **CHANGES**

IN SOIL CHEMISTRY BENEATH EXPOSED POULTRY HOUSE PADS AND MANURE STORAGE AREAS

9:15 M. A. Miah, Department of Chemistry and Physics, P.O. Box 4941, University of Arkansas at Pine Bluff, Pine Bluff, AR 71611. **ARSENIC CONTAMINATION IN BANGLADESH**

9:30 Paul Nave and Mark Draganjac, Department of Chemistry and Physics, Arkansas State Univesity, State University, AR 72467; A. W. Cordes and Tosah Barclay, Department of Chemistry and Biochemistry, University of Arkansas, Fayetteville, AR 72701. **LIGAND SUBSTITUTION REACTIONS OF [CuRu(PPh$_3$)(tht)$_2$]OTfl. MOLECULAR STRUCTURE OF [CpRu(PPh$_3$)(pms)$_2$]OTfl x 3/4C$_2$H$_4$Cl$_2$, pms = pentamethylene sulfide.**

10:00 Johnetta Price and Victor M. Blunt, Department of Chemistry & Physics, University of Arkansas at Pine Bluff, AR 71601. **SYNTHESIS AND CHARACTERIZATION OF CALCIUM (II) ADAMANTANEDICARBOXYLATE**

10:15 Brian D. Abbott, Robert Allen, and Robin D. Rogers, Department of Physical Sciences, Arkansas Tech University, Russellville, AR 72801. **ROOM TEMPERATURE IONIC LIQUIDS AND THEIR USE IN LIQUID/LIQUID EXTRACTIONS**

10:30 Michael Shane Greene, Rose M. McConnell, and Walter E. Godwin, School of Mathematics & Natural Sciences, University of Arkansas at Monticello, Monticello, Arkansas 71657. **PLANAR COPOLYMERS OF FURAN, THIOPHENE, AND PYRROLE: A MOLECULAR MODELING STUDY**

POSTER SESSIONS

Friday, April 2, 1999
Location: McEver Hall

Michael J. Panigot, Kevin Lawrence, and Laura Benton. **APPROACHES TO THE SYNTHESIS OF STEREOSELECTIVELY BETA-DEUTERATED LEUCINE AND TRYPTOPHAN.**

Leslie Parsley and Rory A. Roberts, Arkansas Tech University, Russellville, AR 72801. **INDUCING WING-LIKE FLUTTER IN A WIND TUNNEL.**

Matthew W. Nix and Thomas M. Walker, Department of Biology, University of Central Arkansas, Conway, AR 72035-0001. **MACROPHAGES ACTIVATED BY PACLITAXEL EXPRESS CD40 AND CD80.**

Thomas M. Walker, Department of Biology, University of Central Arkansas, Conway, AR 72035. **DECREASED VIABILITY OF PACLITAXED-ACTIVATED MACROPHAGES OCCURS THROUGH NITRIC OXIDE DEPENDENT AND INDEPENDENT MECHANISMS.**

Michael D. VanPelt, LaTonya Green and Clifton Orr, Department of Biology, University of Arkansas at Pine Bluff, Pine Bluff, Arkansas 71611. **SULFORHODAMIEN B (SRB) COLORMETRIC CYTOTOXICITY ASSAY FOR MEASURING ANTICANCER EFFECTS.**

Sherry Puterbaugh and K. C. Larson, Department of Biology, University of Central Arkansas, Conway, AR 72035. **SEED GERMINATION AND SEEDLING RECRUITMENT OF LONICERA JAPONICA, JAPANESE HONEYSUCKLE.**

LaTonya Green, Michael D. VanPelt, Clifton Orr, Department of Biology, University of Arkansas at Pine Bluff, Pine Bluff, Arkansas 71601. **THE CURRENT STATUS OF THE PLATINUM COORDINATION COMPLEXES IN CANCER CHEMOTHERAPY**

Occurrence and Reproduction of the Alabama Shad, *Alosa alabamae* Jordan and Evermann, in the Ouachita River System of Arkansas

Thomas M. Buchanan* and Josh Nichols
Department of Biology
Westark College
Fort Smith, AR 72913

Don Turman, Colton Dennis, Stuart Wooldridge, and Brett Hobbs
Arkansas Game & Fish Commission
2 Natural Resources Drive
Little Rock, AR 72205

*Corresponding Author

Abstract

The anadromous Alabama shad, *Alosa alabamae*, has drastically declined in abundance in recent decades throughout its historic range and has previously been reported in Arkansas from only five localities. Three of those locality records are pre-1900. Sampling by seine in the Ouachita River drainage system of southern Arkansas in July and August of 1997 and 1998 produced more than 300 juvenile *A. alabamae* from two localities on the Little Missouri River and four localities on the Ouachita River. One record of an adult Alabama shad, taken on 4 April 1997 by an angler below Remmel Dam on the Ouachita River, was also documented. Adults apparently ascended the Ouachita River and spawned successfully in 1997 and 1998 despite the construction of four locks and dams on that river in Louisiana and Arkansas in the 1980s. The Ouachita River drainage and a few streams in east-central Missouri are currently the only known spawning areas for *A. alabamae* in noncoastal regions of the entire Mississippi River basin. Continued survival of the Alabama shad in Arkansas depends on protecting critical spawning and nursery habitats in the Ouachita River system from deleterious alteration and on preserving that migratory species' access to those habitats.

Introduction

The Alabama shad, *Alosa alabamae* Jordan and Evermann, has a unique life history pattern among Arkansas fish species. It is the only anadromous species known from Arkansas, with the adults inhabiting coastal marine environments of the Gulf of Mexico from Louisiana to Florida. The sexually mature adults ascend the Mississippi River system and a few other coastal drainages in late winter and early spring to spawn in fresh water in April and May from Florida to Missouri (Mills, 1972; Pflieger, 1997), and from May through July in more northern states (Coker, 1930). The juveniles remain in tributary streams until late summer or fall and then migrate downstream toward the ocean after reaching a length of 75-125 mm.

The Alabama shad formerly ascended the Mississippi River and many of its major tributaries, including the Red, Ouachita, Arkansas, Missouri, Ohio, and Tennessee rivers, for considerable distances (Burgess, 1980). In the late 1800s, it was common enough during its spring spawning runs to support a limited commercial fishery in the Mississippi River system (Mills, 1972) and was reportedly a highly regarded food fish (Pflieger, 1997). However, *A. alabamae* drastically declined throughout its range during the 20th century, especially in recent decades. The construction of numerous dams severely limited the number of streams available for spawning migrations, and Burr and Warren (1986) suggested that increased siltation and dredging also contributed to its decline. There are no recent records of Alabama shad from Tennessee and only one recent record (a migrating adult taken in 1986) from Kentucky (Etnier and Starnes, 1993). Burr et al. (1996) reported the first Illinois records in over 30 years, two juveniles taken from the Mississippi River (one in November 1994, and one in September 1995), and Pflieger (1997) reported several recent records of juveniles and adults from Missouri. Declines in abundance have also been recently documented in coastal drainages, such as the Pearl River system of Louisiana and Mississippi (Gunning and Suttkus, 1990), and in Alabama and Florida (Mettee et al., 1996). Mettee et al. (1996) also reported that *A. alabamae* still spawns successfully in the Choctawhatchee and Conecuh river systems in southeastern Alabama, and that the largest known remaining spawning population occurs in the Apalachicola River system of the Florida panhandle below Jim Woodruff Dam. The United States Fish and Wildlife Service (USFWS) is currently reviewing the status of the Alabama shad to determine its conservation needs (Stuart Poss, USFWS, pers. comm.).

There are only five previously reported collection localities for Alabama shad in Arkansas, and three of those records are more than 100 years old. The pre-1900 records (Fig. 1) are based on specimens in the United States National Museum (USNM) of the Smithsonian Institution and are as follows:

(1) One female specimen (USNM 22709) collected by T.M. Thorpe on 15 April 1879 from the Washita (sic) River, 8 miles from Hot Springs, AR.

(2) Three specimens (USNM 36424) collected by D.S. Jordan and C.H. Gilbert in 1884 (no month or day) from the Washita (sic) River at Arkadelphia, AR.

(3) One specimen (USNM 62225) collected by S.E. Meek (no date given) from the Mulberry River at Mulberry, AR. (the specimen was reported missing in 1946).

The approximate date of Meek's collection from the Mulberry River can be inferred. Seth Meek was a professor at the Arkansas Industrial University (University of Arkansas) and collected fishes in Arkansas from 1889 to 1893 (Robison and Buchanan, 1988). The only reported collection by Meek from the Mulberry River occurred in the spring of 1892 (Meek, 1894), and his Mulberry River specimen of *A. alabamae*, initially reported as *Clupea chrysochloris*, was almost certainly taken during that 1892 collecting trip.

The only recent records of *A. alabamae* from Arkansas were reported by Stackhouse (1982) and Loe (1983). Stackhouse reported 16 juvenile Alabama shad from the Saline River in Ashley County collected on 5 August 1972 and deposited in the Northeast Louisiana University Museum of Zoology (NLU 24173). Loe's survey of the fishes of the Little Missouri River produced three juvenile specimens of Alabama shad from the mouth of that river in Ouachita County. Two of the specimens were collected on 18 September 1982 (NLU 51697), and one specimen was taken on 24 September 1982 (NLU 51720).

Our specimens of *A. alabamae* reported herein are the first records for that species from the mainstem Ouachita River in more than 100 years. We also document its occurrence at additional sites on the Little Missouri River and provide the only recent record for an adult Alabama shad from Arkansas.

Materials and Methods

Eighteen localities in the Ouachita River drainage system of southern Arkansas were sampled by seine in 1997 and 1998. The 1997 sampling included two localities on tributary creeks of the Ouachita River in Clark County on 7 July, three localities on the Saline River in Bradley and Drew counties on 14 July, three localities on the Little Missouri River in Clark, Nevada, and Ouachita counties on 21 and 22 July, and one locality on the Ouachita River in Dallas County on 22 July. In 1998, fishes were sampled at one locality on the Saline River in Drew County on 6 July, four localities on the Little Missouri River in Clark, Nevada, and Ouachita counties on 13, 22, and 24 July, and four localities on the Ouachita River in Clark, Dallas, Hot Spring, and Ouachita counties on 13, 20, and 24 July, and 10 August.

All fish collections were made between the hours of 1000 and 1700 with 3 x 1.2 m and 9 x 1.8 m nylon seines of 3.2 mm mesh. At each collecting site all available habitats were sampled, and specimens were preserved in 10% formalin and later washed and transferred to 45% isopropanol. Preserved specimens were identified in the laboratory, and

Table 1. Comparison of morphometric characters of *Alosa alabamae* and *A. chrysochloris*.

Character	*A. alabamae*	*A. chrysochloris*
Relative lengths of upper and lower jaws	Jaws approximately equal in length	Lower jaw projecting distinctly beyond upper jaw
Number of gill rakers on lower limb of first gill arch	30 or more	24 or fewer
Scales in a lateral series	Usually more than 50	Usually fewer than 50
Dark humeral spot behind operculum	Present	Absent
Dark pigment on lower jaw	Extending along most of jaw length	Restricted to tip of jaw
Principal dorsal rays	14-16 ($\bar{x}$ = 15.5)	15-17 ($\bar{x}$ = 16.9)
Principal anal rays	18-20 ($\bar{x}$ = 18.8)	15-18 ($\bar{x}$ = 16.9)
Number of prepelvic scutes	20-22 ($\bar{x}$ = 21.4)	18-20 ($\bar{x}$ = 19.5)
Number of postpelvic scutes	13-16 ($\bar{x}$ = 15.2)	15-18 ($\bar{x}$ = 16.6)

several meristic and morphological characters were examined to determine the best features for distinguishing *A. alabamae* from the very similar skipjack herring, *A. chrysochloris* (Table 1). Fifty-six specimens of skipjack herring from the Arkansas, Mississippi, Ouachita and White river drainages of Arkansas were also examined for comparison with *A. alabamae.* At localities where *A. alabamae* was found, we measured the following habitat features: water temperature, pH, depth, current velocity, substrate composition, vegetation present, and Secchi disk visibility.

Stomach contents were examined from ten *A. alabamae* juveniles from the 24 July 1998 Ouachita River sample and from ten specimens from the 10 August 1998 Ouachita River sample. Stomach contents of each fish were identified using a dissecting microscope, and percent volume of each food item category was estimated visually. The intestinal contents, which were generally too digested to be identified and enumerated accurately, were also examined.

Alabama shad specimens were sent to L. Knapp of the Smithsonian Institution's United States National Museum (USNM) for confirmation of our identification. Twelve of those specimens from the Ouachita River were deposited in the USNM fish collection (USNM 351074). Most of the remaining preserved specimens of *A. alabamae* were catalogued into the Westark College Zoology Collection (WZC 1549, 1551, 1596, 1597, and 1598) and four specimens each were donated to the collections of Arkansas Tech University and Southern Arkansas University.

Results

Alosa alabamae was found at two of the localities sampled in the Little Missouri River and at four localities in the Ouachita River (Fig. 1) and was abundant at most of those sites. Seventy-one juvenile Alabama shad were preserved during the two summers of field work, ten in 1997 and 61 in 1998. Over 100 juvenile specimens were captured and released at each of three of the sample sites.

The ten juvenile specimens taken on 21 and 22 July 1997 ranged in total length (TL) from 47 to 65 mm ($\bar{x} = 56.5$ mm). Thirty-four juveniles collected one year later on 22 and 24 July 1998 were 47 to 85 mm TL ($\bar{x} = 68.7$ mm), and juveniles collected from the Ouachita River on 10 August 1998 were 103 to 131 mm TL ($\bar{x} = 115.5$ mm).

Alosa alabamae juveniles occurred in moderate to swift current ranging in velocity from 0.47 m/s (Little Missouri River, 22 July 1998) to 1.14 m/s (Ouachita River, 10 August 1998) and at water depths of 0.55 to 0.76 m. The substrate at most sites was entirely gravel, but two sites also had small patches of sand. All collection sites had sparse to heavy growths of the filamentous green alga, *Spirogyra*, on the gravel substrate. The most upstream locality where juvenile *A. alabamae* were found on the Ouachita River (near Malvern) was the most heavily vegetated site, having dense growths of the macrophytes *Anacharis* and *Potamogeton*, in addition to *Spirogyra.* Water temperatures at the capture sites ranged from 27.8°C (Ouachita River site closest to Remmel Dam) to 32.5°C (Little Missouri River). The pH varied from 6.9 to 7.2, and water was clear, with Secchi disk visibility extending to the substrate at each site. Thirty-eight other fish species were captured at localities with *A. alabamae.*

Juvenile *A. alabamae* with a mean total length of 73.4 mm fed exclusively on benthic invertebrates in the Ouachita River. Of the ten stomachs examined from the 24 July 1998 collection, two were empty (but the intestines were full), two had only a small amount of food, and six were full. The most commonly eaten items by percent frequency of occurrence were larval Trichoptera (80%), Diptera (60%), Plecoptera (30%), Pelecypoda (10%), and terrestrial Hymenoptera (10%). By estimated percent volume, those same food items made up 70, 20, 8, 1, and 1% of the diet, respectively. The ten larger specimens ($\bar{x} = 113.1$ mm TL) from the 10 August 1998 Ouachita River sample all had full stomachs. By percent frequency of occurrence, those stomachs contained adult Amphipoda (100%), and larval Diptera (80%), Trichoptera (80%), Odonata (20%), and Plecoptera (10%). By estimated percent volume, those food items made up 63, 21, 9, 6, and 1% of the diet, respectively. No fish remains or plant material were found in any stomachs or intestines.

Table 1 compares nine morphological and meristic features of *A. alabamae* and *A. chrysochloris.* The most reliable characters for distinguishing the two species are differences in relative lengths of upper and lower jaws, number of scales in lateral series, and number of gill rakers on the lower limb of the first gill arch. These species also differ in two pigmentary patterns, with *A. alabamae* having melanophores distributed along the lower jaw (vs pigment confined to tip of jaw in *A. chrysochloris*) and having a small, dark humeral spot (vs humeral spot absent in *A. chrysochloris*). Additional meristic features are also useful, but show some overlap in values.

We also documented a recent record for an adult Alabama shad from Arkansas. In 1997 the Arkansas Game & Fish Commission certified a new state angling record for skipjack herring, *Alosa chrysochloris.* In August 1998 we obtained the frozen specimen from the fisherman (Monte Pascoe of Hot Springs) who had caught and saved it for over one year. We reidentified that specimen and verified it to be an adult *A. alabamae*, 46 cm TL, with a mass of 1.3 kg when caught. The adult Alabama shad was caught on an artificial lure (yellow marabou leadhead jig) on 4 April 1997 in the Ouachita River immediately below Remmel Dam in swift current and was deposited in the Westark College Zoology Collection (WZC 1595).

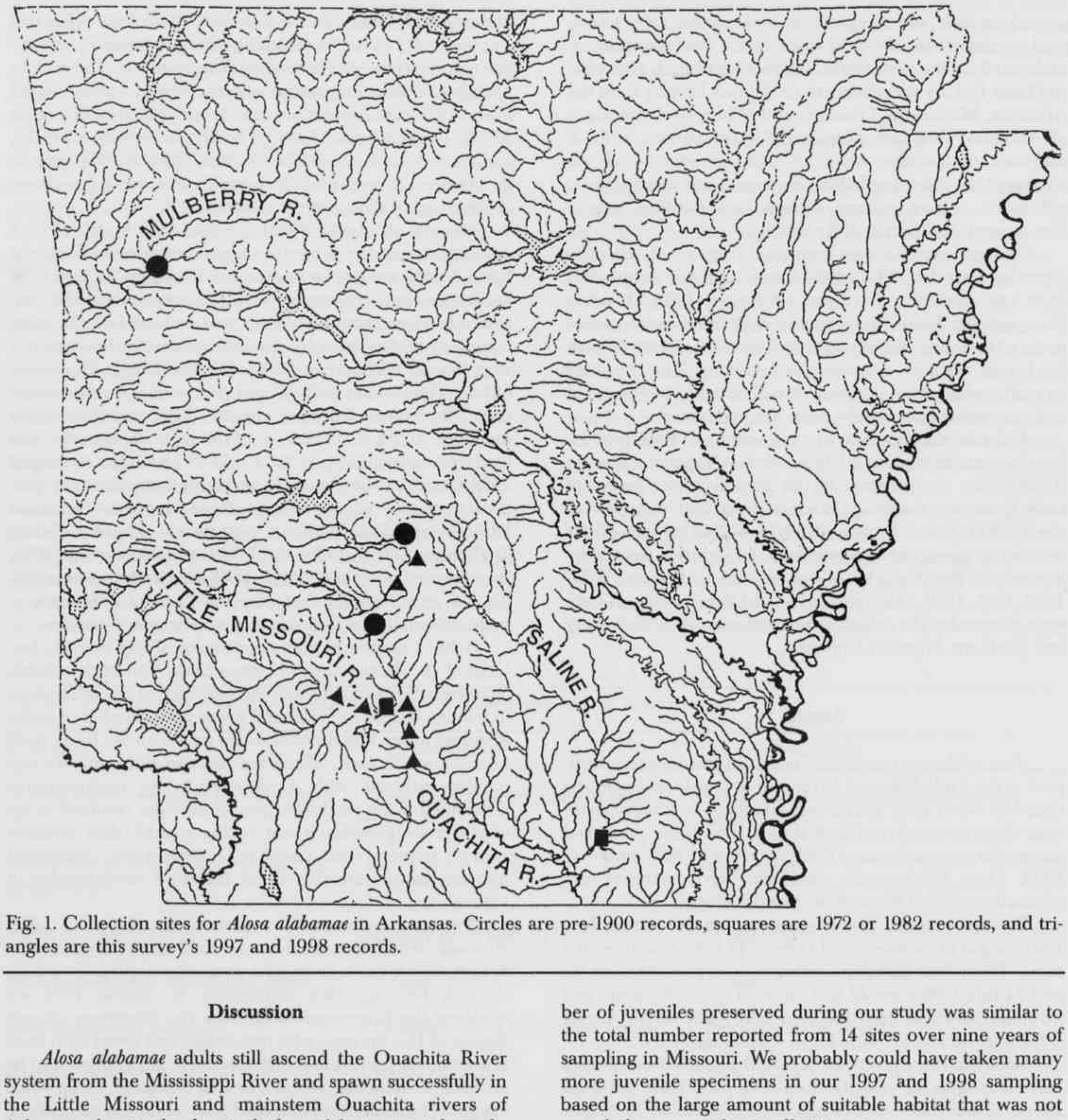


Fig. 1. Collection sites for *Alosa alabamae* in Arkansas. Circles are pre-1900 records, squares are 1972 or 1982 records, and triangles are this survey's 1997 and 1998 records.

Discussion

Alosa alabamae adults still ascend the Ouachita River system from the Mississippi River and spawn successfully in the Little Missouri and mainstem Ouachita rivers of Arkansas, despite the drastic decline of that species throughout its range. The only recent report of successful reproduction of the Alabama shad from farther inland than the Ouachita River drainage of Arkansas is from tributaries of the Mississippi River in Missouri (Pflieger, 1997). The number of juveniles preserved during our study was similar to the total number reported from 14 sites over nine years of sampling in Missouri. We probably could have taken many more juvenile specimens in our 1997 and 1998 sampling based on the large amount of suitable habitat that was not sampled at some of our collecting sites.

The main cause of the decline of the Alabama shad throughout its range appears to be the construction of barriers that prevent upstream migration to spawning grounds. In Arkansas the upstream spring spawning runs of *A. alaba-*

mae are blocked at Remmel Dam, near Jones Mills, Hot Spring Co., on the Ouachita River and at Narrows Dam, Pike Co., on the Little Missouri River, yet successful spawning apparently occurs in the tailwaters below those dams. Variability in water releases from the dams produces drastic fluctuations in discharge, current velocity, and water temperature in the spawning areas. Water levels in the rivers below the dams fluctuate as much as 1-2 m daily, and water temperatures can vary as much as 27 C° daily. The present ability of *A. alabamae* to ascend the Ouachita River system is even more remarkable considering the completion of a series of four locks and dams, two in Louisiana and two in Arkansas, on the Ouachita River in 1985. However, during March and April of most years, the peak months of the spring spawning run, high water frequently flows over and around those locks and dams, providing access to upstream habitats up to Remmel Dam.

The Saline River of Arkansas is the only remaining free-flowing major tributary of the Ouachita River, but specimens of *A. alabamae* were taken in that stream only in 1972 (Stackhouse, 1982). Previous fish sampling from the Saline River, including an extensive survey by Reynolds (1971), produced no specimens of Alabama shad. Stackhouse collected no specimens in his study in the early 1980s, and we collected no specimens from the Saline River in 1997 and 1998.

The scarcity of records of Alabama shad from Arkansas during the past century is probably related to that species' unusual life history pattern, to its overall decline in recent decades throughout its range, to the lack of sampling effort, and to the difficulty in distinguishing *A. alabamae* from the closely related skipjack herring, *A. chrysochloris.* The skipjack herring, which is widespread and common today in the largest rivers of Arkansas, is morphologically similar to the Alabama shad, and misidentifications have occurred. Records of *A. alabamae* from the Illinois, Poteau, and Little rivers of Oklahoma in the 1940s and 1950s confirm that species occurrence in the Mississippi, Arkansas, and Red rivers of Arkansas at those times (Moore, 1973). Dams on the Illinois and Little rivers now block upstream access to those rivers. Isolated records from the Mississippi River of Missouri (Pflieger, 1997), Kentucky (Etnier and Starnes, 1993), and Illinois (Burr et al., 1996) in the 1970s, 1980s, and 1990s demonstrate that adults migrated through Arkansas in those decades as well.

Our documentation of successful spawning of *A. alabamae* in the Ouachita River drainage of Arkansas in two consecutive years suggests that spawning may occur frequently in that system. Successful spawning occurred in 1972 and 1982, based on the juvenile specimens reported by Stackhouse (1982) and Loe (1983) and examined during this study. It is possible that in some years, spawning does not succeed because of the variability in discharge patterns at the dams on the Ouachita and Little Missouri rivers. It is surprising that fish surveys of the Ouachita (Raymond, 1975) and Little Missouri (Meyers, 1977) rivers produced no Alabama shad specimens, although Loe's 1983 survey did produce three juveniles from the mouth of the Little Missouri River. A recent change in the tailwater release from Narrows Dam on the Little Missouri River occurred in 1996. Prior to 1996, a cold-water release occurred, but the dam has now been modified to achieve a multi-level water release. As a result, the tailwaters are now much warmer than before for most of the year. The new release pattern, also produces a more consistent discharge in the Little Missouri River. It is not known whether the modified release pattern influenced the successful spawning of *A. alabamae* in that river in 1997 and 1998.

One possible selective advantage of the unusual anadromous life history pattern of *A. alabamae* is the rapid growth of the young in freshwater environments. Growth rates in fishes typically vary from year-to-year with varying environmental conditions. The difference in growth rates for July 1997 ($\bar{x}$ = 56.5 mm. TL) and July 1998 ($\bar{x}$ = 68.7 mm TL) may reflect such variables as food availability, water temperature, or even spawning date. Information on the growth rate in 1998 was obtained by comparing the lengths of *A. alabamae* taken on 24 July and 10 August from the Ouachita River. In approximately three weeks, the mean total length increased by 46.8 mm, assuming that the shad at those two sites hatched on approximately the same date. Based on the total lengths of the juvenile specimens collected in August 1972 (NLU 24173), September 1982 (NLU 51697, 51720), and July 1997 and 1998, spawning of Alabama shad probably occurs in Arkansas from April to early June. Juveniles have been collected in Arkansas between 22 July and 24 September.

The juveniles collected on 24 July 1998 fed primarily on Trichoptera and Diptera larvae, while larger juveniles collected three weeks later at a site further upstream fed mainly on Amphipoda and Diptera larvae. Those dietary differences were probably related more to food availability than to fish size. The latter site was heavily vegetated with macrophytes, providing more amphipod habitat, while the 24 July site lacked macrophytes, having only the filamentous green alga, *Spirogyra.* The lack of fish remains in the stomachs and intestines of the largest juveniles was surprising. Adult Alabama shad fed mainly on fish in their marine environment, and juveniles fed on small fishes and aquatic insects in the Apalachicola River, Florida (Laurence and Yerger, 1966).

Two of the three pre-1900 Arkansas records for *A. alabamae* came from the Ouachita River, and the third came from near the mouth of the Mulberry River (Arkansas River). This species may no longer be able to ascend the Arkansas River due to the construction of 17 locks and dams on the river in Arkansas and Oklahoma. During the last 25 years, the Arkansas River has been extensively sampled by seine (more than 200 samples by T. Buchanan), rotenone (at least six annual samples by the Arkansas Game & Fish Commission), and various sampling methods by the U.S. Army Corps of Engineers (Sanders et al., 1985). *Alosa chrysochloris* was commonly reported in those sampling efforts, but no *A. alabamae* specimens were found. The Ouachita River drainage of Arkansas and a few streams in east-central Missouri are currently the only known spawning areas for *A. alabamae* in noncoastal regions of the entire Mississippi River basin. The continued survival of the Alabama shad as part of the Arkansas fish fauna depends on protecting its critical spawning and nursery habitats in the Ouachita River system from deleterious alteration and on preserving access to those habitats for that migratory species. It is important to identify the conditions required by *A. alabamae* for successful spawning in the Ouachita and Little Missouri rivers and to learn as much as possible about its biology in those fresh waters. That information is essential for making recommendations about water release patterns from Narrows and Remmel dams, especially during spawning runs, to provide optimum conditions for the conservation of this rare species.

ACKNOWLEDGMENTS.—We are grateful to Westark College for providing partial funding for this study through a faculty development grant and the Scholar-Preceptor Program. Additional funding was provided through a National Science Foundation grant to South Central Partnership for Environmental Technology Education for an internship by TMB with the Arkansas Game & Fish Commission. We also thank Leslie Knapp of the United States National Museum for verifying our identification of *Alosa alabamae*, Neil Douglas of Northeast Louisiana University for the loan of specimens from the NLU Museum of Zoology, and Charles J. Gagen of Arkansas Tech University for a helpful review of the manuscript. Jerry Smith, Diana Saul, Randy Johnson, Daniel Ellis, Deanna Buie, and Ross Wooldridge assisted in the field work, and Cheryl Pacheco and Vicki Bond helped prepare the manuscript.

Literature Cited

Burgess, G. H. 1980. *Alosa alabamae* Jordan and Evermann, Alabama shad. p. 62. *In*: D.S. Lee et al. Atlas of North American Freshwater Fishes. N.C. State Mus. Nat. Hist., Raleigh, i-x + 854 pp.

Burr, B. M., and **M. L. Warren.** 1986. A distributional atlas of Kentucky fishes. Kentucky Nature Preserves Comm. Sci. and Tech. Ser. No. 4, 398 pp.

Burr, B. M., K. M. Cook, D. J. Eisenhour, K. R. Piller, W. J. Poly, R. W. Sauer, C. A. Taylor, E. R. Atwood, and **G. L. Seegert.** 1996. Selected Illinois fishes in jeopardy: new records and status evaluations. Trans. Ill. State Acad. Sci. 89:169-186.

Coker, R. E. 1930. Studies of common fishes of the Mississippi River at Keokuk. Bull. U.S. Bur. Fish. 45:141-225.

Etnier, D. A., and **W. C. Starnes.** 1993. The fishes of Tennessee. Univ. Tennessee Press, Knoxville, 681 pp.

Gunning, G. E., and **R. D. Suttkus.** 1990. Decline of the Alabama shad, *Alosa alabamae*, in the Pearl River, Louisiana-Mississippi: 1963-1988. Proc. SE Fishes Council 21:3-4.

Laurence, G. C., and **R. W. Yerger.** 1966. Life history studies of the Alabama shad, Alosa alabamae, in the Apalachicola River, Florida. Proc. 20th Ann. Conf. Southeastern Assoc. Game & Fish Comm.:260-273.

Loe, R. A. 1983. A subsequent study of the fishes of the Little Missouri River, west central Arkansas. Unpublished M.S. Thesis. Northeast Louisiana Univ., Monroe, 139 pp.

Mills, J. G. 1972. Biology of the Alabama shad in northwest Florida. Tech Series No. 68, State of Florida Dept. of Natural Resources, 24 pp.

Meek, S. E. 1894. Report of investigations respecting the fishes of Arkansas, conducted during 1891, 1892, and 1893, with a synopsis of previous explorations in the same state. Bull. U.S. Fish. Comm. 14:67-94.

Mettee, M. F., P. E. O'Neil, and **J. M. Pierson.** 1996. Fishes of Alabama and the Mobile Basin. Oxmoor House, Birmingham, Al. 820 pp.

Meyers, J. W. 1977. Fishes of the Little Missouri River, southwest Arkansas. Unpublished M.S. Thesis. Northeast Louisiana Univ., Monroe, 25 pp.

Moore, G. A. 1973. Discovery of fishes in Oklahoma (1852-1972). Proc. Oklahoma Acad. Sci. 53:1-26.

Pflieger, W. L. 1997. The fishes of Missouri. Missouri Dept. Conservation, Jefferson City, 372 pp.

Raymond, L. R. 1975. Fishes of the hill province section of the Ouachita River, from Remmel Dam to the Arkansas-Louisiana line. Unpublished M.S. Thesis. Northeast Louisiana Univ., Monroe, 38 pp.

Reynolds, J. T. 1971. The fishes of the Saline River, south central Arkansas. Unpublished M.S. Thesis. Northeast Louisiana Univ., Monroe, 36 pp.

Robison, H. W., and **T. M. Buchanan.** 1988. Fishes of Arkansas. Univ. Arkansas Press, Fayetteville, 536 pp.

Sanders, L. G., J. A. Baker, C. L. Bond, and **C. H. Pennington.** 1985. Biota of selected aquatic habitats of the McClellan-Kerr Arkansas River Navigation System. Tech. Rept. E-85-6. U.S. Army Engineer Waterways Experiment Station, Vicksburg.

Stackhouse, R. A. 1982. A subsequent study of the fishes of the Saline River, south central Arkansas. Unpublished M.S. Thesis. Northeast Louisiana Univ., Monroe, 142 pp.

Changes in Soil Chemistry Beneath Exposed Poultry House Pads and Manure Storage Areas

Stanley L. Chapman and William Teague
University of Arkansas
P. 0. Box 391
Little Rock, AR 72203

Abstract

Concerns about nitrates in private drinking water supplies in the older poultry growing areas of Arkansas prompted soil and water testing in the early 1990's. Exposed poultry house pads were recognized as a potential source of nitrates in the groundwater. Soils beneath nine different poultry house pads in five counties were sampled in 10-30 cm increments to bedrock or to a maximum sampling depth of 90 cm. The nine sites had been exposed to natural weathering conditions ranging from never to for more than 20 years. Routine soil tests were conducted by the University of Arkansas Soil Testing Lab at Marianna according to standard methods (Mehlich III extractant). The relatively immobile elements P, Ca, Mg, Fe, Mn, Cu, and Zn were mainly concentrated in the upper part of the soil profiles (0-30 cm). The more leachable NO_3-N, K, and SO_4-S were generally found throughout the soil profile. Sodium was found in high concentrations throughout the soil profile at two sites. This study shows that nitrate-N, potassium, and sulfate-S from exposed poultry house pads and manure storage areas have the potential of leaching into groundwater. The other eight elements tested do not pose a threat of leaching, but are possible surface water contaminants.

Introduction

Concerns about nitrates in private drinking water supplies in the older poultry growing areas of Arkansas prompted soil and water testing in the early 1990's (Austin and Steele, 1990; Daniel et al., 1991; Daniel et al., 1992; Edwards and Daniel, 1992; Gilmour et al., 1987; and Smith and Steele, 1990). Exposed poultry house pads were recognized as a potential source of nitrate contamination of the groundwater. (Teague et al., 1993).

Poultry houses are typically built by cutting and filling the soil to form a level base for construction. Wood chips, rice hulls, or other carbonaceous materials are placed on the dirt floor as bedding to absorb the wet poultry droppings (Boles et al., 1995a; Boles et al., 1995b). The resulting by-product called "chicken litter" is removed generally on a yearly basis and land applied as fertilizer (Chapman, 1996). In many cases the litter is left on the floor when the poultry house is torn down or destroyed by natural forces. The remaining litter, which may be 10-20 cm deep, contains a high concentration of chemical elements some of which may be subject to leaching into the groundwater.

Information on the contribution of exposed poultry house pads to groundwater contamination is lacking. Ritter (1991) showed that both nitrate-N and NH_4-N concentrations were at or above 300 mg/kg in the surface 30 cm of soil beneath the litter in producing broiler houses in Delaware. The concentrations declined to less than 100 mg/kg at about 60 cm of soil depth in 25 year-old houses, but remained above 50mg/kg to the maximum sampling depth of 135 cm.

Materials and Methods

Soils beneath nine different poultry house pads in five counties in Arkansas were sampled by auger in increments ranging from 10 to 30 centimeters (cm) in thickness to bedrock or to a maximum sampling depth of 90 cm. The poultry house pads were sampled because water in nearby wells used for drinking tested above the health advisory level of 10 mg/l of nitrate-nitrogen (Tacker, 1991; Teague, et al., 1993). The nine sites had been exposed to natural weathering conditions ranging from never to for more than 20 years. Routine soil tests were conducted by the University of Arkansas Soil Testing Lab at Marianna according to standard methods (Mehlich III extractant). Soil pH was reported in standard units using distilled water for dispersion (Chapman, 1998). The other 11 elements were reported in milligrams per kilogram (mg/kg) of soil.

Results and Discussion

The nine sample location sites are numbered in perceived weathering sequence based on historical records from non- or freshly-exposed (site number 1) to long-term exposure of more than 20 years (site number 9). Relative values (Chapman et al., 1997; Chapman et al., 1998) for individual elements are shown in Table 1 along with maximum depths at which high concentrations were detected. The relative element concentrations are based on the results of 60,000 to 100,000 routine soil samples tested annually by the University of Arkansas Soil Testing Lab at Marianna.

The relatively immobile elements P, Ca, Mg, Fe, Mn, Cu, and Zn were mainly concentrated in the upper part of the soil profiles (0-30 cm). The more leachable NO_3-N, K, and SO_4-S were generally found throughout the soil profile. Sodium was found in high concentrations throughout the soil profile at two sites.

The following is a discussion of each of the individual sites.

Site 1 - Covered Poultry House Pad, Coastal Plains, Pike County, Arkansas.

The poultry house was empty of chickens. Dry litter remained on the floor from the last batch grown. Soil samples were collected in 15 cm increments beneath the dry litter to a depth of 90 cm.

Soil test results showed extremely acid pH throughout

Table 1. Maximum Depth (cm) of High Element Concentration in Soil Beneath Poultry House Pads

Soil Test Element	Highest Observed Concentration (mg/kg)	Site Number								
		1	2	3	4	5	6	7	8	9
NO_3-N	50+	90*	90*	90*	0	45*	15	90*	0	0
P	150+	15	15	30	40	10	15	15	30	30
K	300+	60	90*	90*	60*	45*	60*	60	90*	90*
Ca	1000+	15	15	30	20	10	0	0	0	0
Mg	250+	15	15	30	0	0	0	0	0	0
Na	200+	30	90*	0	0	0	60*	60	0	0
SO_4-S	50+	90*	90*	90*	60*	45*	60*	90*	90*	90*
Fe	100+	0	15	90*	20	10	15	0	45	30
Mn	100+	0	0	0	0	0	15	0	0	0
Cu	3+	15	15	30	20	0	0	0	0	30
Zn	9+	15	15	30	20	10	0	15	45	30

*Maximum soil depth sampled.

the profile and high or very high concentrations of most elements in the upper 15 cm (Table 2). Even though the pad had not been exposed to the weather, the more mobile sulfates and nitrates showed evidence of downward movement to the greatest depth sampled (90 cm). Potassium concentrations indicated downward movement to at least 60 cm. The other elements showed little evidence of moving below the upper 15 cm of soil.

Site 2 - Freshly Exposed Poultry House Pad, Ozark Highlands, Benton County, Arkansas.

Litter present from the last batch of broilers grown had been exposed to rainfall for several months. Soil samples were collected in 15- to 30-cm increments beneath the litter surface.

The soil was extremely acid (pH below 4.5) throughout the profile with high or very high concentrations of most elements in the upper 15 cm (Table 3). In addition to the sulfates and nitrates, potassium and sodium showed evidence of leaching to a depth of 90 cm.

Site 3 - Poultry Manure Storage Area Exposed to the Weather, Coastal Plains, Columbia County, Arkansas.

Soil samples were collected in 30 cm increments to a depth of 90 cm. Previously stockpiled litter had been removed prior to sampling.

There was a high concentration of most elements (P, K, Ca, Mg, nitrates, Cu, and Zn) in the upper 30 cm of soil. There was a higher than expected (but not high) concentration of potassium, sulfates, and nitrates throughout the soil profile.

Site 4 - Exposed Poultry House Pad (five years), Ozark Highlands, Washington County, Arkansas.

Soil test results were similar to those from site three

Table 2. Chemical Analysis of Soil Beneath a Covered Poultry House Pad - Site 1, Coastal Plains, Pike County, Arkansas.

Soil Depth (cm)	Observed Element Concentration											
	pH	P	K	Ca	Mg	Na	SO_4-S	NO^3-N	Fe	Mn	Cu	Zn
		mg/kg										
0-15	4.3	650	6364	1065	395	1520	566	499*	63	15	3.2	26.2
15-30	3.8	13	1904	114	28	257	278	499*	40	0	0.5	3.4
30-45	3.1	2	742	69	16	106	206	227	46	0	0.7	3.1
45-60	3.0	5	489	67	14	95	178	140	41	0	0.9	4.1
60-75	3.1	11	297	84	14	117	142	108	37	0	0.8	4.1
75-90	3.1	5	241	104	15	95	93	107	50	1	0.8	2.1

*Upper reporting limit for the element.

except that nitrate concentrations remained low throughout the soil profile. Soil pH dropped from 6.6 in the upper 20 cm to 4.3 at the 40-60 cm depth.

Site 5 - Exposed Poultry House Pad (five years), Ozark Highlands, Washington County, Arkansas.

Soil test results indicated a buildup of P, K, Ca, sulfates, nitrates, and zinc in the upper 10 cm of soil (Table 4). Soil pH was acidic throughout the profile (5.2 to 3.9). Sulfate, nitrate, and potassium concentrations varied from low to high with depths to 45 cm.

Site 6 - Exposed Poultry House Pad (five years), Ozark Highlands, Washington County, Arkansas.

Soil test results indicated a buildup of P, K, sulfates and nitrates in the upper 15 cm of soil. In addition, potassium and sulfate were high throughout the soil profile. The other elements tested in the normal range.

Site 7 - Exposed Poultry House Pad (10 years), Ouachita Mountains, Sevier County, Arkansas.

Soil test results indicated a large buildup of potassium, sulfates and nitrates throughout the soil profile (Table 5). Extremely high potassium concentrations decreased with depth, whereas sulfate concentrations increased with depth.

Site 8 - Exposed Poultry House Pad (15 years), Coastal Plains, Sevier County, Arkansas.

The entire soil profile was acidic (pH 5.1-4.6). Phosphorus was high (above 150 mg/kg) in the upper 30 cm of soil.

Potassium was high (above 300 mg/kg) in the lower third of the soil profile (60-90 cm). All other elements were in normal ranges throughout the soil profile. Nitrate con-

Table 3. Chemical Analysis of Soil Beneath a Freshly Exposed Poultry House Pad - Site 2, Ozark Highlands, Benton County, Arkansas.

Soil Depth (cm)	Observed Element Concentration											
	pH	P	K	Ca	Mg	Na	SO_4-S	NO_3-N	Fe	Mn	Cu	Zn
		mg/kg										
0-15	4.4	1401	8080	3812	911	499*	492	499*	175	65	4.2	48.9
15-30	4.4	81	3122	535	173	446	406	406	65	10	0.7	5.8
30-60	4.2	11	2220	266	96	351	401	375	41	4	0.5	2.1
60-90	3.9	7	2544	292	109	543	350	456	33	4	0.3	1.4

*Upper reporting limit for the element.

Table 4. Chemical Analysis of Soil Beneath Exposed Poultry House Pad - Site 5, Ozark Highlands, Washington County, Arkansas.

Soil Depth (cm)	Observed Element Concentration											
	pH	P	K	Ca	Mg	Na	SO_4-S	NO_3-N	Fe	Mn	Cu	Zn
		mg/kg										
0-10	5.2	1430	948	1632	144	144	220	85	118	63	1.7	24.4
10-30	4.2	61	140	856	116	60	19	183	69	82	2.7	6.5
30-45	3.9	52	572	233	45	80	83	62	58	7	0.8	1.9

Table 5. Chemical Analysis of Soil Beneath Exposed Poultry House Pad - Site 7, Ouachita Mountains, Sevier County, Arkansas.

Soil Depth (cm)	Observed Element Concentration											
	pH	P	K	Ca	Mg	Na	SO_4-S	NO_3-N	Fe	Mn	Cu	Zn
		mg/kg										
0-15	5.0	227	499	492	175	212	67	252	27	12	2.0	14.7
15-30	3.7	10	499*	219	116	202	72	272	21	2	0.5	6.3
30-45	3.4	10	499*	257	142	207	141	325	22	2	0.6	4.9
45-60	3.2	43	399	223	128	217	180	291	30	1	0.8	3.3
60-75	3.3	28	281	170	108	164	130	231	27	1	0.8	2.7
75-90	3.3	10	202	154	117	166	143	191	25	1	0.8	2.7

*Upper reporting limit for the element.

Table 6. Chemical Analysis of Soil Beneath Exposed Poultry House Pad - Site 9, Coastal Plains, Columbia County, Arkansas.

Soil Depth (cm)	Observed Element Concentration											
	pH	P	K	Ca	Mg	Na	SO_4-S	NO_3-N	Fe	Mn	Cu	Zn
		mg/kg										
0-15	6.1	336	117	384	53	84	1	3	176	17	5.1	47.3
15-30	5.5	417	250	507	91	71	13	2	100	3	3.4	18.2
30-60	4.6	113	345	237	69	71	33	4	67	1	1.6	7.8
60-90	4.4	9	302	91	23	60	70	3	26	1	1.1	4.7

centrations were extremely low throughout the profile. Sulfates were low in the upper two thirds of the profile (060 cm) but were high in the lower third (60-90 cm).

Site 9 - Exposed Poultry House Pad (20 years), Coastal Plains, Columbia County, Arkansas.

Phosphorus, copper and zinc concentrations were high in the upper third (0-30 cm) of the soil profile (Table 6). The other elements were in the normal concentration range. Potassium concentrations increased from normal in the 0-30 cm depth to high (above 300 mg/kg) in the lower two thirds of the soil profile.

Our observations suggest that nitrate-N, potassium and sulfate-S from exposed poultry house pads and manure storage areas have the potential of leaching into groundwater. The other eight elements tested do not pose a threat of leaching, but are possible surface water contaminants.

One of the most practical ways of protecting groundwater and nearby water wells from nitrate contamination from abandoned poultry houses is to remove and land-apply the accumulated poultry manure immediately after the final growout. Exposed poultry house pads should be planted to forages or other vegetation to take up excess plant nutrients and reduce the potential for additional loss by leaching and surface runoff.

Literature Cited

Austin, A. Y. and **K. F. Steele.** 1990. Nitrate concentrations of groundwater in northern Madison County, Arkansas. AWRRC Miscellaneous Publication No. 74.

Boles, J. C., Jr., G. Huitink, and **K. VanDevender.** 1995a. Utilizing dry poultry litter - an overview. University of Arkansas Cooperative Extension Service Fact Sheet 8000.

Boles, J. C., Jr., K. VanDevender, J. Langston, and **A. Rieck.** 1995b. Dry poultry manure management. University of Arkansas Cooperative Extension Service Miscellaneous Publication 358.

Chapman, S. L. 1996. Soil and solid poultry waste nutrient management and water quality. Poultry Science 75:862-866.

Chapman, S. L. 1998. 1998 soil test recommendations guide. University of Arkansas Cooperative Extension Service.

Chapman, S. L., M. Daniels, Y. S. McCool, W. H. Baker, and **W. E. Sabbe.** 1997. Soil test characteristics of major land areas in Arkansas - 1966. In W. E. Sabbe (ed). Arkansas Soil Fertility Studies 1966. Arkansas Agri. Exp. Sta. Res. Ser. 455:12-14.

Chapman, S. L., W. E. Sabbe, and **W. H. Baker**. 1998. Understanding the numbers on your soil test report. University of Arkansas Cooperative Extension Service Fact Sheet 2118.

Daniel, T. C., D. R. Edwards and **B. Moore.** 1991. Non-point pollution: sources and concerns. University of Arkansas Cooperative Extension Service Fact Sheet 1013.

Daniel, T. C., D. R. Edwards, D. C. Wolf, K. F. Steele and **S. L. Chapman.** 1992. Nitrates in Arkansas groundwater. University of Arkansas Cooperative Extension Service Fact Sheet 2084.

Edwards, D. R. and **T. C. Daniel.** 1992. Environmental impacts of on-farm poultry waste disposal - a review. Bioresource Technology. 41:9-33.

Gilmour, J. T., D. C. Wolf and **P. M.. Gale.** 1987. Estimating potential ground and surface water pollution from land application of poultry litter. AWRRC Publication No. 128.

Ritter, W. F. 1991. Movement of nitrogen in poultry houses. Technical Report, Delaware Department of Natural Resources and Environmental Control. Dover, Delaware.

Smith, C. R. and **K. F. Steele.** 1990. Nitrate concentrations of groundwater in Benton County, Arkansas. AWWRC Miscellaneous Publication No. 73.

Tacker, P. 1991. Testing of nitrate levels in 21 counties. Abstracts of Fourth Arkansas State Water Conference, Ferndale, Arkansas, September 3-4, 1991.

Teague, W., P. Tacker and **S. Chapman.** 1993. Nitrate testing and source evaluation of private rural water supplies in Arkansas. Progress Report to USDA, Washington, D.C.

A Revised List of Arkansas Terrestrial Mollusks with Notes on the Geographic Distribution of Species

Brian F. Coles*
4202 Scottie Smith Drive
Jefferson, AR 72079

Gerald E. Walsh
9 Yocum Road
Rogers, AR 72756

*Corresponding Author

Abstract

A revised list of of Arkansas terrestrial mollusks is presented, based on the authors' collections, incorporating data from the scientific literature and taking into account recent changes in taxonomy and species concepts. 144 species are recorded for Arkansas, of which 127 represent the autochthonous fauna of the state. The biogeographical position of Arkansas is reflected in its land mollusks, i.e., approximately 40% of Arkansas species are also widely distributed in the United States east of the Rocky Mountains, 12% are more widely distributed to the north, 11% are typical of the Gulf Coastal Plain, 14% form a "Mid Western" assemblage and 18% are endemic to the Ouachita-Ozark regions of Arkansas, Oklahoma and Missouri. The remaining 5% are species for which the geographic distribution is unclear. Diversity of Arkansas land mollusks is apparently due to the conjunction of these geographical zones within the state. Taxonomic problems exist for the genera *Mesomphix* and *Paravitrea* (family Zonitidae) and *Succinea* (family Succineidae) in Arkansas.

Introduction

Distribution of the land mollusks of the United States is poorly understood, especially in Arkansas. The most recent summary of Arkansas mollusks is that of Gordon (1980) who listed all mollusks, terrestrial and freshwater, then known from the state. His list of terrestrial mollusks is based primarily on that of Hubricht (1972). However, more recent data for land mollusks can be abstracted from Hubricht (1985). Hubricht's (1985) data are based primarily on his enormous collecting experience. However, he excluded species in the earlier literature (i.e., pre-Pilsbry, 1940-1948) that appeared to be outside of their main range and those species that appear to be alien introductions. He also revised his identification of some forms between his 1972 and 1985 publications. The later publication also reflects changes in taxonomy. We present an updated list of Arkansas land mollusks with comments on species that cause identification or taxonomic problems or are of restricted distribution.

Materials and Methods

The list of Arkansas land mollusks is based primarily on the authors' collections during 1995-1998. Collections were made at over 300 sites in all Arkansas counties except Craighead and Sebastian counties. Collection sites included all major habitat types within the state. These include margins of bayous, streams, and major rivers, bottomland woodland and headwaters swamp in the Delta and Gulf Coastal Plain, prairies (notably the black soil prairies of southwestern Arkansas), and a wide range of woodland sites (bluffs, gullies, boulder talus) throughout Crowley's Ridge, and the Ouachita and Ozark mountains. In general, localities were under federal or state ownership, i.e., national forests and parks, state parks, and state natural areas. Collections were also made in lands managed by The Nature Conservancy and Arkansas Natural Heritage Commission.

Identification was made by reference to Pilsbry (1940-1948), Emberton (1988, 1991, 1995), Burch (1980), and the collections in the Field Museum of Natural History, Chicago, and the Academy of Natural Sciences, Philadelphia. For the family Succineidae (genera *Oxyloma*, *Succinea* and *Catinella*), where examination of genital anatomy is critical for accurate identification, specimens were drowned overnight in water and preserved in 70% ethanol for subsequent dissection. Voucher material is at present in the authors' possession and will be deposited in the University Museum, University of Arkansas at Fayetteville, and the Field Museum of Natural History, Chicago.

In the list of Arkansas land mollusks that follows, we have incorporated Emberton's (1995) taxonomic revision of the family Polygyridae and names given by the American Fisheries Society (1988). Otherwise, we have followed the arrangement of Hubricht (1985). Notes on problems of species identification are given. Records from Pilsbry (1940-1948) and Hubricht (1962, 1985) are included in the list.

Results and Discussion

Some problems of taxonomy must be addressed before an analysis of the biogeographical relationships of Arkansas terrestrial mollusks can be made:

1. Most *Carychium* sp. in the state are referable to *Carychium exile.* Smaller and less striate forms that seem to be *Carychium mexicanurn* occur with *C. exile* in southwestern Arkansas. The problem of species recognition in *Carychium* is discussed by Burch and Van Devender (1980).

2. *Cochlicopa lubrica senso stricto (Cionella lubrica* of Gordon (1980) has not been seen in the state. Since it was not the practice to distinguish between species of *Cochlicopa* in the past, we assume that Gordon's record refers to *Cochlicopa morseana.* Hubricht does not record *C. lubrica* for Arkansas.

3. *Gastrocopta mcclungi* was described as [sub]fossil from upper Pleistocene deposits in Phillips County, Kansas. (Hanna and Johnston, 1913). Pilsbry (1948) regarded *G. mcclungi* as a variation of *Gastrocopta procera sterkiana,* but it is clear that he was referring to material from the southwestern United States (possibly subfossil), i.e., west of Arkansas. Judging from his illustrations and comments, and from our examination of material in the Academy of Natural Sciences, Philadelphia, the southwestern form of "*mcclungi*" belongs to the *Gastrocopta procera/sterkiana* aggregate. Hubricht (1985) gives *Gastrocopta sterkiana* specific status but essentially follows Pilsbry's views. In addition to his comments, Pilsbry (1948) illustrated but did not otherwise mention *G. mcclungi* from Rogers, Benton County, Arkansas. Examination of Pilsbry's specimen, which is the only one in the Academy's collection, confirmed its identity with our form and that it is a form distinct from both *G. procera* and *G. sterkiana.* Figures of the type specimen of *G. mcclungi* (Hanna and Johnston, 1913) are not sufficiently detailed to establish whether *G. mcclungi sensu* Hannah and Johnston is the same as the living Arkansas form. We have not examined the type specimen.

4. Hubricht (1985) states that at least two species are included in the *Columella simplex* aggregate. Two forms appear to be distinguishable in Arkansas: a smaller form and a larger, more cylindrical form, the latter with strong, regular striation. The larger form may be that described as *Columella edentata* var. *turritella* (see Pilsbry, 1948).

5. Hubricht (1985) records only *Oxyloma salleanum* for Arkansas, and this species certainly occurs in the state. However, several populations of *Oxyloma* are referable to *Oxyloma retusa* both in their shell form and genital morphology, notably in the long, spirally twisted vas deferens of *O. retusa* as illustrated by Pilsbry (1948) and confirmed by the authors' dissection of specimens from Arkansas and Joliet, Illinois.

6. Hubricht (1985) includes *Succinea ovalis, S. indiana, S. grosvenori, S. unicolor, S. forsheyi* and *S. luteola* for Arkansas. Identification of *Succinea* species in Arkansas presents considerable problems. We have found specimens from southeastern Arkansas that resemble *S. unicolor* in size, color, rather squat shell form and deep suture and that have male genitalia varying in exertion of the penis from the penis sheath and the extent to which the penis-epiphallus forms a loop free of the penis sheath. Other specimens from southwestern Arkansas have similar (and variable) genitalia but appear to resemble *S. indiana* in shell form. However, the habitat, lake margins, disagrees with that given for *S. indiana* by Hubricht (1985). Nevertheless, Hubricht (1985) records *S. indiana* and *S. unicolor* from Arkansas. There is an apparent resemblance of some specimens to *S. aurea* but the exact identity of this species is unclear (Hubricht, 1985). Hubricht (1967, 1972) also records *S. witteri* for Arkansas (and thus is recorded by Gordon, 1980), but as he does not record it in his later study (Hubricht, 1985), we assume that he regarded this as a misidentification of *S. forsheyi. Succinea concordialis* (listed by Gordon, 1980) presumably refers to *S. forsheyi* (see synonymy in Hubricht, 1985). We have confirmed the identity of Arkansas *S. forsheyi* by anatomical studies. Other species of *Succinea* listed for Arkansas by Hubricht (1985), *S. luteola,* and *S. grosvenori,* have not been confirmed to be living in the state in recent studies, although *S. luteola* has been found in river drift (shells of undetermined age and origin found near rivers). Our specimens of *S. ovalis* consistently agree in both shell and genital morphology with description of the species (Pilsbry, 1948).

7. *Catinella texana* and *Catinella vermeta* (listed by Gordon, 1980) are given as synonyms by Hubricht (1985). Our dissections of *Catinella* confirm that *C. texana* and *C. vermeta* can be ascribed to a single variable species, *C. avara.* Notably, genital morphology of *C. avara* is variable and, in Arkansas specimens, the relative size of the penis to the penial appendix (the basis for identification of *C. texana*) increases with age of the animal.

8. *Anguispira kochi* is recorded for Arkansas by Pilsbry (1948) but is not included for the state by Hubricht (1985).

9. Hubricht (1985) regards Arkansas *Discus* of the *Discus patulus* group as *D. nigrimontanus,* stating that *D. nigrimontanus* and *D. patulus* hybridize in the Ozark mountains, but he gives little evidence for this view. Specimens labeled "*Discus nigrimontanus*" from Mount Magazine, Logan County, in the Hubricht collection at the Field Museum of Natural History are identical in range of form to those that we have seen from the same and other sites during the present study. Other forms in the Hubricht collection labeled "*Discus nigrimontanus*" from western North Carolina agree in form with the generally accepted view of *nigrimontanus.* Arkansas *Discus* species are variable in the angularity of the shell periphery, openness of the umbilicus and height of the shell, but such variation appears to be within that of *D. pat-*

ulus. In the absence of convincing contradictory evidence, we regard Arkansas *Discus* as *patulus.*

10. Hubricht (1972) listed *Helicodiscus jacksoni* for Arkansas, and, thus, it is included in Gordon (1980). However, Hubricht (1985) lists *H. jacksoni* as a synonym of *Hawaiia alachuana,* and *H. jacksoni* is not included in our list.

11. Specimens of *Punctum* that are clearly *P. minutissimum* or *P. vitreum* occur in the state. Others are not readily separable into either form, bearing the lamellar sculpture of *P. vitreum* but lacking the distinction between major and minor riblets.

12. European slugs of the families Limacidae, Milacidae, and Arionidae are presumed introductions. Gordon (1980) listed *Lehmannia poirieri,* presumably having taken it from Hubricht (1972). This is a synonym for *L. valentiana,* which is given in our list.

13. *Glyphyalinia indentata* appears to be an aggregate of species that differ anatomically but with little or no shell differences (Hubricht, 1985). The group has not been dissected adequately for separation of the species.

14. The specific identities of Arkansas *Mesomphix (Omphalina)* forms *cupreus, cupreus ozarkensis* and *capnodes* are uncertain. Hubricht (1985) regards *Mesomphix cupreus ozarkensis* as *M. capnodes.* Pilsbry (1946) records *M. cupreus* for the state with *M. cupreus ozarkensis* as a possible subspecies. All mature specimens of Arkansas *Mesomphix (Omphalina)* collected by the authors are *M. friabilis.* Nevertheless, we have provisionally retained *M. cupreus* as an Arkansas species. We therefore list *M. cupreus, M. friabilis, M. capnodes* and *Mesomphix (Mesomphix) globosus* for the state.

15. Pilsbry's separation of Arkansas *Paravitrea* (sections *Paravitrea* and *Parmavitrea*) into *significans* and *simpsoni* does not seem to accommodate well all Arkansas specimens. Forms similar to the *Paravitrea capsella* species aggregate (Hubricht, 1985) occur in the state, some of which have a resemblance in their shells to *P. lacteodens.* The localized occurrence of *Paravitrea petrophila* in Arkansas and the southern Appalachian Mountains (Hubricht, 1985) is anomalous. This presents the only instance of a species endemic to both of these regions. Revision of Arkansas *Paravitrea* spp. requires preserved material from throughout the southeastern United States.

16. *Ventridens demissus* is separable into two forms: *V. demissus sensu stricto,* recorded from Jefferson County by Hubricht (1985), and forms from further west that are referred to as *Ventridens brittsi.* In the western Ouachita Mountains, *V. brittsi* is represented by a large form reminiscent of *Ventridens acerra.* Although strikingly different from shells further east within the Ouachita Mountains, this is regarded as a large form of the (sub)species *brittsi* (Pilsbry, 1946).

17. Details of the *Neohelix albolabris/Neohelix alleni* complex are discussed by Emberton (1988).

18. Records of *Xolotrema obstricta* (listed by Gordon, 1980) are referable to *Xolotrema occidentalis.* Our collections of *X. occidentalis* display a range of shell form from that of the acutely keeled *X. obstricta* to bluntly keeled forms similar to *Xolotrema fosteri.* Although all of these bear the characteristic coarse shell ribbing and reduced apertural dentition of *X. occidentalis* (Pilsbry, 1940), none correspond exactly in form to that of the types in the Academy of Natural Sciences, Philadelphia. Material from near the type locality of *X. occidentalis* (i.e., Independence County, Arkansas) has been dissected by Emberton (1988) and closely resembles *X. fosteri* in genital anatomy. However, this material also does not agree in form with the type material, being similar in shell shape to *X. fosteri.* We have never seen live adults of the acutely keeled forms and they have never been dissected. Emberton points out the need to investigate this problem, but preserved material is not available. Because of the general similarity in shell shape of *X. obstricta* of the southern Appalachians to some of the acutely keeled *X. occidentalis,* the Arkansas record of Gordon (1980) is regarded as an error of identification.

19. *Stenotrema caddoense* is referred to as a subspecies of *Stenotrema unciferum* by Pilsbry (1940) and Hubricht (1985). However, Emberton (1995) lists *Stenotrema caddoense* as a separate species.

20. *Polygyra triodontoides* is recorded for Arkansas by Pilsbry (1940) but not by Hubricht (1985). The form is not included in Emberton (1995), but because of the close similarity of its shell to that of *Linisa texasiana,* presumably, it belongs to the genus *Linisa.*

21. Examination of Hubricht's *Millerelix lithica* from Arkansas and our specimens of *Millerelix dorfeuilliana* from throughout the state does not lead to the conviction that *M. lithica* is a species distinct from *M. dorfeuilliana.* It possibly represents one extreme of a cline. *Millerelix dorfeuilliana* is very variable (Branson, 1970) in shape and development of the parietal tooth and in size and placement of the upper lip tooth (separating characters of *M. lithica*). Additionally, a species of *Millerelix* distinct from all other Polygyrini of the United States has recently been found in the state by the authors.

22. *Millerelix deltoidea* and *M. simpsoni* are regarded as forms of *M. jacksoni* by Pilsbry (1940) but as separate species by Hubricht (1985) and Emberton (1995).

23. *Inflectarius edentatus* is regarded as a form of *Inflectarius inflectus* by Pilsbry (1940) and Hubricht (1985) but as a separate species by Emberton (1995).

The above considerations were used in compiling our list of terrestrial mollusks of Arkansas. Gordon (1980) lists 107 terrestrial species of Gastropoda for Arkansas, Hubricht (1985) lists 96 and we list 144. Of the 144 species given in Table 1, nine have been recorded only from river drift or as subfossil and may not, therefore, be living in the state. Of the remaining 135, 109 were found living in the state by the authors, four species were seen as dead (but recent) shells and 22 were not seen in the state by the authors (Table 1). Of the 135 species noted above, five represent alien slug introductions and three are apparent adventive populations. Thus, the Arkansas autochthonous fauna, as presently understood, consists of 127 species.

The increase of 48 species compared with the most recent summary (Hubricht, 1985) includes 22 additional native species, the remainder being forms listed in earlier literature or apparently introduced aliens not included by Hubricht. Of these, three represent species in the process of description by the authors; one, *Neohelix albolabris bogani*, was not described until 1988 (Emberton, 1988). Most of the remaining 18 species not recorded previously for the state are minute forms that have been overlooked. Of these, *Vertigo gouldi*, and *V. meramecensis* represent records that are significant extensions of the ranges presented by Hubricht (1985).

Using Hubricht's (1985) distributions of land mollusks for the eastern United States (i.e., east of the Rocky Mountains), the Arkansas forms appear to group into five broad categories, viz:

1. A group of species of generally widespread occurrence in the eastern United States of which some forms are absent from, or of restricted distribution in the Atlantic and Gulf Coastal plains (approximately 40%).
2. Species of general distribution in the northern tier of states extending south into the Appalachian, Cumberland and Ozark Mountains (approximately 12%).
3. A group of species that are widespread in the Gulf Coastal Plain and absent or of restricted distribution further north (approximately 11%).
4. Species that show a mid-western distribution, i.e., those that occur in a broad band from Louisiana and Texas (east of the Edwards Plateau) to the western Great Lakes (approximately 14%).
5. Species endemic to the Ozark/Ouachita Mountains (approximately 18%).
6. The remaining 5% are species for which the geographical distribution is unclear.

Thus, the diversity of Arkansas land Mollusks is apparently due to the conjunction of these biogeographical zones within the state.

Regarding the endemic land mollusks, the mountains of western Arkansas and adjacent regions of Oklahoma and Missouri have long been known to be an area of considerable endemicism (Pilsbry and Ferriss, 1906; Pilsbry, 1940; Gordon, 1980). Endemic species include forms that occur in both the Ouachita and Ozark Mountains, forms that are restricted to either the Ouachita or Ozark Mountains, and a group of five species endemic to Arkansas. The area around the White and Buffalo Rivers contains the largest concentration of Arkansas endemics.

The survival of these localized forms and, particularly, that of species apparently restricted to the state, is of some concern. Of the five state endemics, *Inflectarius magazinensis* is afforded federal protection on the basis of a single extended site on Mount Magazine. Similarly, one site for *Patera clenchi* is protected within Mount Nebo State Park, Yell County. However, all populations of *Millerelix peregrina* and *Xolotrema occidentalis* known to the authors are outside of protected sites such as state or national parks. *Paravitrea aulacogyra* is still known from only a single specimen. (Pilsbry, 1946).

ACKNOWLEDGMENTS.—We are grateful to the staff of the Arkansas Game and Fish Commission, the Ozark Saint Francis and Ouachita National Forests, the Nature Conservancy and private land owners who have given permission to collect snails on their lands. In particular, we wish to acknowledge the assistance of Gregg Butts of the Arkansas State Parks, Douglas Zollner of the Arkansas Field Office of the Nature Conservancy, Cindy Osborne of the Arkansas Natural Heritage Commission, George Oviatt of the Buffalo National River, John Slapcinsky of the Field Museum of Natural History, Chicago, and Gary Rosenberg of the Academy of Natural Sciences, Philadelphia.

Table 1. Arkansas terrestrial Mollusca. [1]Not seen alive by the authors, [2]apparently alien introduction, [3]Arkansas records appear to represent adventive populations, [4]Arkansas records are from river drift, [5]subfossil.

Family Helicinidae
- *Helicina orbiculata* (Say, 1818)

Family Pomatiopsidae
- *Pomatiopsis lapidaria* (Say, 1817)

Family Carychiidae
- *Carychium mexicanum* Pilsbry, 1891
- *C. exile* I. Lea, 1842

Family Cochlicopidae
- *Cochlicopa morseana* (Doherty, 1878)

Family Valloniidae
- *Vallonia perspectiva* Sterki, 1892
- *V. parvula* Sterki, 1893

Family Pupillidae
- *Pupoides albilabris* (C.B. Adams, 1821)
- *Gastrocopta armifera* (Say, 1821)
- *G. contracta* (Say, 1822)
- *G. holzingeri* (Sterki, 1889)
- *G. pentodon* (Say, 1821)

G. tappaniana (C.B. Adams, 1842)
G. corticaria (Say, 1816)
G. procera (Gould, 1840)
G. sterkiana (Pilsbry, 1912)
G. rupicola (Say, 1821)[1,3]
Gastrocopta sp. nov. [?] cf. *mcclungi* Hanna and Johnston, 1913
G. cristata (Pilsbry and Vanatta, 1900)[4]
G. pellucida (Pfeiffer, 1841)[4]
Vertigo milium (Gould, 1840)
V. oscariana Sterki, 1890
V. rugulosa Sterki, 1890
V. oralis Sterki, 1898
V. teskeyae Hubricht, 1961
V. ovata (Say, 1822)
V. tridentata Wolf, 1870
V. gouldi (A. Binney, 1843)
V. meramecensis Van Devender, 1979
Columella simplex (Gould, 1841)

Family Strobilopsidae
Strobilops labyrinthicus (Say, 1817)
S. texasianus Pilsbry and Ferriss, 1906
S. aeneus Pilsbry, 1926

Family Succineidae
Oxyloma retusum (I. Lea, 1834)
O. salleanum (Pfeiffer, 1849)
Succinea ovalis Say, 1817
S. indiana Pilsbry, 1905
S. grosvenori I. Lea, 1857
S. unicolor Tryon, 1866
S. forsheyi I. Lea, 1864
S. luteola Gould, 1848
Catinella avara (Say, 1824)
C. oklahomarum (Webb, 1953)
C. wandae (Webb, 1953)[1]

Family Philomycidae
Philomycus carolinianus (Bosc, 1802)
Megapallifera mutabilis (Hubricht, 1951)
M. ragsdalei (Webb, 1950)[1]
Pallifera marmorea Pilsbry, 1948

Family Discidae
Anguispira alternata (Say, 1816)
A. strongylodes (Pfeiffer, 1854)
A. kochi (Pfeiffer, 1821)[1]
Discus cronkhitei (Newcomb, 1865)[1,5]
D. patulus (Deshayes, 1830)

Family Helicodiscidae
Helicodiscus tridens (Morrison, 1935)[4]
H. eigenmanni Pilsbry, 1900[4]
H. notius Hubricht, 1962
H. parallelus (Say, 1817)
H. roundyi (Morrison, 1935)[4]
H. singleyanus (Pilsbry, 1890)
H. inermis H.B. Baker, 1929[4]
H. nummus (Vanatta, 1899)[4]

Family Punctidae
Punctum minutissimum (I. Lea, 1841)
P. vitreum H.B. Baker, 1930

Family Limacidae
Limax flavus (Linnaeus, 1758)[2]
L. maximus Linnaeus, 1758[2]
Deroceras laeve (Müller, 1774)[2]
Lehmannia valentiana (Férussac, 1821)[1,2]

Family Milacidae
Milax gagates (Draparnaud, 1801)[1,2]

Family Arionidae
Arion subfuscus (Draparnaud, 1805)[2]

Family Zonitidae
Nesovitrea electrina (Gould, 1841)[1]
Glyphyalinia wheatleyi (Bland, 1833)
G. roemeri (Pilsbry and Ferriss, 1906)[4]
G. indentata (Say, 1823)
G. solida (H.B. Baker, 1930)
G. luticola Hubricht, 1966
G. umbilicata (Cockerell, 1893)
G. lewisiana (Clapp, 1908)[1]
Mesomphix globosus (MacMillan, 1940)
M. friabilis (W.B. Binney, 1857)
M. cupreus (Rafinesque, 1831)[1]
M. capnodes (W.G. Binney, 1857)
Paravitrea multidentata (A. Binney, 1840)
P. significans (Bland, 1866)
P. simpsoni (Pilsbry, 1899)
P. petrophila (Bland, 1883)
P. aulacogyra (Pilsbry and Ferriss, 1906)[1]
Paravitrea sp. nov. [?] cf. *lacteodens*
Hawaiia minuscula (A. Binney, 1840)
H. alachuana (Dall, 1885)
Ventridens demissus (A. Binney, 1843)
V. brittsi (Pilsbry, 1892)
V. ligera (Say, 1821)
Zonitoides arboreus (Say, 1816)
Striatura meridionalis (Pilsbry and Ferriss, 1906)

Family Helicarionidae
Euconulus chersinus trochulus (Say, 1821)
E. dentatus (Sterki, 1893)
Guppya sterkii (Dall, 1888)

Family Haplotrematidae
Haplotrema concavum (Say, 1821)

Family Bulimulidae
Rabdotus dealbatus (Say, 1821)

Family Polygyridae
Webbhelix multilineata (Say, 1821)
Neohelix divesta (Gould, 1848)
N. albolabris bogani Emberton, 1988
N. alleni (Sampson, 1883)

Xolotrema fosteri (F.C. Baker, 1932)
X. caroliniensis (I. Lea, 1834)[1]
X. occidentalis (Pilsbry and Ferriss, 1907)
X. denotata (Férussac, 1821)
Triodopsis cragini Call, 1886
T. vultosa (Gould, 1848)[1]
T. hopetonensis (Shuttleworth, 1852)
T. neglecta (Pilsbry, 1899)
Allogona profunda (Say, 1821)[1]
Euchemotrema fraternum imperforatum (Pilsbry, 1900)
E. leai aliciae (Pilsbry, 1893)
Stenotrema pilsbryi (Ferriss, 1900)
S. labrosum (Bland, 1862)
S. stenotrema (Pfeiffer, 1842)
S. unciferum (Pilsbry, 1900)
S. caddoense (Archer, 1935)[1]
S. blandianum (Pilsbry, 1903)[1]
Linisa texasiana (Moricand, 1833)
L. triodontoides (Bland, 1861)[1]
Praticolella berlandieriana (Moricand, 1833)[1,3]
Millerelix dorfeuilliana (I. Lea, 1838)
M. lithica (Hubricht, 1961)
M. jacksoni (Bland, 1866)
M. deltoidea (Simpson, 1899)[1]
M. simpsoni (Pilsbry and Ferriss, 1907)[1]
M. peregrina (Rehder, 1932)
Millerelix. sp. nov.
Daedalochila leporina (Gould, 1848)
Patera binneyana (Pilsbry, 1899)
P. clenchi (Rehder, 1932)
P. indianorum (Pilsbry, 1899)
P. kiowaensis (Simpson, 1888)
P. roemeri (Pfeiffer, 1848)[1,3]
P. perigrapta (Pilsbry, 1894)
Inflectarius magazinensis (Pilsbry and Ferriss, 1907)
I. inflectus (Say, 1821)
I. edentatus (Sampson, 1889)
Mesodon elevatus (Say, 1821)
M. zaletus (A. Binney, 1837)
M. clausus (Say, 1821)
M. thyroidus (Say, 1816)

Literature Cited

American Fisheries Society. 1988. Common and Scientific Names of Aquatic Invertebrates from the United States and Canada: Mollusks. American Fisheries Society Special Publication 16, 277 pp. Bethesda, MD.

Burch, J. B. and **A. S. Van Devender.** 1980. Identification of eastern North American land snails: the Prosobranchia, Opisthobranchia and Pulmonata (Actophila). Walkeriana 1:33-80. Museum of Zoology and Department of Ecology and Evolutionary Biology, University of Michigan, Ann Arbor.

Branson, B. A. 1970. Shell variability in *Polygyra dorfeuilliana.* Nautilus 83:120-133.

Emberton, K. C. 1988. The genitalic, allozymic, and conchological evolution of the eastern North American Triodopsinae (Gastropoda: Pulmonata: Polygyridae). Malacologia 28:159-273.

Emberton, K. C. 1991. The genitalic, allozymic, and conchological evolution of the tribe Mesodontini (Pulmonata: Stylommatophora: Polygyridae). Malacologia 33:71-178.

Emberton, K. C. 1995. What shells do not tell: 145 million years of evolution in North America's polygyrid land snails, with a revision and conservation priorities. Malacologia 37:69-110.

Gordon, M. E. 1980. Recent mollusks of Arkansas with annotations to systematics and zoogeography. Proc. Arkansas Acad. Sci. 34:58-62.

Hanna, G. D. and **E. C. Johnston.** 1913. A Pleistocene molluscan fauna from Phillips County, Kansas. Kansas Univ. Sci. Bull. 7:111-121.

Hubricht, L. 1962. Drift land shells from the Red River, Arkansas. Sterkiana 8:33-34.

Hubricht, L. 1967. Some land snail records from Oklahoma and Arkansas. Nautilus 81:65-67.

Hubricht, L. 1972. The land snails of Arkansas. Sterkiana 46:15-17.

Hubricht, L. 1985. The Distributions of the Native Land Mollusks of the Eastern United States. Fieldiana, NS (Zoology), No. 24. Field Museum of Natural History, Chicago. 191 pp.

Pilsbry, H. A. 1940-1948. The Land Mollusca of North America (North of Mexico). Vol. 1, Part 2 (1940), 994+ix pp.; Vol. 2, Part 1 (1946), 520 pp.; Vol. 2, Part 2 (1948), 1113 pp. The Academy of Natural Sciences of Philadelphia.

Pilsbry, H. A. and **J. H. Ferriss.** 1906. Mollusca of the Ozarkian fauna. Proc. Acad. Nat. Sci. Philadelphia. December, pp. 529-567.

Clinostomum marginatum (Yellow Grub) Metacercaria in Black Bass from the Caddo River in West Arkansas

James J. Daly Jr., and H. Michael Matthews
Department of Biology
Henderson State University
Arkadelphia, AR 71999-0001

Randal J. Keller
Department of Occupational Safety and Health
P.O. Box 9
Murray State University
Murray, KY 42071

James J. Daly*
Southeast Arkansas College
1900 Hazel St.
Pine Bluff, AR 71603

*Corresonding Author

Abstract

Seventy-two bass (Micropterus-spp.), mostly smallmouth, were collected from three areas of the Caddo River in west Arkansas and examined for the presence of *Clinostomum marginatum* metacercariae. Prevalence, mean abundance, and abundance for all fish were 68%, and 4.2 ±6.5, and 30, respectively. Fish from the upstream area near the headwaters were more heavily infested than those from further downstream. A gill/total body larval ratio of seven, was found for bass from another Arkansas stream, was examined as a predictor for total *Clinostomum* populations in stream bass. Using the formula gill parasites X seven divided by N (72), a value of 3.3 was found for mean abundance. The gill/total body ratio for Caddo bass was found to be higher at 8.9 but the ratio of 7 gives a reasonable estimate of *Clinostomum* burdens in a stream bass population. Use of this ratio allows bass hosts to be examined without necropsy thus preserving the host population in its environment.

Introduction

Clinostomum marginatum a trematode that has a fish-eating bird as its definitive host, a snail and fish as intermediate hosts. The metacercarial form has been found in 56 freshwater species of fish (Hoffman, 1967). In Arkansas, it is found in noticeable numbers in the tissues of stream bass, particularly the smallmouth (*Micropterus dolomieui*). Smallmouth taken from Crooked Creek, a stream in north central Arkansas, have been shown to have high *mean* abundances, (average number of parasites/fish) of 23 (Daly et al., 1987) and 32.7 (Daly et al., 1991); and record-setting abundances (number of parasites/individual fish) of 2500, 852, and 627 (Daly et al., 1991). These larvae can be up to 0.5 cm in length and are called yellow grub because of their pigmentation. Such large and obvious parasites can make the fish flesh unpalatable and may even effect the hosts' survival.

Also found in Crooked Creek bass was an arithmetic relationship between the easily visible grubs found in the gill area (gills, mucosal and membrane surface of the gill cavity, and the mouth) and the total body grub burden (including the number in the gills). Regression analysis showed a high correlation between the two variables with a ratio of approximately seven (Daly et al., 1992). Use of such a ratio to estimate total number of yellow grubs in bass without tissue invasion would allow large populations of hosts to be surveyed with little mortality thus preserving a valuable sport fishing resource.

Methods

During the summer of 1996, 72 smallmouth and largemouth bass (*Micropterus salmoides*) were collected from three areas on the Caddo River (Montgomery and Pike counties) by rod and reel using live or artificial bait. The areas were (1) upstream at Black Springs near the headwaters of the Caddo, (2) further south from Caddo Gap to confluence of the South Fork of the Caddo, and (3) and from the confluence of the South Fork of the Caddo to the Caddo at Glenwood. Fish were placed on ice and later necropsied with all of the soft tissue of the host being examined. Some host measurement data were lost. Records were available, regarding standard length and girth (cm), for only 49 fish from Caddo Gap to Glenwood. These fish measured (mean ±standard deviation) 24.7 ±4.1 cm in length and 7.5 ±1.7 cm in girth. A ratio of 3.3±0.3 was found between length and girth. Regression analysis showed an r-value of 0.92 with a P of <0.001. Of 72 hosts, 66 were smallmouth and six were largemouth bass. Parasite ecology terminology follows that of Bush et al. (1997).

Results and Discussion

Bass from the sampled areas showed much lower mean abundance and abundance of yellow grub than fish taken from Crooked Creek (Table 1). Prevalence, abundance, and mean abundance were higher upstream at Black Springs than downstream between Caddo Gap and Glenwood. Data from Crooked Creek showed much higher yellow grub loads downstream than upstream (Daly, J. J., unpubl. data). It is difficult to speculate the reasons for these differences in yellow grub populations for either a comparison between Crooked Creek and the Caddo or within the Caddo itself. The population densities of the different hosts regulate parasite populations and such data for birds, snails, and host fish are not available for these streams. However, it has been noted from casual examination and years of collecting that smallmouth populations are much greater in Crooked Creek than in the Caddo (crowding effect?). Another factor may be human activity. The downstream area in this study is the most utilized portion of the Caddo for recreation and agriculture as well as having the highest human population density. This may reduce the presence of the definitive host, most usually the great blue heron. Also, pollution contaminants may play a role. House et al. (1993) have shown that total coliforms and other bacterial markers for fecal contamination are highest in the downstream area of the present study. On Crooked Creek the upstream areas have the most chemical and physical contamination (Drope, 1997). These are also the sections with the fewest yellow grubs in bass (Daly, J. J., unpubl. data). Reasons for differences in grub loads in fish are presently speculative and, unfortunately, there are no other similar stream profile studies available for comparison. A peculiar aspect of helminth parasite populations can be seen in Table 1. The standard deviations of the mean abundances are as large or larger than the means themselves. This usually indicates a negative binomial distribution because of the uneven dispersion of the parasites within the host population, i.e. with some hosts having large numbers of a parasite while many hosts have none at all (Esch et al., 1990). For example, prevalence (Table 1) for hosts from all sites show 32% of bass to have no detectable yellow grubs.

Table 1. Prevalence, maximum abundance and mean abundance of *Clinostomum marginatum* larvae in *Micropterus* species from the Caddo River and the total body/gill ratio as a predictor of total number of grubs in a population of bass hosts. Values in parentheses are the predicted average/fish derived from the number in the gills times the ratio of seven found for Crooked Creek bass.

Collection sites	N	Prevalence	Maximum Abundance	Number in Gills	Number in Body	Total Number	Ratio Total/Gills	Avg/Fish Mean± SD	(Avg/Fish)
All sites	72	68%	---	34	270	304	8.9	4.2± 6.5	(3.3)
Black Springs	20	85%	30	23	175	198	8.6	9.9± 9.0	(8.0)
Caddo Gap to South Fork	29	59%	7	6	36	42	7.0	1.5± 1.7	(1.5)
South Fork to Glenwood	23	65%	19	5	59	64	12.8	2.8± 4.1	(1.6)

Ratios of total body grubs to gill grubs can be found in Table 1. For all hosts this value was 8.9. Using the ratio of seven from Crooked Creek bass and multiplying this times the number of grubs found in the gill and mouth area divided by the number of hosts gives an estimate of mean abundances which can be compared to data derived from actual observations of total yellow grub loads. It can be seen from the last two columns of Table 1 that the number of gill parasites can be a reasonable predictor of yellow grub populations in bass populations. Regression analysis of host length and total number of grubs (df = 47) showed a weak ($r = 0.32$) but significant correlation ($P < 0.05$). Table 2 shows the regression analyses for total body vs gill numbers. One regression had a low correlation and no significance at the 0.5 level, which may be explained by the variation found in individual fish in this body/gill relationship. We have found the highest individual host variance primarily in populations of bass with low prevalences and mean abundance. Overall, the body/gill ratio works well as a predictor when host sample size is large enough to balance the individual variability and contains enough gill grubs to make an estimation. For practical purposes we have used this technique in culling fish for obtaining yellow grubs for physiology and biochemical studies thus returning to the stream bass that appear to be poorly infected.

Table 2. Regression analysis of the total of body yellow grubs per body to the number of grubs in the gill area.

Collecting sites	Degrees of Freedom	α	slope	r	*P*
All sites	70	0.02	0.11	0.71	<0.001
Black Springs	18	0.04	0.11	0.69	<0.001
Caddo Gap to South Fork	27	0.09	0.08	0.26	>0.05*
South Fork to Glenwood	21	0.01	0.08	0.61	<0.001

*Not significant

Use of the ratio of seven can be of economic value as well as for understanding yellow grub ecology. Daly and Singleton (1994) have shown a similar relationship in channel catfish (*Ictalurus punctatus*) taken from a farm pond in northwest Arkansas. Fifty-four catfish of similar size showed a prevalence of 100%, a mean abundance of 31.7, and a ratio of 5.56 ($r = 0.61$, $P<0.001$).

Yellow grub is becoming a problem for catfish farmers in Oklahoma, Arkansas, and Mississippi (Mitchell, pers. comm.). Fish infested with too many grubs are rejected at the processing plant. The presence of a wild fish population serving as a yellow grub reservoir for farm fish complicates the control of this parasite. Further studies on Ozark and Ouachita streams would be useful in determining the extent of this problem. The application of the ratio technique for population estimations described herein would allow large numbers of bass to be examined and returned to the environment as well as decreasing necropsy times.

ACKNOWLEDGMENTS.—This study was supported in part by the Arkansas Game and Fish Commission which also supplied the necessary collecting permits.

Literature Cited

Bush, A. O., K. D. Lafferty, J. F. Lotz, and **A. W. Shostak.** 1997. Parasitology meets ecology on its own terms: Margolis et al. Revisited. J. Parasitology. 83:575-583.

Daly, J. J., H. H. Conaway, H. M. Matthews, and **T. Hostetler.** 1987. *Clinostomum marginatum* metacercariae: Incidence in smallmouth bass from a North Arkansas stream and in vitro oxygen consumption studies. Proc. Arkansas Acad. Sci. 41:29-32.

Daly, J. J., B. DeYoung, and **T. Hostetler.** 1991. Hyperinfestation of smallmouth (*Micropterus dolomieui*) by the trematode *Clinostomum marginatum* in stream black bass. Proc. Arkansas Acad. Sci. 45:123.

Daly, J. J., B. DeYoung, and **T. Hostetler.** 1992. Estimating populations of yellow grub (*Clinostomum marginatum*) in stream black bass. Proc. Soc. Exptl. Biol. Med. 206:454.

Daly, J. J., and **J. Singleton.** 1994. Estimating populations of yellow grub (*Clinostomum marginatum*) in channel catfish (*Ictalurus punctatus*). Proc. Soc. Exptl. Biol. Med. 206:454.

Drope, P. B. 1997. A physicochemical survey of Crooked Creek in north Arkansas. Unpublished Masters thesis, University of Arkansas for Medical Sciences, 78 pp.

Esch, G. W., W. A. Shostak, D. J. Margoliese, and **T. M. Goater.** 1990. Patterns and processes in helminth communities: An overview. *In* Parasite communities: Patterns and processes, G. W. Esch, A. O. Bush, and J. M. Aho (eds.). Chapman and Hall, New York, NY, p. 1-19.

House, K. L., J. D. Bragg, C. Kuyper, T. K. Thomas, and **R. Tumlison.** 1993. Environmental analysis of the Caddo River and its tributaries: Comparison of water quality during 1992 with 1974-1975.

Hoffman, G. L. 1967. Parasites of North American Freshwater Fishes. University of California Press, Berkley and Los Angeles, CA.

Mitchell, D. (personal communication). USDA National Aquaculture Research Center, Stuttgart, AR.

Survey of Medium and Large Mammals in an Urban Park (Murray Park), Little Rock, Pulaski County, Arkansas

Josie H. Dickins, David W. Clark, Steffany C. White and Gary A. Heidt*

Department of Biology
University of Arkansas at Little Rock
Little Rock, AR 72204

*Corresponding author

Abstract

Because of increased environmental awareness by city planning commissions, there are more urban parks and greenbelt areas. These areas often result in increased human and wildlife contacts, thus resulting in the need for management plans regarding urban wildlife. From September 1998 to March 1999, we conducted mammal surveys of the urban greenspace Murray Park, Little Rock, Pulaski County, Arkansas. Surveys were conducted using five methods : direct observations; spot lighting; live trapping; animal sign; and scent posts. Species recorded included, opossum (*Didelphis virginiana*), nine-banded armadillo (*Dasypus novemcinctus*), fox squirrel (*Sciurus niger*), gray squirrel (*Sciurus carolinensis*), beaver (*Castor canadensis*), woodchuck (*Marmota monax*), muskrat (*Ondatra zibethicus*), eastern cottontail rabbit (*Sylvilagus floridanus*), swamp rabbit (*Sylvilagus aquaticus*), coyote (*Canis latrans*), red fox (*Vulpes vulpes*), raccoon (*Procyon lotor*), mink (*Mustela vison*), river otter (*Lontra canadensis*), bobcat (*Lynx rufus*), skunk sp., white-tailed deer (*Odocoileus virginianus*) and domestic dog (*Canis familiaris*) and cat (*Felis sylvestris*). These species represent 19 of the 23 mammals expected in surrounding natural areas. Management plans for urban wildlife need to include all mammals that potentially occur in the area.

Introduction

Today's wildlife management is rooted in the desire to protect and conserve wildlife for its innate beauty, as well as for outdoor recreation, both consumptive and non-consumptive (Gilbert, 1989; Scalet et al., 1996). Cities have become a new and important type of ecosystem, one that, if managed properly, could enable people to re-establish their contact with living things and natural beauty, perpetuate the idea of land ethic in which humans are not the conqueror but a citizen of the community, and become important reservoirs for wildlife (Gill and Bonnett, 1973).

Urban parks and refuges provide wildlife-related educational opportunities for urban youth, most of whom are deprived of such experiences. The idea that regular contact with nature has positive effects on health and mental well being and also reduces stress and anxiety is becoming a more popular philosophy (VanDruff et al., 1995). When people are aware of wildlife near their homes their recognition of more distant conservation issues, such as the retention of wilderness and wetland areas, can increase (Gill and Bonnett, 1973). Also disparity in perception of natural areas by laymen and biologists can be reduced. This is important, however, because it is laymen who control many decisions which effect natural areas (Gill and Bonnett, 1973).

Greenbelts that connect greenspaces into a habitat network are important design considerations for urban environments. Greenbelts retain and create corridors of linear wildlife habitat along creeks, ridge tops, and utility rights of way (Gill and Bonnett, 1973). Connecting areas of different habitat types and those in various successional stages and then linking them to the rural periphery increases the diversity of wildlife in an urban area.

People-animal conflicts are a negative aspect of urban wildlife (Adams, 1994). Property damage resulting from animals nesting in homes and attics can cause structural and safety risks. The possibility of car collisions either with an animal or another object when swerving to miss an animal also increases as wildlife become prevalent in an area. Animals such as pocket gophers, deer, skunks and other mammals have been known to destroy vegetation and consume crops. Of greatest concern are the potential public health problems since over 200 animal diseases can be transmitted to humans (VanDruff et al., 1995), including rabies, tularemia, Lyme disease, and histoplasmosis. With proper management of wildlife and the education of the public these risks decrease.

Traditional methods and techniques to conduct inventory surveys of mammals in nonurban areas are well codified, but urban studies are still in their infancy. Most urban studies apply a mixture of traditional techniques (VanDruff et al., 1994) in an effort to be complete and efficient. The purposes of our study were to document the presence of medium and large mammals in an urban park setting and to determine the similarity of these animals with those expected to be found in a similar non-urban area.

Materials and Methods

Study Area.--The study area is comprised of an U.S.

Army Corps of Engineers Lock and Dam installation (Murray Lock and Dam), a 67.2 ha recreational park (Murray Park), a 153 ha golf course (Rebsamen Golf course) and the adjacent wooded bluff (Fig. 1) in greater Little Rock, Arkansas (T2N, R12W, S19). The northern boundary is the Arkansas River whereas the less rigid southern boundary is a residential area. Within the park area, an active railroad transverses southeast to northwest, and a powerline right-of-way transverses east and west on the western edge of the park.

Several different habitat types can be found in this area. The wooded area consists of mixed hardwood/pine species on a steep slope; the major tree species include oaks (*Quercus* sp.), sweetgum (*Liquidambar styraciflua*), hickory (*Carya* sp.), loblolly pine (*Pinus taeda*), and other overstory species. Within the wooded area are several rocky outcroppings, a few of which incorporate small streams. Parts of the river-bank are composed of sandy substrate with tall grasses. Maintained grass areas can be found throughout the golf course, park, and dam complex.

Survey Methods.--Between September 1998 and March 1999, observations were conducted to sample for the presence of medium and large mammals within the study area. Medium sized mammals included those species between approximately 0.4 - 15 kg (gray squirrel - coyote). Large mammal species were those larger than 15 kg. Direct methods of survey were performed by daytime observations (over 60 days at various times), nighttime spotlighting (10 trips), and live trapping (26 trap nights) using Tomahawk live traps (model 104.5, Tomahawk Live Trap Co.,

Table 1. Annotated Checklist of Medium to Large Mammals in Murray Park, Little Rock, Pulaski County, Arkansas

Species		Documentation Method[1]	Estimated Abundance[2]
Order Didelphimorphia			
Didelphis viriginiana	Virginia Opossum	SS, T, DO	A
Order Xenarthra			
Dasypus novemcinctus	Nine-banded Armadillo	DO	R
Order Rodentia			
Sciurus niger	Fox Squirrel	DO,SN	C
Sciurus carolinensis	Gray Squirrel	SS, DO, SN	A
Marmota monax	Woodchuck	DO	C
Castor canadensis	Beaver	SN	C
Ondatra zibethicus	Muskrat	DO	C
Order Lagomorpha			
Sylvilagus aquaticus	Swamp Rabbit	DO, H	R
Sylvilagus floridanus	Eastern Cottontail	DO, SN, H	C
Order Carnivora			
Canis latrans	Coyote	SS, S, DO	C
Vulpes vulpes	Red Fox	SS, DO	C
Lynx rufus	Bobcat	SS	C
Procyon lotor	Raccoon	SS, T, DO, S	A
Mustela vison	Mink	T, DO	R
Lontra canadensis	River Otter	SS, DO, SN	C
Skunk sp.		SS	R
Canis familiaris	Domestic Dog	SS, DO	C
Felis sylvestris	Domestic Cat	SS, DO	C
Order Artiodactyla			
Odocoileus virginianus	White-tailed Deer	SS, T, S, DO, SN	A

[1]SS- Scent Station, T- Tracks, S-Scat, DO- Direct Observation, SN- Sign, H- Hair
[2]A- Abundant - Noted in 75 - 100% of observational periods
C- Common - Noted in 25-75% of observational periods
R- Rare - Noted < 25% of observational periods

Tomahawk, WI). Indirect methods of survey included the use of scent stations and animal signs.

To further document mammal presence and relative activity, eight scent stations were established in the park. The scent stations were operable for 134 station nights. Due to ground moisture, high humidity and frequent rains, scent stations were constructed by clearing a 1 m diameter area, and laying a base of plastic sheet (4 mil. poly sheeting). Powdered lime ($CaCO_3$) was poured to a depth of 2 centimeters. A cotton ball was soaked with an attractant composed of liquid synthetic fermented egg (Sterling Fur and Tool Co., Sterling, Ohio) and was then attached to a 30 cm. nail driven into the ground in the center of the station (Roughton, 1982). When not in use, the attractant was removed and another sheet of plastic was used to cover the station. This kept the station dry and immediately operable when needed. Powdered lime was used in lieu of sand because lime produces tracks of higher definition.

Additional animal signs used to identify presence of species included, but were not limited to, scats, deer rubs, slides, tracks left in mud, and various runways. Tumlison's (1983) hair key was used to determine the species of prey found in the scats.

Results and Discussion

Using a species checklist (Sealander and Heidt, 1990), we determined that 23 species of medium to large mammals could be present in central Arkansas. We found that 19 (82.6%) of those species were present in our study (Table 1). There was not a positive identification on two sets of skunk tracks located at two scent stations. Both the striped skunk (*Mephitis mephitis*) and the eastern spotted skunk (*Spilogale putorius*) have been recorded from the Little Rock area. Species that were not documented from our study area include the nutria (*Myocastor coypus*), black bear (*Ursus americannus*), gray fox (*Urocyon cinereoargenteus*), and possibly one species of skunk. These species have access to Murray Park (they have been documented in other Little Rock areas), and thus may be found in the park in the future.

The opossum, raccoon, and white-tailed deer were considered to be abundant because they were documented in more than 75% of the potential observational periods and by most of the survey techniques. The gray squirrel, which was mostly documented by direct observations, was also considered to be abundant. All of these species are considered abundant in central Arkansas.

The only other comprehensive mammalian survey in central Arkansas (of which we are aware) was a study of Camp Joseph T. Robinson Military Installation (10,000 ha) in North Little Rock (Penor et al., 1996). With the exception of the mink and river otter, they reported all of the mammals found in this study. They did, however, report the presence of the gray fox.

The relative high percentage (86%) of medium and large mammals found in Murray Park adjacent to downtown Little Rock was expected. Corridors play a major role in linking urban Little Rock greenspace to Pulaski County non-urban areas. The Arkansas River is a natural corridor for wildlife. The railroad tracks which parallel the Arkansas River within Little Rock connect downtown Little Rock with Pinnacle Mountain State Park and non-urban areas westward of Little Rock. The river, the railroad, and current greenspace corridors within Little Rock link these areas and facilitate movement of mammals. The railroad tracks that run through the greenbelt are used in the City Planning Map (Fig. 2) as a buffer to ensure that this corridor remains undeveloped for the continued use of wildlife.

Literature Cited

Adams, Lowell W. 1994. Urban wildlife habitats, a landscape perspective. Univ. of Minnesota Press, Minneapolis. 187 pp.

Gilbert, O. L. 1989. The ecology of urban habitats. Chapman and Hall, London. 369 pp.

Gill, D., and **P. Bonnett.** 1973. Nature in the urban landscape. York Press, Baltimore. 209 pp.

Penor, J. R., A. A. Karlin, and **G. A. Heidt.** 1996. Biodiversity of Camp Joseph T. Robinson Military Installation North Little Rock, Arkansas 1994-1995. Proc. Arkansas Acad. Sci., 50:91-95

Roughton, R. D. 1982. A synthetic alternative to fermented egg as a canid attractant. J. Wildl. Manage. 46:230-234.

Scalet, C. G., L. D. Flake, D. W. Willis. 1996. Introduction to wildlife and fisheries, an integrated approach. W. H. Freeman, New York. 512 pp.

Sealander, J., and **G. A. Heidt.** 1990. Arkansas mammals: their natural history, classification and distribution. Univ. Arkansas Press. Fayetteville, Arkansas. 308 pp.

Tumlison, R. 1983. An annotated key to the dorsal guard hairs of Arkansas game mammals and furbearers. The Southwest. Nat. 28:315-323.

VanDruff, L. W., E. G. Bolen, and **G. J. San Julian.** 1994. Management of urban wildlife. *In* T.A. Bookhout (ed.) Research and management techniques for wildlife and habitats, pp. 507-530. The Wildlife Society, Bethesda, Maryland.

VanDruff, L. W., D. L. Leedy, and **F. W. Stearns.** 1995. Urban wildlife and human well being. *In* H. Sukopp, M. Numata, and A. Huber (eds.) Urban ecology as the basis of urban planning, pp. 203-211. SPB Academic Pub., The Hague, The Netherlands.

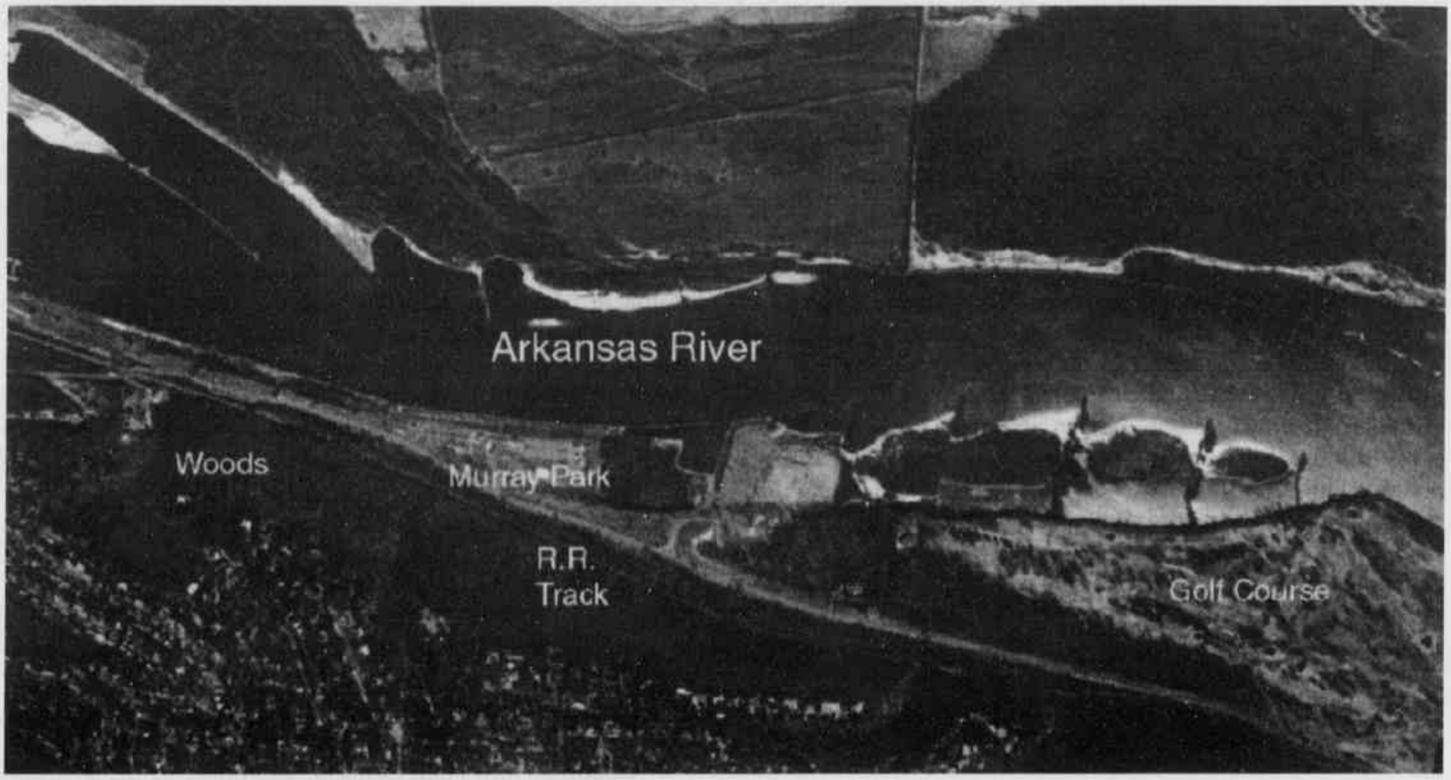


Fig. 1. Aerial photograph of the northwestern portion of Little Rock including Arkansas River, Murray Park, Murray Lock and Dam, Rebsamen Golf Course, railroad corridor, and the north facing woods that were included in this study.

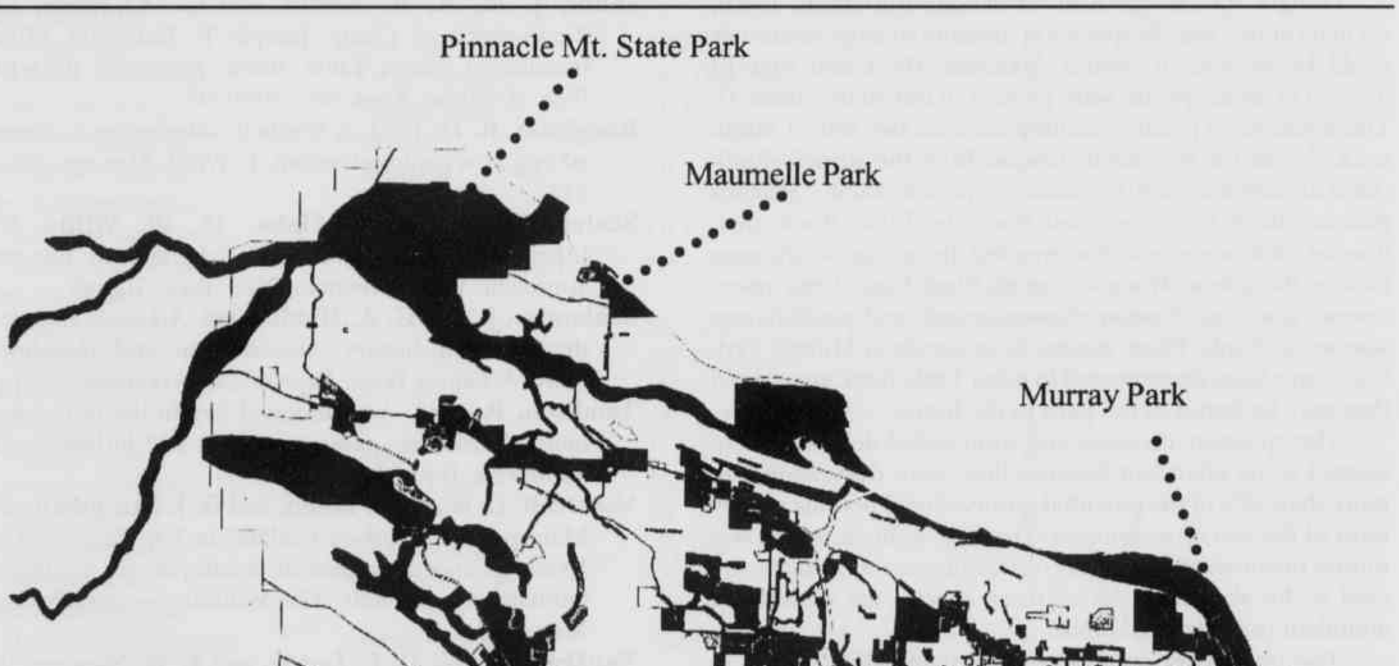


Fig. 2. GIS generated city planning map showing greenspace (black tone) for northwestern Little Rock including Murray Park, Rebsamen Golf Course, and railroad/greenspace corridor leading westward from Murray Park to Pinnacle Mountain State Park and into the rural portions of the county.

Effects of Predation on Two Species of Stream-Dwelling Crayfish (*Orconectes marchandi* and *Cambarus hubbsi*) in Pool and Riffle Macrohabitats

Heidi Dukat and Daniel D. Magoulick
Department of Biology
University of Central Arkansas
Conway, Arkansas 72035
501-450-5930
501-450-5914 FAX

Abstract

Community structure may be governed by many abiotic and biotic factors. Of the biotic factors, predation is often considered to be critical in structuring freshwater stream communities. In the Warm Fork of the Spring River, the crayfish *Cambarus hubbsi* is found mainly in riffles, whereas the crayfish *Orconectes marchandi* is found in high numbers in pools. We hypothesized that predation, mainly by fish, is a factor causing this segregation. Higher predation rates for *C. hubbsi* than *O. marchandi* in the pools and higher predation rates for *O. marchandi* than *C. hubbsi* in the riffles were expected. A transplant tethering experiment was conducted to test whether predation influences habitat selection. Substrate, water depth, and current velocity were also taken into account. In the pool, predation rates were significantly greater on *C. hubbsi* than *O. marchandi*, but predation rates were equal for the two species in the riffle. This suggests that predation is a factor in keeping *C. hubbsi* out of pools, but is not a factor in keeping *O. marchandi* out of riffles. Also, significantly greater predation rates overall were found in the pool than in the riffle. The pool was significantly deeper and had lower substrate diversity than the riffle. These findings suggest that predators are important in affecting crayfish habitat use; differential predation rates occur between habitats and greater predation rates occur in pools than in riffles.

Introduction

Many species in streams show habitat segregation, including crayfish (Bovbjerg, 1970; Jordan et al., 1996), fish (Stauffer et al., 1996), and algae (Traaen and Lindstrom, 1983). There are many hypotheses that attempt to explain why segregation among crayfish occurs. Most hypotheses explaining habitat segregation deal with either biotic factors (competition, behavior or predation), or abiotic factors (habitat complexity, current velocity, substrate). Resource partitioning may lead to species segregation based on Gause's principle (Schoener, 1974). For two species that share both a food source and common predators, it would be expected that competition occurs mainly for habitat locations which provide the highest foraging rates and the lowest predation rates (Schoener, 1974; Bowyer et al., 1998), assuming there are no significant behavioral differences.

Based on studies on rocky intertidal zones, Menge and Sutherland (1976) suggested that predation is a more important factor for determining community structure at high trophic levels with high trophic complexity, whereas competition is more important at low trophic levels with low trophic complexity. Some studies have shown a positive relationship between the presence of predators and crayfish segregation. For example, Jordan et al. (1996) found that the presence of predatory fish influenced habitat selection in populations of the crayfish *Procambarus alleni.* If segregation is due primarily to unequal predatory effects among the competing species, then there is some morphological and/or behavioral adaptation in one species which allows it to outcompete the other (Vance, 1978). For example, certain crayfish morphologies are better suited to high current velocities, indicating that morphology is an important factor in determining the most suitable macrohabitat for a crayfish (Maude and Williams, 1983). Also, some crayfish species use aggression to compete for food and shelter, which may lead to competitive exclusion (Bovbjerg, 1970).

Reice (1983) found that substrate was more influential than predation for habitat choice in macroinvertebrates. In general, more complex habitats would provide more possible niches than less complex habitats (Downes et al., 1998). Jordan et al. (1996) found that crayfish survival rates increased with increased habitat complexity due to lower predation rates in complex habitats. Bovbjerg (1970) found evidence suggesting that abiotic conditions including current velocity, substratum, and oxygen content were factors that contributed to the segregation of two similar crayfish species. These studies suggest that abiotic conditions may be the most important factor in habitat selection and, therefore, should be included when exploring the cause of segregation.

Quantitative sampling on the Warm Fork of the Spring River found that relative abundances of *Orconectes marchandi*

(Mammoth Spring crayfish) were positively correlated with margins, backwaters, and pools, whereas relative abundances of *Cambarus hubbsi* (Hubbs' crayfish) were positively correlated with riffles and runs (D.D. Magoulick and C.A. Flinders, unpublished data). The presence of predatory fish as well as many other benthivorous animals suggests that predation is a possible explanation for the segregation of these two species. We hypothesized that *C. hubbsi* would be preyed upon more heavily in pools, and *O. marchandi* would be preyed upon more heavily in riffles. A transplant experiment was designed to determine whether predation has an effect on the segregation of these two species.

Materials and Methods

The study site was on the Warm Fork of the Spring River north of the city of Thayer, Oregon County, Missouri, along County Road 19-326. The Warm Fork is in the eastern Ozark Mountains; land use is dominated by agriculture with riparian corridors ranging from several hundred meters to 3 meters or less. The study site had an average width of 12.2 m and an average depth of 30 cm. The riffle used in the study was a heterogeneous mixture of pebble, cobble and boulder. The study pool, directly downstream of the riffle, was composed mainly of sand.

Crayfish were collected from the study site on 28 July 1998 using a kicknet technique (Mather and Stein, 1993). Individuals from the same size class were selected for the experiment with preference given to those with both chela intact. Crayfish were pierced in the abdomen just above the telson, tied with 0.5m of clear monofilament line, and anchored to a rock. The tether did not seem to impede the mobility of the crayfish, and it is unlikely that the crayfish would be able to remove itself from the tether (Heck and Wilson, 1987; Power, 1987; McIvor and Odum, 1988). Transects were placed 1.5m or more apart running perpendicular to the flow of the stream. Crayfish were placed 1.5m or more apart along the transects and at least 0.5m from shore. The species placed at each location was chosen randomly. The carapace length, sex, and species of each crayfish were recorded. Estimations of the percent abundance of each substrate size class and depth from the area of crayfish mobility were recorded at each crayfish location. Ten random readings of the mean and substrate current velocities were taken in each macrohabitat. Twenty crayfish of each species were placed in the riffle between the hours of 09:30 and 14:30, and 19 crayfish of each species were placed in the pool between the hours of 16:00 and 20:00 on 29 July 1998. The next two consecutive mornings the sites were searched to determine which crayfish survived.

To calculate substrate diversity at each crayfish location, the following formula (Simpson's Index) was used. Substrate Diversity = $1- [\Sigma n_1(n_1-1)/N(N-1)]$ where n_1 = the percent of a substrate at a crayfish location, and N = the total percent of substrates at each crayfish location. Chi square tests were used to determine if significantly more ($P<0.05$) of either species were consumed in each macrohabitat (Figs. 1 and 2). T-tests were used to determine if the mean values for depth, current velocity, and substrate diversity were significantly different between the riffle and pool macrohabitat (Table 1). SYSTAT version 6.0 was used for all statistical tests (SPSS, Inc., Chicago, IL).

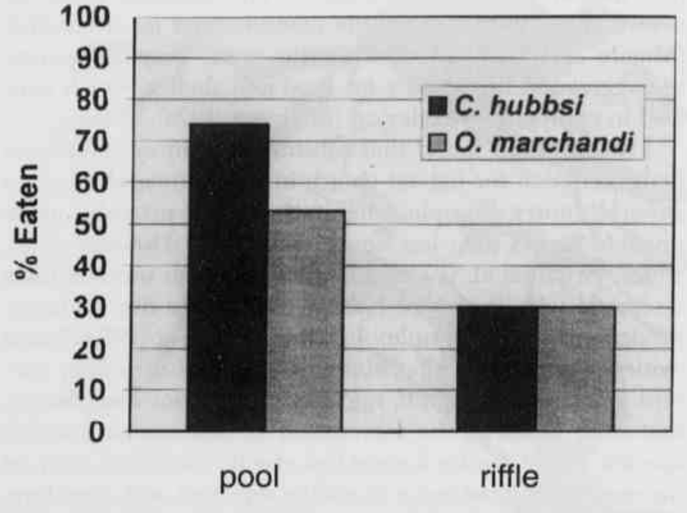


Fig. 1. Percent of *Orconectes marchandi* and *Cambarus hubbsi* consumed on day one in pool and riffle macrohabitats. The experiment began with 20 of each species in the riffle, and 19 of each species in the pool.

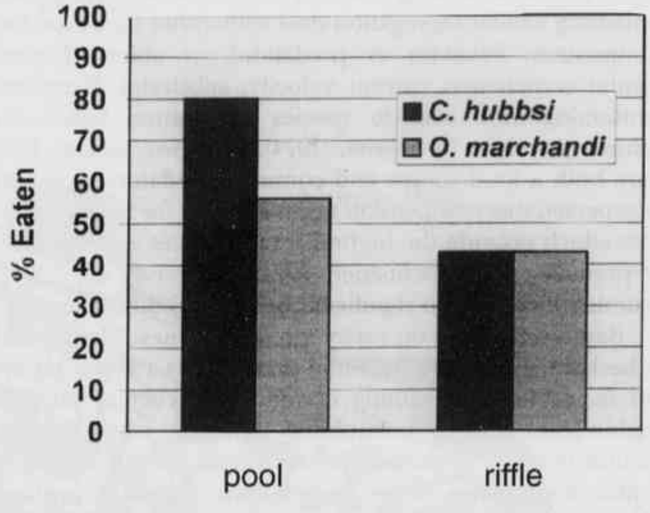


Fig. 2. Percent of *Orconectes marchandi* and *Cambarus hubbsi* consumed on day two in pool and riffle macrohabitats. The experiment began with 20 of each species in the riffle, and 19 of each species in the pool.

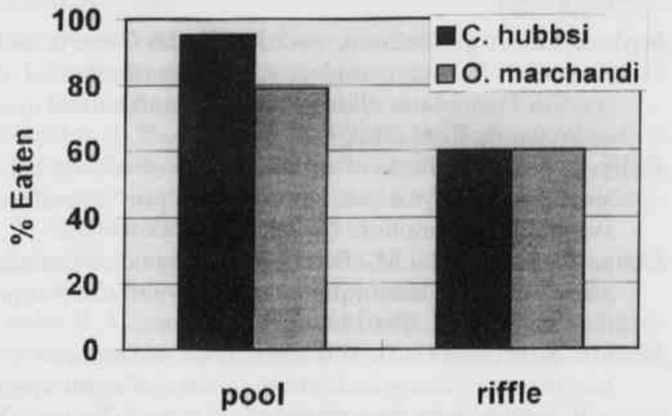


Fig. 3. Total cumulative percents of *Orconectes marchandi* and *Cambarus hubbsi* consumed after two days. The original numbers were 20 of each species in the riffle and 19 of each species in the pool.

Results

Equal numbers of both species were preyed upon in the riffle (Figs. 1, 2 and 3). On the first day and for the total of both days, significantly more *C. hubbsi* were preyed upon in pools than *O. marchandi* (Chi square day one $P=0.028$, total $P<0.001$; Figs. 1 and 3). On the second day more *C. hubbsi* were preyed upon in the pool than *O. marchandi*, but the sample size was too small to be significant (Chi square $P>0.05$; Fig. 2). Also, there were significantly more crayfish preyed upon overall in the pools than in the riffles (Chi square $P<0.05$; Figs. 1, 2 and 3).

Pools were significantly deeper, with significantly lower current velocity than riffles (Table 1). There was no significant difference in the mean substrate diversity index between pool and riffle (Table 1). However, one crayfish location in the riffle was encompassed entirely of boulder, giving it a substrate diversity of 1.0. If this location is treated as an outside value, then the riffle has significantly greater substrate diversity than the pool ($P<0.05$).

Table 1. Mean (SE) of depth (cm), current velocity (cm-s^{-1}), and substrate diversity in pool and riffle macrohabitats. T-test probability values are for each habitat variable.

Habitat variable	Pool	Riffle	*P*
Depth <0.001	47.00 (1.20)		25.20 (1.74)
Velocity <0.001	14.30 (1.09)		54.00 (6.20)
Substrate diversity	0.54(.02)0.59(.02)		0.096

Discussion

Many studies have examined how predators affect different crayfish species in freshwater communities (Stein and Magnuson, 1976; McNeely et al., 1990; Soderback, 1992; Mather and Stein, 1993; Soderback, 1994; Garvey et al., 1994). It has been shown that predators affect certain habits of their prey, for example changing feeding patterns, habitat use or patch use (Lima and Dill, 1989). In the current study, one of the observed predatory affects was that significantly higher numbers were consumed in the pool than in the riffle (Figs. 1, 2 and 3). Higher predation rates in streams have often been associated with pools because of higher concentrations of predators. Power (1987) noted that "pools are habitats for larger species and size classes of stream fish", leading to the suggestion that predators were responsible for the often-noted bigger fish – deeper water pattern found in streams. Furthermore, Todd and Rabeni (1989) found that adult smallmouth bass, which are major predators of crayfish and occur in the Warm Fork of the Spring River, seemed to prefer deeper water (> 0.66m) and current velocities of less than 20cm/s (i.e. pools). Other studies have shown a tendency for piscivorous fish to exclude prey items from deeper water (Mittelbach and Chesson, 1987; Power, 1987; Schlosser, 1988). Therefore, our results confirm that predators can have a strong influence on prey in deeper, more slowly flowing water.

Along with shallower water, there was also a trend toward lower predation rates in areas of higher substrate diversity (Table 1). Prey available for predation decreases with increasing habitat complexity because of an increase in refugia (Kelly, 1996; Mather and Stein, 1993). There can be competition if one refuge is sought by two organisms (Mittelbach and Chesson, 1987). This has been shown between species of crayfish (Soderback, 1994; Garvey et al., 1994) and between a benthic fish and a crayfish (McNeely et al., 1990). This type of exploitative competition is described by Power (1987) when the dominant species was changed by the addition of shelter. Since the lower substrate diversities were associated with the pool at the study site, the lack of habitat complexity could be a contributing factor to the higher predation rates observed in the pool.

Our hypothesis was partially supported because significantly more *C. hubbsi* than *O. marchandi* were preyed upon in pool than in riffle habitat (Figs. 1 and 3). However, the prediction of more *O. marchandi* than *C. hubbsi* being eaten in riffles was not supported. These data suggest that factors other than predation may be responsible for the selection of habitats by *O. marchandi*. Conversely, *Cambarus hubbsi* appears to be strongly affected by predation in pools and may avoid pool habitat due to predation risk. Additional experiments will be required to address the underlying causes of the observed differences in predation rates, such as different behaviors or morphologies.

The selection of riffles and runs by *C. hubbsi* may be related to their strategy of burrowing, as large substrates in riffles and runs provide large pore space for use as shelter and also facilitates movement. Pflieger (1996) found that both *O. marchandi* and *C. hubbsi* prefer boulder, cobble and gravel over sandy areas. However, in a more quantitative study, *O. marchandi* densities were correlated with pebble and sand substrates, whereas *C. hubbsi* densities were correlated with boulder and cobble substrates (D.D. Magoulick and C.A. Flinders, unpublished data). Maude and Williams (1983) found that morphologies of burrowing species help crayfish to burrow, as well as maintain positions in strong currents, so *C. hubbsi* may be better suited to riffles and runs than *O. marchandi* based on morphology. However, Pflieger (1996) noted that *C. hubbsi* was a poor swimmer, which would make them less suited to macrohabitats with fast flow. Further work will be necessary to determine whether crayfish morphology or predation risk is more important in affecting crayfish habitat selection.

Observations from the current study suggest that predation could participate in the segregation of *C. hubbsi* into riffles, but has less influence on the distribution of *O. marchandi*. However, both species were preyed upon more heavily in pools and in areas of lower substrate diversity. In accordance with findings from related studies, this may be due to greater concentrations of predators in pools and a smaller number of refugia in areas of lower substrate diversity.

ACKNOWLEDGMENTS.—We thank Camille Flinders for generous help with the experiment and her support during the study. This study was supported in part by a grant from the Missouri Department of Conservation to D.D. Magoulick.

Literature Cited

Bovbjerg, R. V. 1970. Ecological isolation and competitive exclusion in two crayfish. Ecology 51:225-236.

Bowyer, R. T., J. G. Kie, and **V. Van Ballenberghe.** 1998. Habitat selection by neonatal black-tailed deer: climate, forage, or risk of predation? J. Mammal. 79:415-425.

Downes, B. J., P. S. Lake, E. S. G. Schreiber, and **A. Glaister.** 1998. Habitat structure and regulation of local species diversity in a stony, upland stream. Ecol. Monog. 68:237-257.

Garvey, J. E., R. A. Stein, and **H. M. Thomas.** 1994. Assessing how fish predation and interspecific prey competition influence a crayfish assemblage. Ecology 75:532-547.

Heck, K. L., and **K. A. Wilson.** 1987. Predation rates on decapod crustaceans in latitudinally separated seagrass communities: a study of spatial and temporal variation using tethering techniques. J. Exp. Mar. Biol. and Ecol. 107:87-100.

Jordan, F., C. J. DeSeon, and **A. C. McCreary.** 1996. Predation, habitat complexity, and distribution of the crayfish *Procambarus alleni* within a wetland habitat mosaic. Wetlands 16:452-457.

Kelly, J. F. 1996. Effects of substrate on prey use by belted kingfishers (*Cerlye alcyon*): a test of the prey abundance-availability assumption. Can. J. Zool. 74:693-697.

Lima, S. L., and **L. M. Dill.** 1989. Behavioral decisions made under the risk of predation: a review and prospectus. Can. J. Zool. 68:619-640.

Maude, S. H., and **D. D. Williams.** 1983. Behavior of crayfish in water currents: hydrodynamics of eight species with reference to their distribution patterns in southern Ontario. Can. J. Fish. Aqua. Sci. 40:68-77.

Mather, M. E., and **R. A. Stein.** 1993. Direct and indirect effects of fish predation on the replacement of a native crayfish by an invading congener. Can. J. Fish. Aqua. Sci. 50:1279-1288.

McIvor, C. C., and **W. E. Odum.** 1988. Food, predation risk and microhabitat selection in a marsh fish assemblage. Ecology 69:1341-1351.

McNeely, D. L., B. N. Futrell, and **A. Sih.** 1990. An experimental study on the effects of crayfish in the predator-prey interaction between bass and sculpin. Oecologia. 85:69-73.

Menge, B. A., and **J. P. Sutherland.** 1976. Species diversity gradients: synthesis of the roles of predation, competition and temporal heterogeneity. Amer. Natur. 110:351-369.

Mittelbach, G. G., and **P. L. Chesson.** 1987. Predation risk: indirect effects on fish populations. Pp. 351-330 *In* W. C. Kerfoot and A. Sih (eds). Direct and indirect impacts on aquatic communities. Univ. Press New England, Hanover.

Pfleiger, W. L. 1996. The crayfishes of Missouri. Missouri Department of Conservation, Jefferson City, Missouri.

Power, M. E. 1987. Predator avoidance by grazing fishes in temperate and tropical streams: importance of steam depth and prey size. Pp. 333-351 *In* W. C. Kerfoot and A. Sih (eds). Direct and indirect impacts on aquatic communities. Univ. Press New England, Hanover.

Reice, S. R. 1983. Predation and substratum factors in lotic community structure. Pp. 325-345 *In* T. D. Fontaine III and S. M. Bartell (eds). Dynamics of lotic ecosystems. Ann Arbor Science, Michigan.

Schlosser, I. J. 1988. Predation risk and habitat selection by two size classes of a stream cyprinid: experimental test of a hypothesis. Oikos. 52: 36-40.

Schoener, T. W. 1974. Resource partitioning in ecological communities. Science 185:27-38.

Soderback, B. 1992. Predator avoidance and vulnerability of two co-occurring crayfish species, *Astacus astacus* (L.) and *Pacifastacus leniusculus* (Dana). Ann. Zool. Fennici.

29:253-259.

Soderback, B. 1994. Interactions among juveniles of two freshwater crayfish species and a predatory fish. Oecologia. 100:229-235.

Stauffer, J. R., Jr., J. M. Boltz, K. A. Kellogg, and **E. S. van Snik.** 1996. Microhabitat partitioning in a diverse assemblage of darters in the Allegheny River system. Environ. Biol. Fish. 46:37-44.

Stein, R. A. and **J. J. Magnuson.** 1976. Behavioral response of crayfish to a fish predator. Ecology. 57:751-761.

Todd, B. L., and **C. F. Rabeni.** 1989. Movement and habitat use by stream-dwelling smallmouthbass. Trans. Amer. Fish. Soc. 118:229-242.

Traaen, T. S. and **A. E. Lindstrom.** 1983. Influence of current velocity on periphyton distribution *In* R. G. Wetzel (ed). Periphyton of freshwater ecosystems. W. Junk Publishers, the Hague.

Vance, R. R. 1978. Predation and resource partitioning in one predator-two prey model communities. Amer. Natur. 112:797-813.

Arkansas Gray Fox Fur Price-Harvest Model Revisited

Peta Elsken-Lacy, Amy M. Wilson, Gary A. Heidt* and James H. Peck

Department of Biology
University of Arkansas at Little Rock
Little Rock, AR 72204

*Corresponding author

Abstract

Peck and Heidt (1985) proposed a linear model that demonstrated that for gray fox (*Urocyon cinereoargenteus*) in Arkansas; total fur harvests from 1966-1982 were highly correlated with mean pelt values. Single variable models using linear regression analysis of current season pelt values (CSPV) and previous season pelt values (PSPV) were designed to predict total fur harvests. These models demonstrated high correlations ($r = 0.93$ and 0.89, respectively). In the past 15 years, markets for fur have undergone many perturbations within Arkansas and overseas resulting in great changes in mean pelt prices. In an attempt to evaluate the continued performance of the original model, pelt price and harvest data from 1983-1997 were tested for correlation using linear regression analysis. The results from these tests showed a high correlation. Two specific years (1983 and 1987) were affected strongly by political and economic events. A new model encompassing trapping seasons from 1966 through 1997 was evaluated. Mean pelt value remains a significant predictor of total gray fox fur harvest in Arkansas.

Introduction

Over the past 20 years, the Arkansas furbearer market has undergone drastic changes. In 1979, the mean pelt value of gray fox (*Urocyon cinereoargenteus*) was $42.50, which was the highest value ever recorded. This value marked the beginning of the downward trend in pelt values of gray fox. Although prices decreased steadily through 1987, they remained high enough (averaging $27.83) to maintain trapper interest and to sustain the fur harvest industry for gray fox. In 1988, the mean pelt value dropped to $11.87 and continued to decline for the next ten years, resulting in average pelt value of $7.39 (Table 1).

When Peck and Heidt (1985) examined the correlation between mean pelt value (MPV) and total fur harvest (TH), fur trappers were very active in harvesting pelts of gray fox, and there was a growing interest in management of the gray fox population through harvest limits (Heidt et al., 1984). Currently, very few trappers are harvesting gray fox, and concern for the impact of trapping on populations of gray fox has greatly declined (P. Dozhier, pers. comm.). Furbearer management now has turned its focus to concerns of possible gray fox overpopulation, as the removal of individuals from the population via trapping is no longer a significant influence. It is widely recognized that the least expensive and simplest means of furbearer management is through fur industry. Given the current fox fur market depression, gray fox management through fur industry is minimal.

Year	Total Harvest	Mean Pelt Value ($)	Exchange Rate (DM / US)	Harvest Value (U.S. Dollars)	Harvest Value (Deutchmarks)
1966	1,761	1.45	N/A	2,553	N/A
1967	561	1.50	N/A	842	N/A
1968	1,079	2.59	N/A	2,795	N/A
1969	756	2.47	N/A	1,867	N/A
1970	644	2.35	N/A	1,513	N/A
1971	734	3.21	3.33	2,356	N/A
1972	1,751	6.89	3.20	12,064	7,845
1973	2,502	13.77	2.58	34,453	38,606
1974	4,235	10.34	2.51	43,790	88,888
1975	3,765	20.78	2.59	78,237	109,913
1976	8,333	30.02	2.41	250,157	202,633
1977	5,547	28.99	2.24	160,808	360,209
1978	6,648	42.14	1.90	280,346	532,279
1979	8,777	42.50	1.77	373,023	660,250
1980	7,109	34.74	1.92	246,967	474,176
1981	4,945	26.37	2.22	130,400	289,487
1982	5,301	26.85	2.55	142,332	362,946
1983	3,434	30.64	2.68	105,218	281,984
1984	4,459	23.24	3.00	103,627	310,881
1985	4,193	15.99	2.60	67,046	174,320
1986	5,911	26.63	2.02	157,410	317,968
1987	7,865	23.86	1.68	187,659	315,267
1988	3,566	11.87	1.75	42,328	74,075
1989	1,096	5.20	1.83	5,699	10,430
1990	502	2.96	1.49	1,486	2,214
1992	1,119	7.75	1.59	8,672	13,789
1993	849	6.40	1.70	5,434	9,237
1994	1,526	8.15	1.54	12,437	19,153
1995	1,881	8.71	1.42	16,384	23,265
1996	2,130	9.86	1.51	21,002	31,713
1997	1,131	7.35	1.73	8,313	14,381

Table 1. Harvest data for the years 1966 - 1997 for gray fox in Arkansas. Exchange rates were obtained from the website http:blacktusk.commerce.ubc.ca/cgibin/fxdata. Total harvest values in Deutchmarks and dollars were computed using total harvest, mean pelt value and exchange rate value.

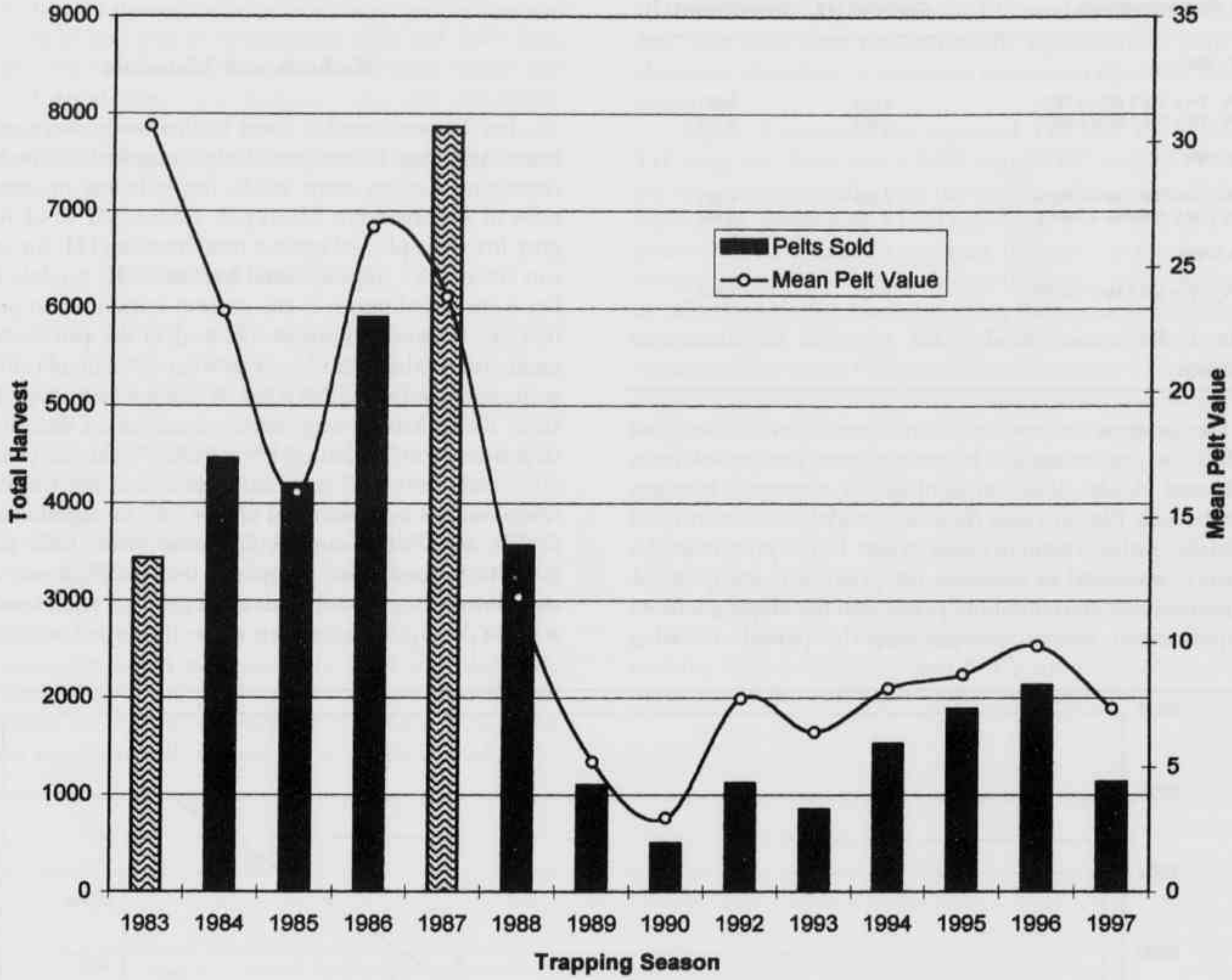


Fig. 1. Size of total gray fox fur harvest (TH) and mean pelt value (MPV) for Arkansas from 1983 - 1997.

The relationship between total harvest and mean values of gray fox pelts over the past fifteen years was influenced by political events that affected the market. The main purchaser of gray fox pelts from Arkansas is Germany (P. Dozhier, pers. comm.). In 1990, Germany's economy suffered greatly as a result of the re-unification between East and West Germany, which in turn led to the gray fox market being negatively affected. The German economy was further damaged by the breakdown of the Soviet Union in 1991, and, since that time, Germany has not recovered sufficiently from its recession to regain its position as a main purchaser of pelts from gray fox. This is evident in the fluctuating exchange rate of the Deutchmark in the years between 1986 through 1997 (Table 1). Fur-harvest analysts speculate that the gray fox market will improve only when the Chinese and Russian economies improve (P. Dozhier, pers. comm.). In the past few years, some Baltic countries such as Estonia and Lithuania have taken an interest in purchasing gray fox pelts from Arkansas. However, these countries have just recently been introduced to the free market economy, and until their economies improve, their purchases will probably not spark the gray fox market into recovery (P. Dozhier, pers. comm.).

It is significant to note that some concerns discussed by Peck and Heidt (1985) are no longer important due to global economic changes, such as 1) rapidly growing demands for furbearers and their products, 2) enactment of endangered species regulations and treaties, 3) a major decline in upland wildlife hunting opportunities, and 4) growing anti-hunting and anti-trapping sentiment. These factors are of minimal importance given the intense influence of economic factors on total pelt harvest and mean pelt values.

Regression Models	Correlation Coefficient (r)	Coefficient of Determination (r^2)
1966 - 1982		
CSPV - TH = 174.3 MPV + 707.4	0.933	0.871
PSPV - TH = 181.5 MPV + 963.9	0.893	0.797
1984 - 1997		
CSPV - TH = 230.1 MPV - 207.9	0.959	0.921
PSPV - TH = 240.9 MPV - 465.5	0.761	0.584
1966 - 1997		
CSPV - TH = 185.8 MPV + 422.9	0.935	0.876

Table 2. Regression models for gray fox fur harvest in Arkansas

We propose to revisit the pertinence of the original models for predicting the harvest of gray fox in Arkansas (Peck and Heidt, 1985), in light of the economic changes over the past fifteen years. The first model was constructed primarily during a time of rising prices. In the present study, we were interested in assessing the predictive ability of the original models during falling prices and developing a more comprehensive model incorporating the periods of rising and subsequently falling prices.

Methods and Materials

Fur harvest records used in this study were compiled from Arkansas Game and Fish Commission records. No correction factors were made for inflation or out-of-state sales of Arkansas fur. Mean pelt values (MPV) of Arkansas gray fox were plotted against total harvest (TH) for each season since 1983 (Fig. 1). Total harvest (TH) models for gray fox were based upon: 1) the current season mean pelt value (CSPV) to predict current TH and 2) the previous season mean pelt value (PSPV) to predict the current TH. Data were analyzed using SAS for Windows 6.11 (SAS Institute Inc., 1991). Linear regression equations to determine the dependence of TH on CSPV and PSPV for the years 1984-1997 and 1966-1997 were calculated, and the t-values from these models were tested at an $\alpha = 0.05$ for significance. The CSPV and PSPV models from the years 1966-1982 and 1984-1997 then were compared using a Students' t-test to determine if they were equivalent in slope and elevation ($\beta_1 = \beta_2$; $\alpha_1 = \alpha_2$). Final models were developed without use of

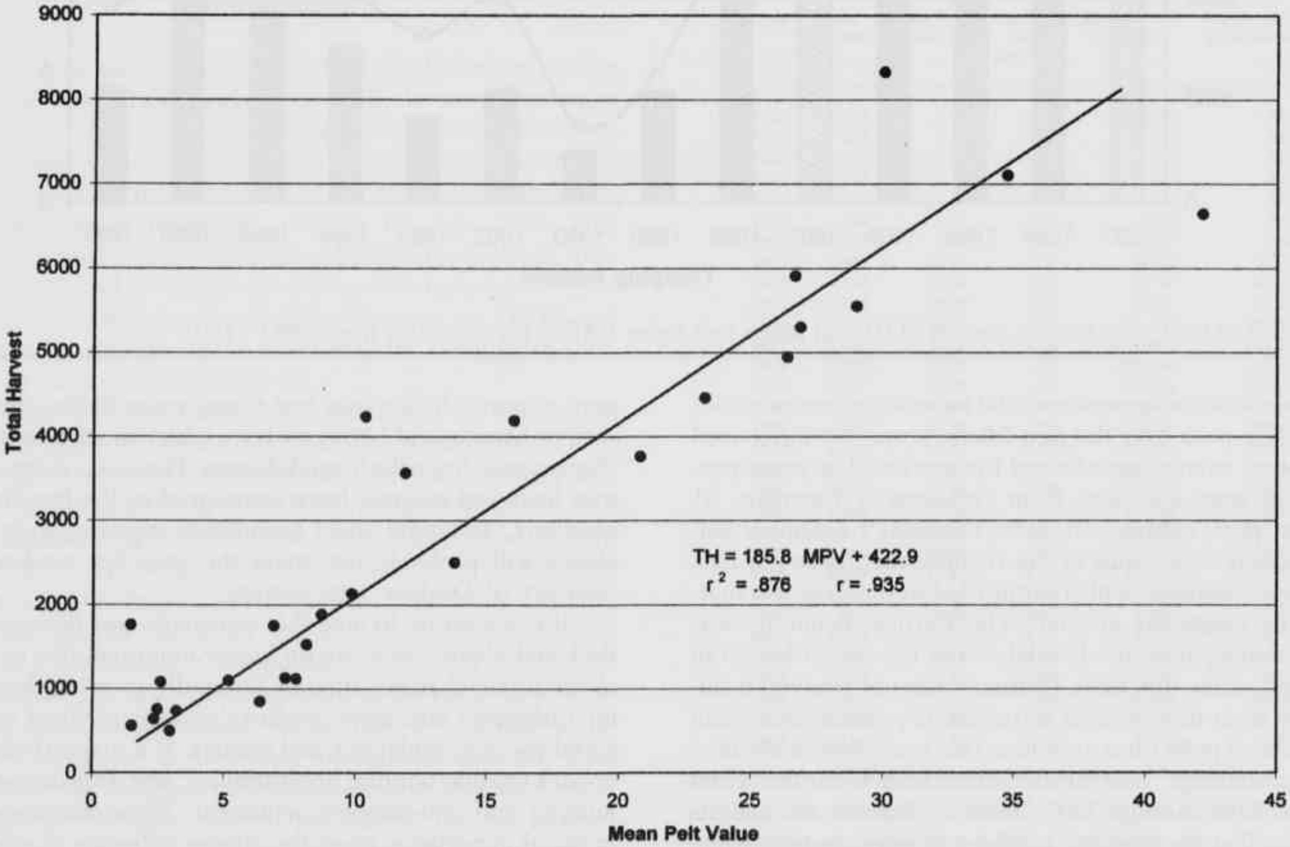


Fig. 2. A scatter diagram, regression line and equation relating mean pelt value (MPV) in dollars to total harvest (TH) for 1966-1997 Arkansas gray fox fur harvests.

data from years 1983, 1987 and 1991. Certain political and economic factors strongly affected the mean pelt values and total harvest of gray fox in Arkansas in 1983 and 1987. Data from 1991 were omitted from analysis because mean pelt value and total gray fox harvest was not available. November values were used in all calculations as they correspond with the beginning of the gray fox trapping season in Arkansas.

Results and Discussion

Table 2 lists the regression equations for gray fox harvests using the CSPV and PSPV models from the data from 1984-1997, Peck and Heidt's (1985) CSPV model using data from 1966-1982, and the final CSPV model using the 1966-1997 data. The 1966-1982 CSPV model and the 1984-1997 CSPV model were found to be statistically equivalent in slope and elevation (Zar, 1999). The linear regression analysis on the 1984-1997 TH and CSPV produced a correlation coefficient of 0.959 ($\alpha = 0.05$, $P < .0001$). The coefficient of determination ($r^2 = 0.921$) indicated that a significant degree of variability in the TH was accounted for by the CSPV. A second linear regression analysis on the 1984-1997 data analyzed TH and PSPV and produced a correlation coefficient of 0.761 with an r^2 value of 0.584 ($P < .0164$). A common regression equation with a correlation coefficient of 0.935 and r^2 value of 0.876 ($P < .0001$), was calculated for the 1966-1997 data (Fig. 2). The PSPV models from 1966-1982 and 1984-1997 were not statistically equivalent in slope and elevation; therefore, a common regression equation was not produced.

Figure 3 contrasts the reported TH with the predicted TH using the 1984-1997 CSPV and PSPV models. This figure shows graphically that the two models are sufficiently capable of predicting TH. Data from the 1984 and 1987 years were not used in creating the models because economic and political events during these two years had drastic affects on the fur market making these years anomalies in our study. In February 1983, the Commissioners of the Arkansas Game and Fish Commission voted 5-to-2 to ban all trapping of gray and red fox statewide. This ban was modified with zones closed to all fox trapping and other zones permitting gray fox trapping in November of 1983. These political decisions affected the subsequent fur harvest of 1983. A second important event that affected the Arkansas fur market was the notorious economic meltdown, Black Monday, of October 1987. On this day the stock market crashed, drastically affecting the total harvest and mean pelt values for that year. Figure 4 demonstrates graphically how well the 1966-1983 CSPV and PSPV models predicted total harvest with the exception of the 1983 and 1987 seasons.

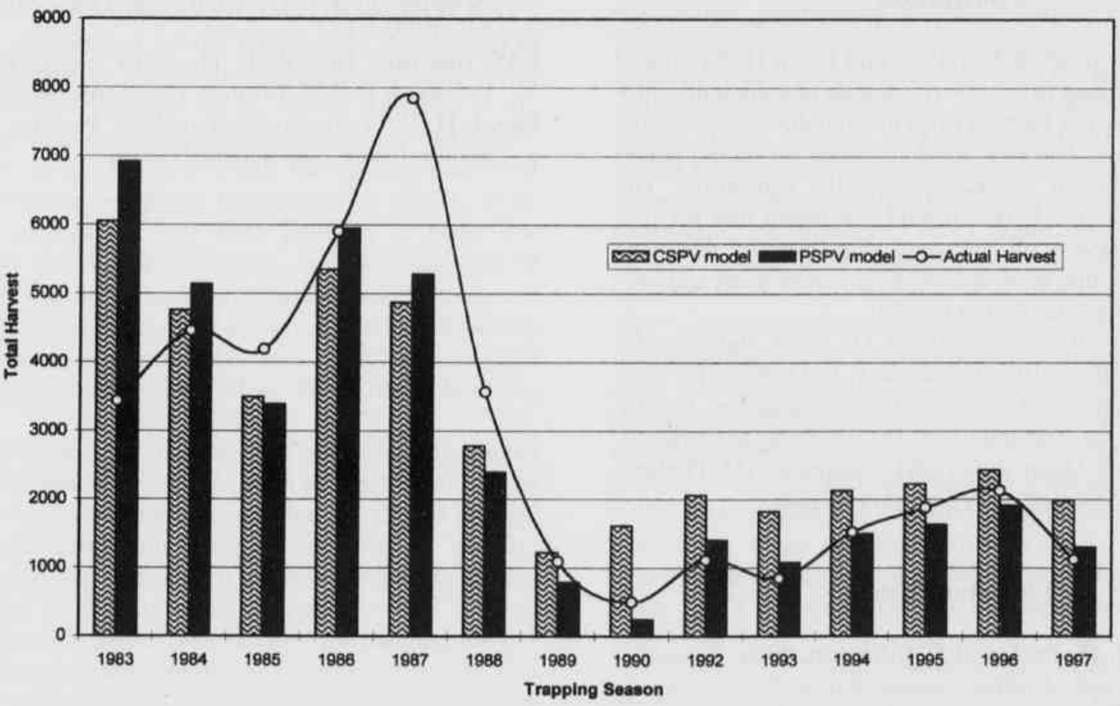


Fig. 3. Comparison of harvests of gray fox in Arkansas from 1983-1997 with predictions using 1984-1997 CSPV and PSPV models.

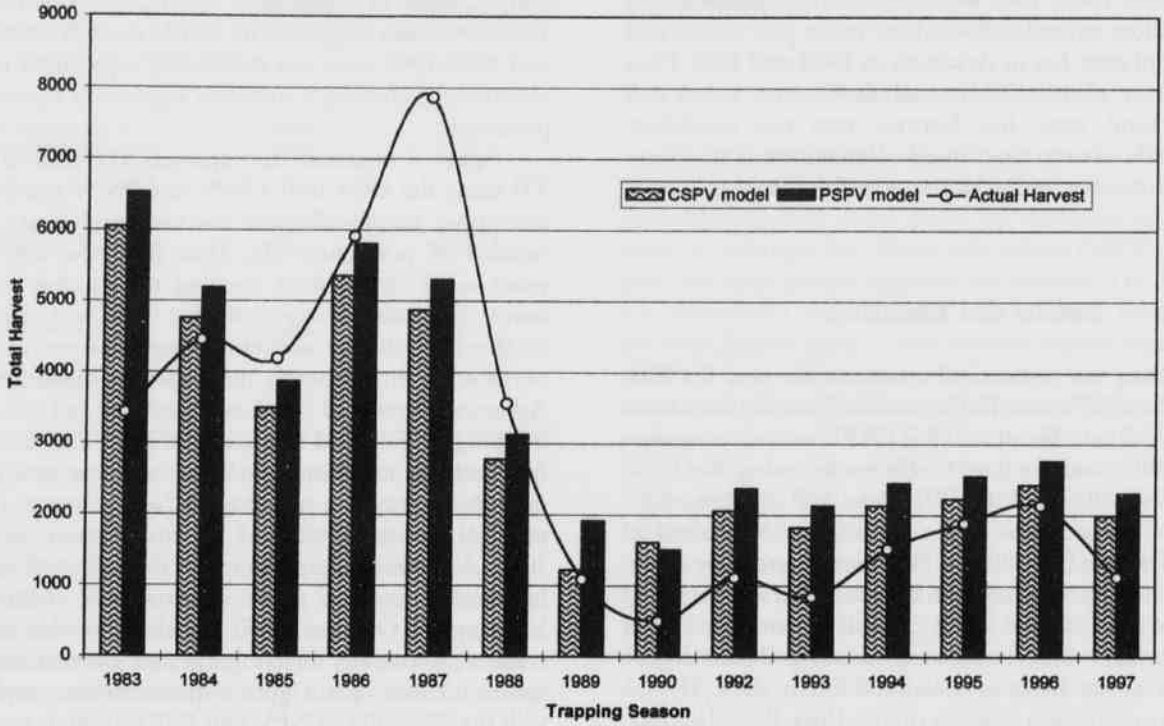


Fig. 4. Comparison of harvests of gray fox in Arkansas from 1983 - 1997 with predictions using Peck and Heidt's (1985) 1966 - 1982 CSPV and PSPV models.

Conclusions

The models proposed by Peck and Heidt (1985), based on a period of rising prices, were capable of sufficiently predicting total gray fox harvest from mean pelt values over the past fifteen years. The new models, based on falling prices over the past fifteen years, were equally significant. The combined 1966-1997 CSPV model is a useful tool for predicting total harvest of Arkansas gray fox. At this time research on the affects of decreased pressure from trappers on the gray fox population is needed.

ACKNOWLEDGMENTS.—We thank Dr. W. H. Baltosser for his assistance with statistical analysis; P. L. Dozhier, fur market editor, Trapper and Predator Caller Magazine, for discussions about fur markets from the 1950s to the present; and the Arkansas Game and Fish Commission (M. Pledger) who provided Arkansas gray fox harvest data.

Literature Cited

Heidt, G. A., J. H. Peck and **L. Johnston.** 1984. An analysis of gray fox (*Urocyon cinereoargenteus*) fur harvests in Arkansas. Proc. Arkansas Acad. Sci. 38:49-52.

Peck, J. H., and **G. A. Heidt.** 1985. A model to predict Arkansas gray fox fur harvests. Proc. Arkansas Acad. Sci. 39:92-94.

SAS Institute Inc. 1991. The SAS system for windows, Release 6.11 SAS Institute Inc., Cary, North Carolina.

Zar, J. H. 1999. Biostatistical analysis. Prentice-Hall, Upper Saddle River, New Jersey. 663 pp.

Locating NAPLs in Ground Water Using Partitioning Fluorescent Dyes

A. Ghanem[1], J. Smith[1], M. Elzey[1], T. S. Soerens[1], M. A. Miah[2], and G. Thoma[3]

[1]Department of Civil Engineering
University of Arkansas at Fayetteville
Fayetteville, AR 72701

[2]Department of Physics and Chemistry
University of Arkansas at Pine Bluff
Pine Bluff, AR 71611

[3]Department of Chemical Engineering
University of Arkansas at Fayetteville
Fayetteville, AR 72701

Abstract

A major challenge in ground water remediation is locating nonaqueous phase liquids (NAPLs). Partitioning tracers can be used to identify NAPL sources between injection and extraction wells. NAPLs are only slightly soluble in water, pose a long-term source of groundwater contamination, and can be difficult to remove. The complexity of recovery processes requires the development of new technologies that guarantee costeffective methods for locating and quantifying NAPLs. Traditional methods like soil coring have been inefficient since they underestimate the quantity of NAPLs and are expensive. Partitioning tracer tests are some of the most recent methods developed for locating these contaminants and determining the volume of the NAPL present in the inter-well zone. The results of the tests can be used to develop remediation techniques to recover NAPLs entrapped in the contaminated zone. Fluorescent dyes may be useful as partitioning tracers. They can be analyzed quickly at the field site, resulting in a shorter analysis time and lower costs than other partitioning tracers. This project pursued the selection of suitable tracers and the development of partitioning tracer techniques to locate and quantify NAPLs in the subsurface.

Introduction

Partitioning tracer methods consist of the simultaneous injection of a conservative (nonpartitioning) tracer along with one or several partitioning tracers. The average NAPL saturation is determined on the basis of the retardation of the partitioning tracer relative to the nonpartitioning tracer (Jin et al., 1995; Hunkeler et al., 1997; Annable et al., 1998a). An ideal partitioning tracer should have the following properties: a) the ability to mimic the velocity pattern of the groundwater movement in the absence of NAPL; b) be somewhat hydrophobic and water-soluble; c) have low retardation in the absence of NAPL and have delayed of breakthrough relative to non-partitioning tracer in presence of NAPL; d) be easily detected in very low concentrations; e) be inexpensive, f) be nonhazardous, nontoxic; and g) be nondegrading (Seaman, 1998; Aley, 1998; Annable et al., 1998b).

The most important characteristic of fluorescent tracers is sorption (Hadi et al., 1997). Sorption properties are due to the polar or non-polar character in their functional groups. Hydrochemical conditions such as temperature, salinity, pH, background fluorescence of dyefree sample, turbidity, and suspended solids may affect the structure and analysis of the dyes (Feuerstein and Selleck, 1963). Changing the pH can change the spectral properties of the dye molecules. The fluorescence of fluorescein and pyranine was observed to decrease at low pH values as a function of the ions causing the pH change. The absorbency of these species was increasing with decreasing pH (Behrens, 1986). Sorption properties of rhodamine WT (RWT) were also observed to increase with decreasing pH (Smart and Laidlaw, 1977).

Previous research works have been performed to find appropriate partitioning fluorescent dyes. Fluorescein and RWT were evaluated as adsorbing ground-water tracers. Experimental results indicated the tracers were effective for characterization of atrazine and alachlor (Sabatini and Austin, 1991). Soerens and Sabatini (1996) examined the effects of experimental methods and conditions on sorption parameters determined for RWT. They found that multiple compounds or isomers in RWT could originate significant errors in contaminant transport studies if they are not recognized in batch or column data. Structural isomers for RWT were also studied by Shiau et al. (1993) in two surface media. Batch and column studies demonstrated that the isomers were responsible for the two-step sigmoidal breakthrough curve. Rhodamine B (RB) and RWT were evaluated as potential partitioning tracers for detection and measurement of tetrachloroethylenene (Stainton and Soerens, 1997). Retardation factors found from batch tests were comparable to those calculated from column tests. RB was determined not to be a suitable partitioning tracer. In this study, RWT did not exhibit the twostep breakthrough curve predicted.

This project pursues the selection of suitable fluorescent tracers to identify zones of residual DNAPLs by inter-well tests. The objective of this study is to evaluate the use of some fluorescent dyes as suitable tracers in a water-saturated porous medium with tetrachloroethylenene (PCE) using laboratory column and batch studies.

Materials and Methods

Materials.--Five fluorescent dyes were tested. They are fluorescein, as a conservative tracer, and eosine, RWT, sulforhodamine B (SRB), and pyranine, as partitioning tracers. PCE was chosen as the NAPL to be tested in this study. Ottawa sand was used as the sorbent for batch and column experiments. For batch experiments, the sand was washed with tap water until clear, then rinsed five times with distilled water, and oven dried at 100°C for 24 hours. Distilled water was used in all experiments.

Batch Tests.--Batch experiments were conducted to calculate the partitioning coefficient in two different systems: PCE/dye and soil/dye. In PCE/dye tests, a volume of dye solution (V_S) was added to a volume of PCE (V_N) in an Erlenmeyer flask. A PCE/dye ratio of 1:4 was used. Four reactors were prepared for tracer concentrations of 25, 50, 100, and 150 µg/L. Flasks were capped to avoid evaporation. Reactors were continuously stirred at approximately 307 rpm for 2 hours; then all were allowed to settle for about 24 hours. The initial concentration (C_O) and concentration of the tracer in the aqueous phase (C_W) for each sample were determined from fluorometer readings. Measurements were compared to a control. The batch tests were conducted at room temperature (22 ± 2°C). The PCE-water partitioning coefficient (K_{NW}) was calculated using the following relationship:

$$K_{NW} = \frac{C_N}{C_W} \tag{1}$$

The concentration of the dye in the PCE (C_N) is given by

$$C_N = \frac{(C_O - C_W)\, V_S}{V_N} \tag{2}$$

Values of C_N versus C_W were plotted to create a linear sorption isotherm, and the K_{NW} value was determined by regression analysis for each dye.

Soil/dye tests were conducted by placing a mass of Ottawa Sand (M_S) in each of a series of sample vessels and adding a volume of dye solution (V_S) at different concentrations. Several ratios of M_S:V_S (g/mL) were analyzed (20:20, 30:15, 30: 10). Tests were conducted at room temperature (22 ± 2°C). Two sets of reactors were evaluated for each group of conditions. After shaking, reactors were allowed to reach the equilibrium for a period of 24 hours. Following this period, reactors were placed in a centrifuge. Dye was drawn off with a 10 mL syringe, and fluorescence was measured. The initial concentration (C_O) and equilibrium concentration (C) of the tracer were determined from fluorometer readings. The amount of dye sorbed to the soil (q) was calculated by using

$$q = \frac{(C_O - C)\, V_S}{M_S} \tag{3}$$

Values of q were determined at different concentrations in the reactors. Plots of q versus C were used to define a linear sorption isotherm, where the slope is the sorption partitioning coefficient (K_P). This value was determined by

$$q = K_P\, C \tag{4}$$

From batch tests, K_{NW} and K_P were used to predict values of R_f (Jin et al., 1997; Annable et al., 1998a, b; Wright et al., 1996).

$$R_f = \frac{t_p}{t_n} = 1 + \frac{K_{NW}\, S_N}{(1 - S_N)} + \frac{\rho_b}{\eta S_W} K_p$$

where, η = porosity, t_p = average travel time for partitioning tracer, t_n = average travel time for non-partitioning tracer, ρ_b= bulk density, S_N = NAPL saturation, and S_W = water saturation.

Column Tests.--Experiments were conducted in a chromatography column, packed with Ottawa sand and then saturated with distilled water for 48 hours at room temperature (22 ± 2°C. The weight of the column was measured before and after saturation. Column properties were calculated by mass balance. The results are as follows: pore volume (V_o) = 97.7 ml, porosity 0.35 (dimensionless), and bulk density = 1.70 g/ml. Flow was pumped through the column vertically using a peristaltic pump. Two different experiments were performed for each dye to determine the R_f of the tracers, soil/dye and soil/dye/PCE. In the former, three pore volumes (PV) of tracer solution (300 mL) were injected through the top of the column followed by several PVs of distilled water flowing in the same direction. In the second experiment, columns were saturated with PCE, following the same procedure used by Stainton and Soerens (1997). The volume of NAPL (V_N) was calculated by mass measurement. The average flow velocity was 4.44 ± 0.31 m/d. Column effluent was collected in a fraction collector. Fluorometer readings (C) were taken after the process was completed.

Results from partitioning tracer experiments in columns were represented by breakthrough curves (BTCs). Microsoft Excel Solver GRG2, a nonlinear optimization code, was applied to determine R_f. The analytical solution of the one-dimensional advection-dispersion equation was used to calculate the predicted concentration of the tracer in the BTCs as follow

$$\frac{C}{C_o}=0.5\left\{erfc\left[\frac{R_f-\frac{V}{V_o}}{2\left(\frac{1}{P_e}R_f\frac{V}{V_o}\right)^{0.5}}\right]+\exp(P_e)\,erfc\left[\frac{R_f+\frac{V}{V_o}}{2\left(\frac{1}{P_e}R_f\frac{V}{V_o}\right)^{0.5}}\right]\right\} \quad (6)$$

where P_e = Peclet number, V = volume of the sample, and *erfc* = complementary error function.

Results and Discussion

Batch Tests.--Batch tests were conducted for all the tracers except for fluorescein since previous studies have demonstrated that it is conservative (Sabatini and Austin, 1991; Hadi et al.; 1997; Stainton and Soerens, 1997).

In soil/dye experiments, RWT demonstrated linearity for different M_S/V_S ratios in 75% of the results. However, SRB isotherms followed a linear relationship in only one of the three experiments conducted, but R^2 was still very low (0.72). K_p values for RWT were between 0.066 and 0.115 cm^3/g (Table 1). For SRB only one value, 0.091 cm^3/g, was acceptable. K_p was independent of the tracer concentration for both RWT and SRB.

Table 1. Soil/Dye Partitioning Coefficient (K_p) from Batch Tests

Tracer	M_S/V_S g/ml	K_p cm^3/g Set #1	Set #2
RWT	20/20	0.115	0.081(NS)
	30/15	0.066	0.082
SRB	20/20	0.091	0.036(NS)
	30/10	0.022(NS)	ND

NS = unsuccessful
ND = no data

Problems with fluorescence were encountered for eosine and pyranine; both of these dyes enhanced their fluorescence after equilibrium conditions were reached. Two possible parameters were thought to have an effect in the final fluorescence of these dyes: a) background fluorescence, and b) pH. The former was measured using a control sample for each dye. Investigations demonstrated that the background fluorescence did not have noticeable influence on the results. A buffer solution (potassium phosphate monobasic-sodium hydroxide, 0.05 M) was added to eosine and pyranine samples in order to adjust the pH to 7. The samples with the buffer corresponded to the M_S/V_S ratio of 25/20. In order to compare the effects of the pH in Pyranine, the buffer solution was added to set #2 prior to performing the batch tests. Fluorometer readings were taken before and after buffering the samples. The adjusted pH had little effect in changing the fluorescence of eosine or pyranine.

PCE/dye partitioning coefficients were represented by linear isotherms. Results are summarized in Table 2. SRB isotherms did not have a good linear regression fit since the higher R^2 value was 0.39. Pyranine increased its fluorescence at the equilibrium stage after the batch test. However, a linear relationship was also observed with respect to fluorescence with a K_{NW} equal to -3.061. This was based on the slope of the isotherm and R^2 = 1.00. This behavior could be the result of a structural change in the pyranine molecules originated by a change in the pH or the formation of a different chemical compound.

Table 2. PCE/Dye Partitioning Coefficient (K_{NW}) from Batch Tests

Tracer	V_S/V_N ml/ml	K_{NW}
RWT	160/40	0.1703
SRB	160/40	0.0603
Eosine	160/40	0.049
Pyranine	160/40	-3.061

Column Tests.--Experiments with fluorescein were conducted at an average flow rate of 1.70 mL/min. Regression analysis for this tracer gave an average R_f value of 1.08 ± 0.07 (dimensionless). For RWT, the flow rate was 1.73 ± 0.1 mL/min. The average retardation factor was determined to be 1.64 ± 0.38. Retardation factors for SRB, eosine, and pyranine were 1.23, 1.45, and 2.97, respectively. Breakthrough curves from column tests without PCE were represented in Fig. 1. Pyranine demonstrated to be the most retarded among the nonconservative tracers, and SRB was the least retarded. RWT showed the two-steps produced by isomers, similar to the results found in previous studies (Sabatini and Austin, 1991; Shiau et al., 1993; Soerens and Sabatini, 1996). Effects of the flow velocity in the Rf were noticed for both fluorescein and RWT. Higher velocities resulted in lower retardation factors. Only one value for RWT did not follow this pattern.

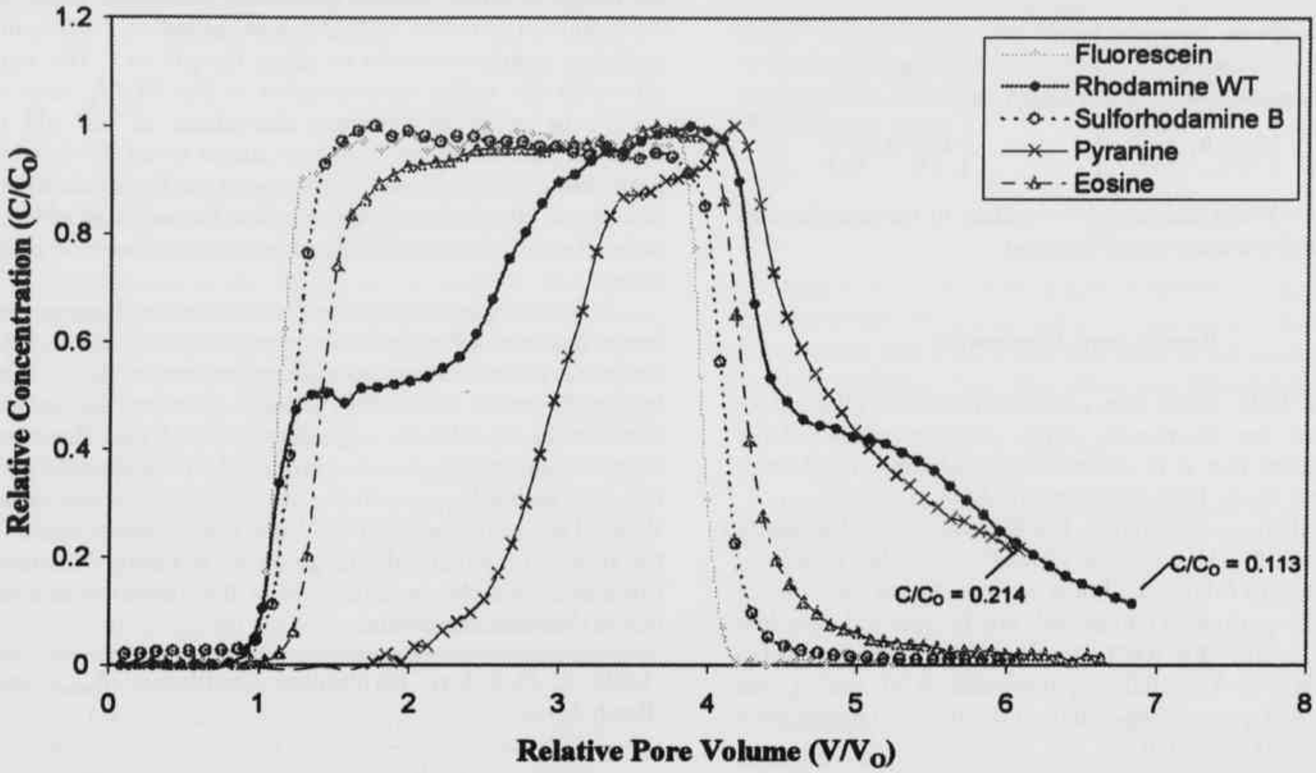


Fig. 1. Breakthrough Curves from Column Tests without PCE

Column results for the fluorescent tracers with PCE are illustrated in Fig. 2. As expected, in the presence of PCE, the retardation factors increased for all the tracers. The average flow rate was 1.47 ± 0.06 mL/min. From regression analysis, measured R_fs values were 1.31, 2.30, 1.33, 1.79, and 3.51, for fluorescein, RWT, SRB, cosine, and pyranine, respectively. All the dyes had retardation factors between 1.2 and 4.25. This approach makes them suitable as partitioning tracers. Among the nonconservative tracers, the least retarded was SRB and the most retarded was pyranine. Eosine produced a peak value $C/C_o > 1$. BTCs, from experiments with PCE and without PCE, displayed similarity with respect to their shapes.

Conclusions

Soil/dye partitioning coefficients for RWT and SRB demonstrated that the adsorption of these dyes into the soil was insignificant. Therefore, they are suitable as partitioning tracers. The increase of fluorescence for cosine and pyranine did not allow the K_d values determined. Background fluorescence and pH did not have an apparent effect on the final fluorescence of these dyes.

Partitioning coefficients for RWT, eosine, SRB, and PCE were very small. However, low K_{NW} values could be a consequence of the small range of concentrations tested, the PCE/tracer ratio, or the nature of the tracer itself. Pyranine enhanced fluorescence after reaching the equilibrium stage with PCE, following a linear isotherm with a negative slope. The formation of a different carboxylic group from a chemical reaction between pyranine and PCE was believed to be the cause of the increase in fluorescence of this tracer in batch tests.

Column tests indicated that RWT, SRB, and eosine are theoretically suitable as partitioning tracers. Among the partitioning tracers evaluated in this study, pyranine was demonstrated to be the most retarded and SRB the least retarded. RWT showed the two-steps BTC produced by isomers present in its molecular structure. Fluorescein and SRB had similar retardation factors. Because these tracers fluoresce at different wavelengths, they can be injected simultaneously in field tests. Flow velocities had a noticeable effect on determination of retardation factors. Higher velocities resulted in lower retardation factors for both RWT and fluorescein.

This study has demonstrated that partitioning fluorescent tracers are a potential resource for detection and esti-

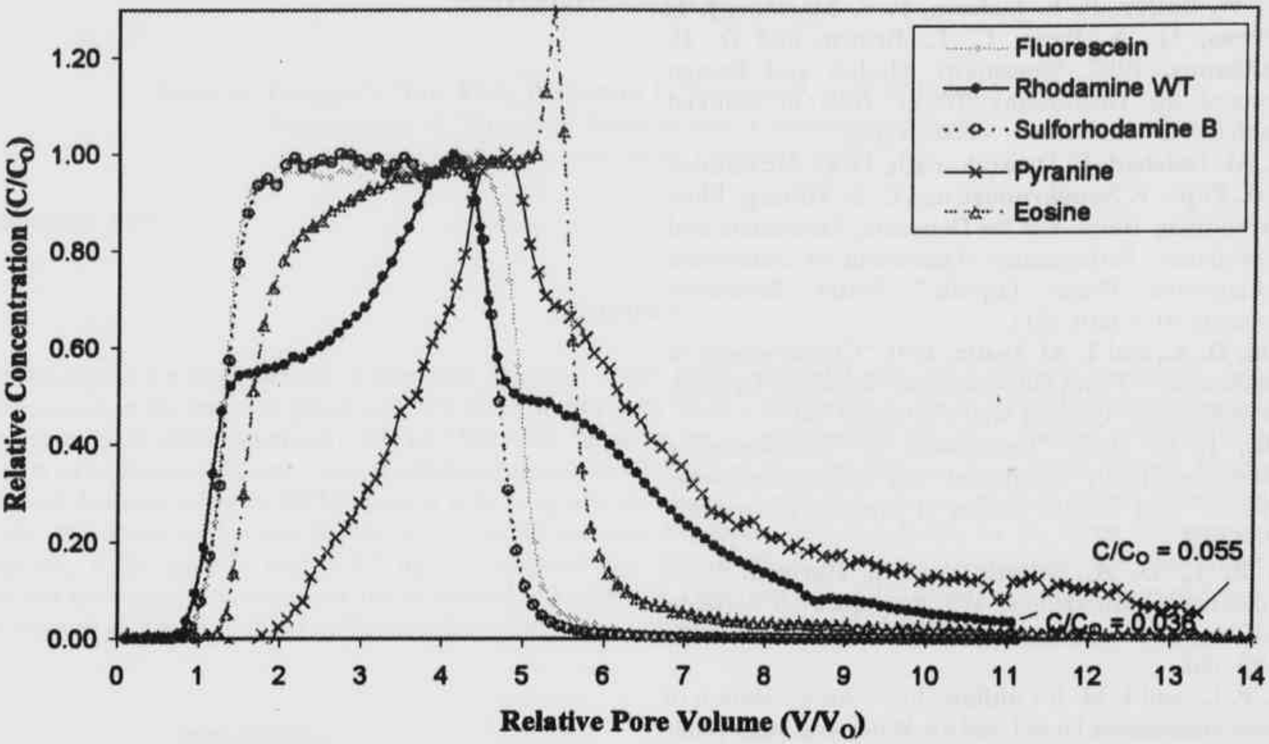


Fig. 2. Breakthrough Curves from Column Tests with PCE

mation of DNAPLs in saturated soils. However, the complexity of their molecular structure produced difficulty in understanding their properties and, consequently, the determination of partitioning coefficients between the tracers and PCE.

Different parameters, such as pH, temperature, PCE/dye ratio, tracer concentration, and orientation of the column, are involved in batch and/or column experiments. Conventional testing methods do not include the control of such variables. Thus, further studies should be done to determine the effect of these variables and design more accurate tests. On the other hand, additional fluorescent tracers should be evaluated in order to increase the number of dyes available for future work.

Literature Cited

Aley, T. 1998. "Procedures and Criteria Analysis of Fluorescein, Eosine, Rhodamine WT, Sulforhodamine B, and Pyranine Dyes in Water and Charcoal Samplers", Ozark Underground Laboratory.

Annable, M. D., J. W. Jawitz, P. S. C. Rao, D. P. Dai, H. Kim, and **A. L. Wood.** 1998a. "Field Evaluation of Interfacial and Partitioning Tracers for Characterization of Effective NAPL-Water Contact Areas." Ground Water. 36-3:495-502.

Annable, M. D., P. S. C. Rao, K. Hatrield, W. D. Graham, A. L. Wood, and **C. G. Enrield.** 1998b. "Partitioning Tracers for Measuring Residual NAPL: Field Scale Test Results." Journal of Environmental Engineering. 124-6:498-503.

Behrens, H. 1986. "Water Tracer Chemistry: "A Factor Determining Performance and Analytics of Tracers." 5th International Symposium on Underground Water Tracing. Institute of Geology and Mineral Exploration. Athens. pp. 121-133.

Feuerstein, D. W., and **R. E. Selleck.** 1963. "Fluorescent Tracers for Dispersion Measurements." Proceedings of the American Society of Civil Engineers. Journal of Sanitary Engineering. Div. 89 (SA4). pp. 1-21.

Hadi, S., C. Leibundgut, K. Friedrich, and **P. Maloszewski.** 1997. "New Fluorescent Tracers." International Symposium, 7th, Portoroz, Slovenia. pp. 55-62.

Hunkeler, D., E. Hoehn, P. Höhener, and **J. Zeyer.** 1997. "^{222}Rn as a Partitioning Tracer to Detect Diesel Fuel Contamination in Aquifers: Laboratory Study and Field Observations." Environmental Science & Technology. 31-11:3180-3187.

Jin, M., W. Butler, R. E. Jackson, P. E. Mariner, J. F. Pickens, G. A. Pope, C. L. Brown, and **D. C. McKinney.** 1997. "Sensitivity Models and Design Protocol for Partitioning Tracer Tests in Alluvial Aquifers." Ground Water. 35-6:964-972.

Jin, M., M. Delshad, V. Dwarakanath, D. C. McVinney, G. A. Pope, K Sepehrnoori, and **C. E. Tilburg.** 1995. "Partitioning Tracer Test for Detection, Estimation, and Remediation Performance Assessment of Subsurface Nonaqueous Phase Liquids." Water Resources Research. 31-5:1201-1211.

Sabatini, D. A., and **T. Al Austin.** 1991. "Characteristics of Rhodamine WT and Fluorescein as Adsorbing Ground-Water Tracers." Ground Water. 29-3:341-349.

Seaman, J. C. 1998. "Retardation of Fluorobenzoate Tracers in Highly Weathered Soil and Groundwater Systems." Soil Science Society of America Journal. 62-2:354-361.

Shiau, B. J., D. A. Sabatini, and **J. Harwell.** 1993. "Influence of Rhodamine WT Properties on Sorption and Transport in Subsurface Media." Ground Water. 31-6:913-920.

Smart, P. L., and **I. M. S Laidlaw.** 1977. "An Evaluation of Some Fluorescent Dyes Used for Water Tracing." Water Resources Research. 13-1:15-33.

Soerens, T. S., and **D. A. Sabatini.** 1996. "Interpretation of Sorption Studies for Compound Isomers or Mixtures." Ground Water. 34-4:605-609.

Stainton, R. M., and **T. S. Soerens.** 1997. "Fluorescent Partitioning Tracers for Subsurface NAPL Characterization", in Sublette. K.L., ed. 4th. International Petroleum Environmental Conference, San Antonio, TX, September 9-12.

Wright, C., C. M. Lee, J. T. Coates, and **R. W. Falta.** 1996. "Investigation of Interwell Tracer Tests Used with Cosolvent Flooding," Non-Aqueous Phase Liquids (NAPLs) in Subsurface Environment: Assessment and Remediation, ASCE, New York, NY. pp. 151-162.

Analysis of Phytoestrogens by High Performance Liquid Chromatography

Anne A. Grippo*[1], Yan Xie[2], Benjamin L. Rougeau[2], and William V. Wyatt[2]
Departments of [1]Biological Sciences and [2]Chemistry & Physics,
Arkansas State University, State University, AR 72467

*Corresponding Author

Abstract

Phytoestrogens are biochemicals synthesized in plants which mimic steroidal estrogen activity in mammals. Analysis of these compounds in the legumes which produce them and in body fluids is important to the study of their physiological effects. High pressure liquid chromatography (HPLC) has been found to be an efficient and sensitive method of identification and quantitation of isoflavonoids, one class of phytoestrogen. Here we report the separation of three isoflavonoids, biochanin A, genistein and daidzein using an HPLC system with a C_8 reverse phase column and a linear gradient mobile phase containing acetonitrile and acetic acid/water (10/90, v/v) over 60 minutes. Minimum detection limits for the three isoflavonoids were 0.556 μg/mL, 0.314 μg/mL, and 0.377 μg/mL, respectively. This method was used to measure the concentrations of isoflavonoids in two types of soy meal and in several animal feeds. Projected use of this assay includes studies of reproductive ability following ingestion of these isoflavonoids in domestic ruminants and in wild rodents.

Introduction

Recently, much interest has focused on environmental endocrine disruptors, compounds available in the environment which interfere with the natural balance of hormones in animals which ingest them (Campbell and Hutchinson, 1998). Many of these compounds have been found to mimic the activity of natural estrogen and, therefore, effect reproduction (European Commission, 1996). One class of agents which has these effects is the phytoestrogens. As their name implies, phytoestrogens are produced by plants and have estrogenic activity in herbivorous animals. Isoflavonoids are a group of phytoestrogens which share a similar 3-phenyl chroman molecular structure (Katzenellenbogen, 1995; Miksicek, 1995) and which are produced in legumes, particularly soybeans and clovers, as well as several other types of plants (Phillips, 1992). The estrogenic effects of isoflavonoids have been studied in humans who consume soy and in ruminants that ingest phytoestrogenic clovers. In the 1940's, ewes grazing on estrogenic clovers suffered both permanent and temporary infertility (Bennets et al., 1946) accompanied by histological changes in cervical and uterine tissues, as well as ovarian failure and changes to other estrogen-sensitive tissues (Cheng et al., 1953; Lightfoot et al., 1967; Adams, 1977, 1981; Nwanenna et al., 1995). Recent studies have focused on phytoestrogens' effects on the developing fetus and gestation success, and on hormone-dependent tumors, such as breast cancers (Faber and Hughes, 1993; Medlock et al., 1995; Lamartiniere et al., 1998; Adlercreutz, 1998).

The isoflavonoids include the two parent compounds, biochanin A and formononetin (Fig. 1), which exist as glycoside conjugates in the plant (Harborne, 19731). These compounds are readily hydrolyzed by plant or digestive enzymes or by microorganisms in the rumen and further metabolized to the demethylated compounds, genistein and daidzein (Lundh, 1995) (Fig. 1). Genistein has been found to be quite estrogenic in several species (Miksicek, 1995) and inhibits tyrosine phosphokinase (Akiyama et al., 1987), an important second messenger system in several cell types including gametes and tumor cells (Moore and Kinsey, 1995; Linassier et al., 1990; Burks et al., 1995). Quantitation of phytoestrogens in foods and in animal tissues and fluids is crucial to future investigation of these agents.

Several techniques have been developed to separate and quantitate phytoestrogens including radioimmunoassay (Wang, 1998), gas chromatographic/mass spectrometric methods (GC/MS) (Adlercreutz et al., 1995), and high performance liquid chromatography (HPLC) (Lagana and Marino, 1991; Franke and Custer, 1994). Radioimmununoassay techniques developed by Wang (1998) are highly sensitive, but limited to only one compound, and may produce false positive results (Lagana and Marino, 1991). GC/MS is also sensitive, but it is time consuming and demands expensive instrumentation and intensive analytical experience (Franke et al., 1995). HPLC has proven to be an excellent separation, purification and detection technique (Lagana and Marino, 1991); it requires fewer preparatory steps than GC/MS and less expensive equipment. Most HPLC assays for phytoestrogens have

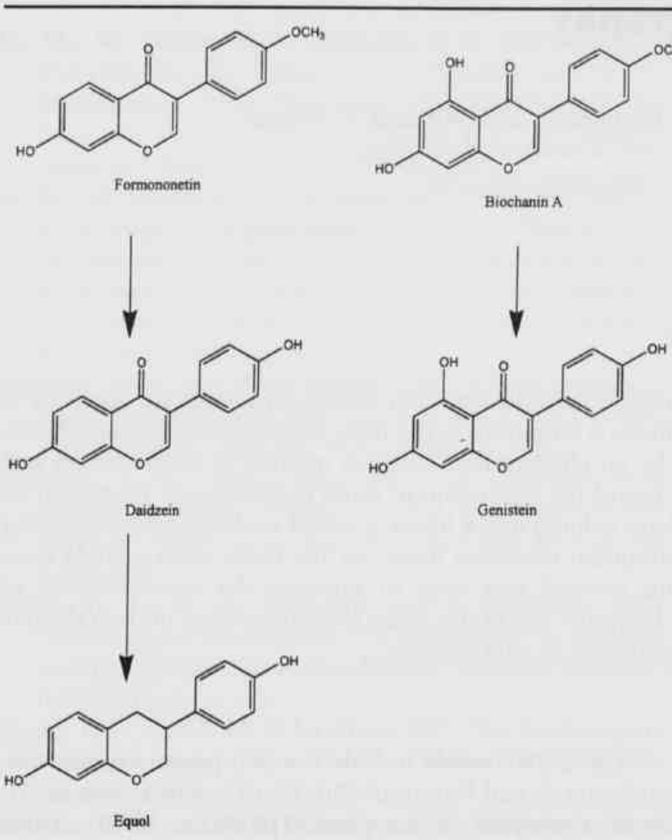


Fig. 1. Structures of parent phytoestrogens analyzed and their metabolites.

employed a C_{18} reverse phase column (Gildersleeve et al., 1991; Coward et al., 1993; Franke and Custer, 1994; Wang and Murphy, 1994) with various mobile phases including acetonitrile and trifluoroacetic acid, methanol and ammonium acetate, and acetonitrile and ammonium formate buffers in different ratios and with various elution programs.

Here we describe an HPLC method employing a C_8 reverse phase column with a linear gradient mobile phase of acetonitrile and acetic acid/water. This system successfully separated one parent isoflavonoid, biochanin A, and two metabolites, daidzein and genistein, and was used to quantitate these compounds in two types of soy meal and three animal feeds.

Materials and Methods

All solvents used for HPLC and optical density readings were of analytical or HPLC grade, vacuum-filtered through a 47 mm 0.45 µm nylon 66 membrane filter (Alltech Associates, Inc., Deerfield, IL). Methanol and HPLC grade water were purchased from J.T. Baker Chemical Co., Phillipsburg, NJ. Acetic acid was purchased from EM SCIENCE, Gibbstown, NJ, and acetonitrile was from Fisher Scientific Company, Fair Lawn, NJ. Daidzein, genistein and biochanin A standards were purchased from Sigma Chemical Co., St. Louis, MO.

A Dionex 500 HPLC system with a 25 µL injector loop, in-line vacuum degasser, and AD20 absorbance detector was used in this study. An Adsorbosphere C_8 direct-connect guard column was coupled through a 2 µm in-line filter to a Zorbax SB-C_8 analytical column (4.6x15 cm, particle size 5 µm; MAC-MOD Analyticals, Inc., PA). Dionex PeakNet software controlled the instruments and automatically collected, processed, and reported the data.

All samples were injected individually through a syringe filter (25 mm diameter PTFE membrane, 0.2 µm pore size, Supelco, Inc., Bellefonte, PA). Elution was performed at 1 mL/min with the following stepwise gradient over 60 minutes. Where A=acetic acid/water (10/90, v/v) and D=acetonitrile, 30%D in A (v/v) ran for 20 minutes; from 20 minutes to 35 minutes, D changes from 30% to 70% and A changes from 70% to 30%; finally 70% D ran for 25 minutes. Phytoestrogens were detected by UV absorbance at 260 nm. A methanol rinse followed each run. Standard phytoestrogen solutions were prepared by addition of methanol to purified phytoestrogen, yielding stock solutions of 10 mg/mL, which were stored in amber vials at <-20°C. Stock solutions were then diluted with methanol to six different concentrations (0.5-100 µg/mL), and triplicate HPLC analyses were performed for each concentration to produce calibration curves for each phytoestrogen. This allowed calculation of the correlation coefficient, response factor, and minimum detection limit for each compound tested.

Phytoestrogens were extracted from two types of soy meal, hull-less and containing hulls (the generous gift of Mr. L. Gringas of Riceland Foods, Stuttgart, AR), and three animal feeds (Bermuda and fescue grasses and cottonseed) by a modification of the method of Franke et al. (1995). Briefly, 10 g of dry meal or chopped feed was finely dispersed in a mixture of 100 mL 77% ethanol containing 2M HC1 and 0.05% BHT as an antioxidant with stirring and sonication for 10 minutes. The solution was then refluxed (boiling point=78.5°C) for 2 hours, cooled to room temperature, and centrifuged at 850xg for at least 10 minutes. The clear supernatant was injected through a syringe filter into the HPLC system.

To quantitate any degradation of the phytoestrogens by the extraction procedure, new phytoestrogen standard solutions were prepared using ethanol as solvent and extracted in 77% ethanol/2 M HC1/0.05% BHT with stirring, sonication and reflux then analyzed by HPLC identically as the meal and feed samples had been. Also, the solution used for extraction was analyzed alone to ensure that it contained no constituents with interfering UV absorbances.

Table 1. Retention times, coefficients of determination, response factors and minimum detection limits for phytoestrogens from HPLC analyses.

Phyto-estrogen	Retention Time (t) (+/- 0.5 min) Unex'd Std.	Ext'd Std.	Coefficient of Determination (r^2) Unex'd Std.	Ext'd Std.	Response Factor	Minimum Detection Limit (µg/mL)
Daidzein	6.12	5.72	0.99972	0.99975	5.90×10^{-5}	0.377
Genistein	9.03	8.15	0.99986	0.99617	7.72×10^{-6}	0.314
Biochanin A	25.02	21.77	0.99991	0.97052	7.76×10^{-6}	0.556

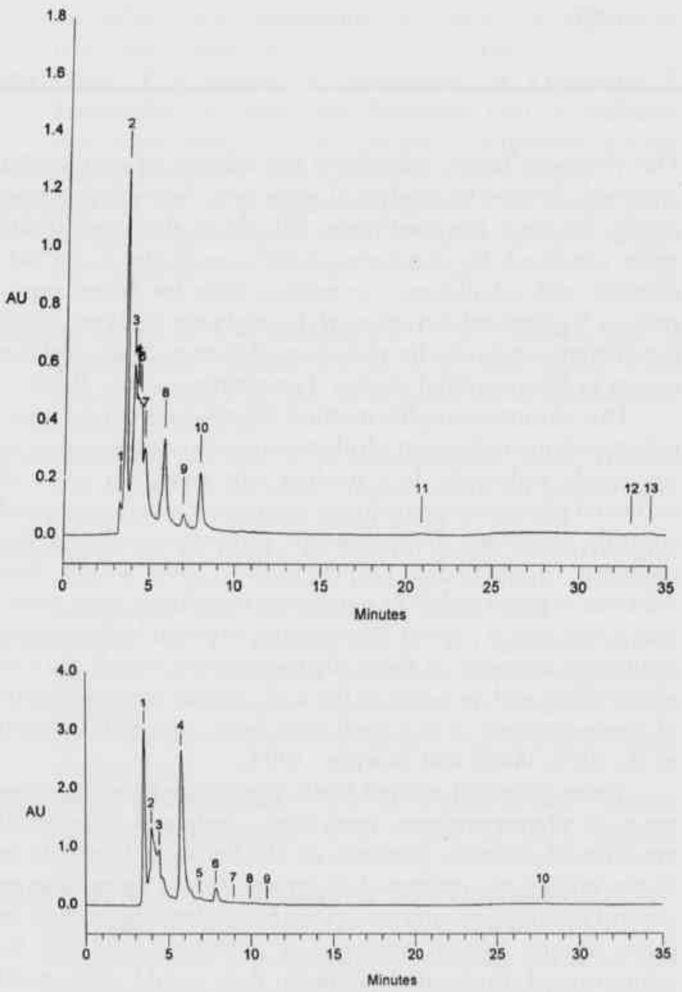


Fig. 2. Chromatographs of phytoestrogens extracted from soy meals by reflux in ethanol/HC1/BHT. (A) Hull-less soy meal extract. Peak identification: 8=daidzein; 10=genistein; peaks 1-7 and 9,11-13 are unknown compounds. (B) Extract of soy meal with hulls. Peak identification: 4=daidzein; 6=genistein; peaks 1-3 and 5,7-10 are unknown compounds.

Results

The elution order for the three phytoestrogens analyzed is daidzein, genistein, biochanin A. Retention time for each phytoestrogen, correlation coefficients, response factors and minimum detection limits were determined from calibration curves for each phytoestrogen, and are summarized in Table 1.

When pure extraction solution (77% ethanol containing 2 M HC1 and 0.05% BHT) was refluxed and analyzed by HPLC, three peaks were identified at retention times of 3.4, 3.5 and 37.23 minutes, which did not overlap with retention times for any phytoestrogen extracted in this solution by this method. Extraction of pure phytoestrogen solutions by stirring, sonication and reflux in ethanol/HC1/BHT yielded recovery of 99.1% daidzein, 49.7% genistein and 93. 0% biochanin A. Mean retention times shifted slightly to the left for each phytoestrogen following extraction (Table 1).

Both hull-less soy meal and soy meal containing hulls contained measurable amounts of daidzein and genistein, but no detectable biochanin A, following their extraction in 77% ethanol containing 2 M HC1 and 0.05% BHT (Fig. 2). Soy meal with hulls contained considerably greater amounts of both daidzein and genistein than hull-less soy meal (Table 2).

Following extraction of phytoestrogens from Bermuda and fescue grasses and cottonseed, daidzein was not detected, but all feeds were found to contain genistein. Bermuda grass showed the highest concentrations of both genistein (2.8% of total peak area) and biochanin A (3.9%). Fescue also contained both of these phytoestrogens, but at less than 0.05% of its total constituents. Cottonseed contained only genistein (0.2% of its constituents). The major peak (91.8% peak area) in the Bermuda grass extract was found at t=4.03 min; the largest HPLC peak in the fescue grass extract (93.9%) occurred at t=12.8 min; and in the cottonseed extract a triplet peak occurred at t=4.03/4.62/4.77 min comprising 86.6% total peak area. None of these appeared to

Table 2. Concentrations of daidzein and genistein in soy meals.

	Hull-less Soy Meal		Soy Meal with Hulls	
	Daidzein	Genistein	Daidzein	Genistein
Peak area	4.87 x 10^6	3.51 x 10^6	5.53 x 10^7	8.83 x 10^6
Sample Concentration (µg/mL)	54.0	25.9	612.2	65.2
Recovery Percentage	0.991	0.497	0.991	0.497
Phytoestrogen Concentration (µg/mL)	54.5	52.2	617.8	131.2

overlap with retention times for daidzein, genistein or biochanin A.

Discussion

The HPLC method developed here allows rapid, precise and inexpensive analysis of daidzein, genistein and biochanin A and is consistent with elution orders of previous HPLC research of similar compounds (Franke and Custer, 1994; Coward et al., 1993; Gildersleeve et al., 1991). While most earlier HPLC separations of phytoestrogens utilized C_{18} columns (e.g., Wang and Murphy, 1994), the results of this study showed that a C_8 column, in combination with an acetonitrile/acetic acid elution system, is also efficient in separating the three compounds. Retention times in both types of columns were similar, though use of the C_8 column seemed to maintain a more stable baseline throughout the run, resulting in enhanced resolution of later peaks, i.e., the biochanin A peak. Also, earlier methods often employed DMSO as solvent for these hydrophobic compounds. However, DMSO apparently interfered with the PEEK tubing in our system, effecting retention times (pers. comm., Dionex Corp.). Better results were obtained when methanol was used to dissolve the samples, avoiding the influence of DMSO.

The correlation coefficient (r^2) provides a measure of the quality of curve fit of the calibration curves, with r^2=1 correlation a perfect linear fit. Calibration curves for each phytoestrogen, either standard solution directly or following extraction in ethanol/HC1/BHT, showed r^2>0.996 with the exception of biochanin A following extraction (r^2=0.971). The response factor, calculated by amount of compound analyzed divided by analytical response, shows strong sensitivity for each phytoestrogen. Minimum detection limits were obtained by analyzing seven replicate 1 µg/mL aliquots and calculating t (retention time for seven replicates) x S (standard deviation of the replicate analyses). This is sufficient sensitivity for detection of dietary doses of these agents in future animal studies (Lamartiniere et al., 1998).

This chromatographic method afforded successful separation and quantification of phytoestrogen concentration in soy meals and feeds. It is unclear why retention times of extracted phytoestrogens shifted compared to non-extracted controls, nor why the extraction procedure reduced the recovery of genistein. Earlier studies have shown that daidzein is more stable to extraction conditions than genistein (Franke et al., 1995). Apparently, soybean hulls contain significant amounts of these phytoestrogens, which are lost after milling with removal of the hull. Similar concentrations of phytoestrogens in soy meal have been reported (Coward et al., 1993; Wang and Murphy, 1994).

Three potential animal feeds were tested for the presence of phytoestrogens, and none contained substantial amounts of daidzein, genistein or biochanin A. Bermuda or fescue grasses or cottonseed, therefore, would be suitable as control or supplementary diets for future feeding studies. In these studies, known amounts of phytoestrogens will be administered to treated animals that would also need supplemental diets containing feeds which would not supply additional phytoestrogens.

ACKNOWLEDGMENTS.—This research was funded by an ASU Faculty Research Award to A.A.G.

Literature Cited

Adams, N. R. 1977. Morphological changes in the organs of ewes grazing on oestrogenic subterranean clover. Res. Vet. Sci. 22:216-221.

Adams, N. R. 1981. A changed responsiveness to oestrogen in ewes with clover disease. J. Reprod. Fertil. 30 (Supplement): 223-230.

Adlerereutz, H., T. Fotsis, M. S. Kurzer, K. Wahala, T. Makela, and **T. Hase.** 1995. Isotope dilution gas chromatographic mass spectrometric method for the determination of unconjugated lignans and isoflavonoids in human feces, with preliminary results in omnivorous and vegetarian women. Anal. Biochem. 225:101-108.

Adlercreutz, H. 1998. Evolution, nutrition, intestinal microflora, and prevention of cancer: a hypothesis. Proc. Soc. Exper. Biol. Med. 217:241-246.

Akiyama, T., J. Ishida, S. Nakagawa, H. Ogawara, S. Watanabe, N. Iton, M. Shibuya, and **Y. Fukami.** 1987. Genistein, a specific inhibitor of tyrosine-specific protein kinases. J. Biol. Chem. 262:5592-5595.

Bennets, H. W., E. J. Underwood, and **F. L. Sheir.** 1946. A specific breeding problem of sheep on subterranean clover pastures in Western Australia. Aust. Vet. J. 22:2-5.

Burks, D. J., R. Carballada, H. D. M. Moore, and **P. Saling.** 1995. Interaction of a tyrosine kinase from human sperm with the zona pellucida at fertilization. Science 269:83-86.

Campbell, P. M., and **T. H. Hutchinson.** 1998. Wildlife and endocrine disrupters: requirements for hazard identification. Env. Toxicol. and Chem. 17:127-135.

Cheng, E. W., L. Yoder, C. D. Story, and **W. Burroughs.** 1953. Estrogenic activity of some naturally occurring isoflavones. Ann. NY Acad. Sci. 61:652-659.

Coward, L., N. C. Barnes, K. D. R. Setchell, and **S. Barnes.** 1993. Genistein, daidzein and their β-glycoside conjugates: antitumor isoflavones in soybean foods from American and Asian diets. J. Agric. Food Chem. 41:1961-1967.

European Commission. 1996. Environment and Climate Research Programme. EUR 17549, DGXII Geneva, Switzerland

Faber, K. A., and **C. L. Hughes.** 1993. Dose-response characteristics of neonatal exposure to genistein on pituitary responsiveness to gonadotropin releasing hormone and volume of the sexually dimorphic nucleus of the preoptic area (SDN-POA) in postpubertal castrated female rats. Reprod. Toxicol. 5:363-369.

Franke, A. A., and **L. J. Custer.** 1994. High performance liquid chromatographic assay of isoflavonoids and coumestrol from human urine. J. Chromat. B. 662:47-60.

Franke, A. A., L. J. Custer, C. M. Cerna, and **K. Narala.** 1995. Rapid HPLC analysis of dietary phytoestrogens from legumes and from human urine. Proc. Soc. Exper. Biol. Med. 208:18-26.

Gildersleeve, R. R., G. R. Smith, I. J. Pemberton, and **C. L. Gilbert.** 1991. Detection of isoflavones in seedling subterranean clover. Crop Sci. 31:889-892.

Harborne, J. B. 1973. Phytochemical methods: a guide to modern techniques of plant analysis. Chapman and Hall, London. pp 52-88.

Katzenellenbogen, J. 1995. The structural pervasiveness of estrogenic acitivity. Env. Health Perspec. 103 (Suppl 7):99-101.

Lagana, A., and **A. Marino.** 1991. General and selective procedure for HPLC determination of anabolic steroids in tissues. J. Chromat. 588:89-98.

Lamartiniere, C. A., W. B. Murrill, P. A. Manzolillo, J. X. Zhang, S. Barnes, X. Zhang, H. Wei, and **N. M. Brown.** 1998. Genistein alters the ontogeny of mammary gland development and protects against chemically-induced mammary cancer in rats. Proc. Soc. Exper. Biol. Med. 217:358-364.

Lightfoot, R. J., K. P. Croker, and **H. G. Neil.** 1967. Failure of sperm transport in relation to ewe infertility following prolonged grazing on oestrogenic pastures. Aust. J. Agric. Res. 18:755-764.

Linassier, C., M. Pierre, J. B. LePeco, and **J. Pierre.** 1990. Mechanisms of action in NIH-353 cells of genistein, an inhibitor of EGF receptor tyrosine kinase activity. Biochem. Pharmacol. 39:187-193.

Lundh, T. 1995. Metabolism of estrogenic isoflavones in domestic animals. Pro. Soc. Exper. Biol. Med. 208:33-39.

Medlock, K. L., W. S. Branham, and **D. M. Sheehan.** 1995. Effects of coumestrol and equol on the developing reproductive tract of the rat. Proc. Soc. Exper. Biol. Med. 208:67-71.

Miksicek, R. J. 1995. Estrogenic flavonoids: Structural requirements for biological activity. Proc. Soc. Exper. Biol. Med. 208:44-50.

Moore, K. L., and **W. H. Kinsey**. 1995. Effects of protein tyrosine kinase inhibitors on egg activation and fertilization-dependent protein tyrosine kinase activity. Dev. Biol. 168:1-10.

Nwanenna, A. I., T. J. O Lundh, A. Madej, G. Fredriksson, and **G. Bjornhag.** 1995. Clinical changes in ovariectomized ewes exposed to phytoestrogens and 17β-estradiol implants. Proc. Soc. Exp. Biol. Med. 208:92-97.

Phillips, D. A. 1992. Flavonoids: plant signals topsoil microbes. Pp 201-231, *In* Phenolic metabolism in plants. (H.A. Stafford, ed.)

Wang, H. J. and **P. A. Murphy.** 1994. Isoflavone content of commercial soy foods. J. Agric. Food Chem. 42:1666-1673.

Wang, W. 1998. Radioimmunoassay determination of formononetin in murine plasma and mammary glandular tissue. Proc. Soc. Exper. Biol. Med. 217:281-287.

Comparison of Environmental Assessments of Two Proposed Harbor Expansions on the Mississippi River

Richard Grippo* and Bobby Bennett
Department of Biological Sciences
Arkansas State University
State University, AR 72467

Randel Cox
Department of Chemistry and Physics
Arkansas State University
State University, AR 72467

*Corresponding Author

Abstract

The National Environmental Policy Act of 1969 requires federally funded projects to be evaluated for environmental impact to determine if a complete environmental impact statement must be prepared. Such an environmental assessment must also be included in any feasibility study for harbor enlargement and bank stabilization measures under the Water Resources Development Act. Population increases, coupled with economic growth from increased agricultural and industrial productivity, have resulted in increased Mississippi River barge transportation needs for Arkansas and Missouri. We report here two such environmental assessments of planned harbor expansions of the New Madrid County and Pemiscot County ports in the Missouri bootheel along the Mississippi River. We evaluated the environmental settings, presence of wetlands, and the presence of hazardous, toxic or radioactive wastes (HTRW) at the two sites. The results of these evaluations were used to determine the possible significant resources and impacts (including endangered species) associated with harbor expansion at the two sites. No significant HTRW were present or likely to be encountered during construction at either site. However, differences in 1) the environmental settings (open high banks vs. bottomland forest), 2) significant resources (historical accounts of least tern colonies at one site), and 3) presence of wetland habitat at one site may preclude or reduce the level of one or both harbor expansions. Careful consideration of possible environmental impacts may help guide the choice of sites for similar harbor expansions in Arkansas.

Introduction

The National Environmental Policy Act of 1969 requires federally funded projects to be evaluated for environmental impact by "providing sufficient evidence and analysis for determining whether to prepare an environmental impact statement" (Federal Register, 1969). Such an environmental assessment must also be included in any feasibility study for harbor enlargement and bank stabilization measures under the Water Resources Development Act of 1966.

Population increases, coupled with economic growth from increased agricultural and industrial productivity, have resulted in increased Mississippi River barge transportation needs for Arkansas and Missouri. Additionally, national and state socioeconomic and political forces are working to increase the use of the Arkansas portion of Mississippi River as a transportation medium (Jonesboro Sun, 1999). Most Mississippi River harbor projects are large and require federal assistance for completion. Thus, the preparation of an environmental assessment for such projects is likely.

We report here two such environmental assessments of proposed harbor expansions of the New Madrid County and Perniscot County ports located in the bootheel region of Missouri on the Mississippi River. Our goal was to evaluate the environmental settings to determine if significant resources were present and if they would be impacted by the expansion projects. Rather then expending time and resources on extensive evaluations of all possible resources we have focused on the few that are likely to influence decisions about the projects. This information was used to determine if the preparation of an environmental impact statement might be necessary at either site. These sites are in proximity to northeastern Arkansas and have similar climate, geology, industrial, agricultural and socioeconomic considerations. Thus, a goal of this report is to provide a single source of information, (appropriate federal and state agencies to be contacted, useful methodologies and reference sources and manuals, etc), that would be applicable to preparing an environmental assessment for similar future harbor expansion projects in Arkansas. Finally, current thinking on environmental assessments suggests that the science and practice of developing assessments will not advance unless methods and results are shared in peer-reviewed forums (Suter, 1999).

Materials and Methods

Environmental Setting.--Both potential harbor expansion sites were evaluated for present land use, vegetation type, geology/groundwater, soils, wildlife and aquatic resources (including endangered and threatened species), cultural resources, the existence of important farmlands, the presence/extent of wetlands and the evaluation of the presence or potential for hazardous, toxic or radioactive waste (HTRW). All inspections, surveys and data collections took place between September 1997 and February 1998.

Qualitative and semi-quantitative assessments of dominant vegetation, wildlife (including rare and endangered species) and aquatic resources were performed using site inspections and interviews. Identifications were established using the following field guides: Bull and Farrand, 1990; Little, 1991; Palmer and Fowler, 1975; Peterson and McKenny, 1968. Further information on rare and endangered species was solicited from appropriate state (Missouri Department of Conservation) or federal agencies (United States Department of the Interior). Geology/groundwater (including potential earthquake hazard) and soils were determined using on-site inspection and published sources (Saucier, 1994; Brown 1977a, 1977b; EHM 1993).

Cultural resources were evaluated using site inspection and Morse and Morse (1983). The presence of HTRW was evaluated by on-site inspection; interviews with personnel associated with each harbor (e.g. harbormasters) and documented research.

Wetland delineations were performed following the Corps of Engineers Wetlands Delineation Manual (COE, 1987) using surveys of vegetation, soil, and hydrology in circular plots established along transects. Vegetation analysis was performed using Reed (1988). The soil analysis for each sample plot was determined using guidelines by the National Technical Committee for Hydric Soils (U.S.D.A., 1987) and soil color was determined using (Munsell 1994). The hydrology at each sample plot was determined by the presence of water in the soil hole within 45 cm of the surface, surface standing water, and hydric soil indicators. At those sites where the soil and hydrology criteria were met, the site was declared wetland if more than 50% of the dominant plant species were those typically found in a wetland and were listed in Reed (1988). Both wetland evaluations were performed during the month of November 1997.

Significant Resources and Impacts.--All information gathered was used to describe the project areas and provide an assessment of the significant resources and impacts likely to occur from each harbor expansion. The potential for significant impact to wooded and agricultural land, wetlands, wildlife, aquatic resources, threatened or endangered species, historic properties, water and air quality, and transportation was determined. The potential for release of hazardous, toxic and radioactive wastes due to past or current storage or use practices was assessed with regard to the proposed harbor expansions.

Results

Assessment of the two proposed harbor expansions showed similarities and differences in the environmental settings between the two proposed harbor expansion sites.

Project Area Descriptions.--The New Madrid County Port is located at km 549 (mile 885) on the lower Mississippi River (latitude N36° 32' 2.6", longitude W89° 34' 14.7") just south of New Madrid, MO as part of the St. Jude Industrial Park. A rice mill and grain operation utilize a general cargo dock and a grain-loading dock. The harbor extends perpendicularly from the Mississippi River, creating a year-round, ice-free slack water harbor. Current harbor size is 460 m long by 135 m wide with a three meter depth. The proposed expansion area (a rectangular shape approximately 300 m long and 90 m wide) is located at the north (upriver) side of the port (Fig. 1). The area is mostly flat with a slight (1-2°) slope from the levee to the river to improve drainage. The soil is composed of sandy fill material from the NW original harbor construction. A narrow tree line buffer strip (8-10m) occurs along the eastern edge of the site at the top of the bank of the Mississippi River. The proposed harbor expansion is extensive, involving the removal of 172,000 cubic m of material and the placement of 27,000 metric tons of riprap after expansion to reduce slope instability.

Fig. 1. Diagram of New Madrid County existing harbor and proposed widening site. Asterisks indicate areas with mature trees.

The Pemiscot County Port is located at km 526 (mile 849) on the lower Mississippi River (36° 13' 42.4" North latitude and 89° 41' 54.9" West longitude) just west of Caruthersville, MO on a portion of the river historically known as Gayoso Bend. This port includes a barge lid manufacturing facility with loading crane, granular fertilizer warehouse, and grain loading facilities and extends approximately 600m along Gayoso Bend. The harbor expansion

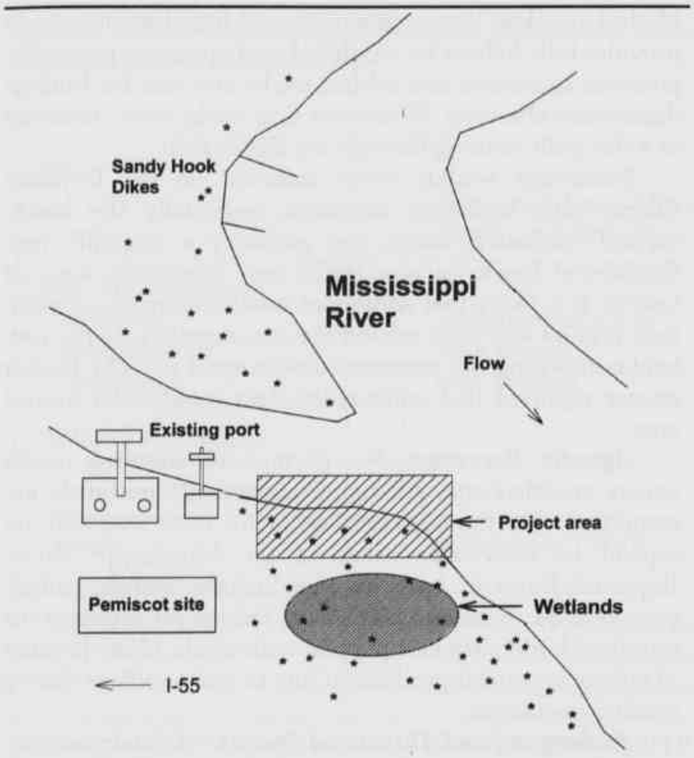


Fig. 2. Diagram of Pemiscot County existing harbor and proposed widening site. Asterisks indicate areas with mature trees

area is located near the confluence with the main channel of the Mississippi River and is separated into a lower riverbank area and an upper inter-levee area by the remains of a levee built in 1915. The riverbank area extends from the chemical warehouse easterly and southerly about 700 m in an elongated double half-moon, ending just downstream of the harbor mouth (Fig. 2). The project plan calls for removal of this half-moon shaped area to enlarge the harbor mouth. The inter-levee section lies between the 1915 levee and the current main-line levee. It is composed of a 6 ha dredge basin filled with dredged material from the harbor and a 7.3 ha willow-dominated wooded area. This wooded area is proposed to be filled by material removed from the expansion area. The amount of material to be removed would be approximately 115,000 cubic m, with 20,000 metric tons of rip-rap placed after expansion to reduce slope instability.

Land Use.--The primary land uses for both the New Madrid and Pemiscot study areas are rural agricultural and industrial with low density residential areas. Both expansions would occur on currently unused land partly (Pemiscot) or almost completely (New Madrid) formed by fill material. Some agriculture and manufacturing occurs immediately adjacent to the New Madrid harbor; a fleeting service (barge storage) is directly across from the Pemiscot harbor.

Vegetation.--The New Madrid site is composed almost entirely of little bluesterm grass with scattered small cotton-

Table 1. Proportional occurrence of major flora within vegetation layer type in the New Madrid County and Pemiscot County proposed harbor expansion sites.

	% Occurrence	
	New Madrid	Pemiscot
Treelayer		
Cottonwood (*Platanus occidentalis*)	98	30*
Black willow (*Salix nigra*)	1	60*
Water locust (*Gleditsia aquatic*)		5
Possumhaw (*Ilex decidua*)		2
Red maple (*Acer rubrum*)	1	2
Osage orange (*Maclura pomifera*)		1
Herbaceous layer		
Little Bluestem grass (*Schizachyrium scoparium*)	95**	0
Goldenrod (*Solidago* spp.)	<5	
Johnson grass (*Sorghum halepense*)	<5	5
Smartweed (*Polygonium* spp.)		30
Pigweed (*Chenopodium album*)		30
Aster (*Aster* spp.)		5
Ballon bine (*Cardisospermum halicacabus*)		5
Greenbrier (*Smilax* spp.)		5
Cocklebur (*Agrimonia* sp.)		15
Vine layer		
Green briar (*Vitus* sp.)		>90
Wild grape (*Vitis vulpina*)		<10

*together comprised 60% of all vegetation in project area. ** comprised 95% of all vegetation in project area.

woods and no wetland species (Table 1). The Pemiscot site is dominated by cottonwood and black willow saplings with a few mature trees and an herbaceous layer containing several wetland species. A vine layer on this site is dominated by green briar. No defined shrub layer is present at either site.

Geology/Groundwater.--Both proposed harbor expansion sites occur within the low relief Mississippi River alluvial valley within the upper Mississippi Embayment geologic province (Table 2). The New Madrid site sits on a Late Pleistocene terrace covered with Holocene natural levee sands/silts and fill sand from harbor construction. The Pemiscot site is composed of unconsolidated fluvial sediments of sand and clay. Both sites exhibit influent alluvial recharge into shallow alluvia aquifers; the Pemiscot site has a locally perched water table. There is a potential for significant geomorphological changes at both sites in the event of a strong earthquake from the nearby New Madrid fault.

Soils.--Soil types and characteristics at both harbor expansion sites are generally those expected in a large river floodplain (Table 3). At both sites the soils are characteristic of nearly level to gently sloping surfaces near the top of natural levees. However, the New Madrid natural levee is relatively old, whereas the natural levee at Pemiscot is relatively young. The New Madrid site soil was quite uniform in texture, color, and structure because it is primarily dredge material from harbor construction. The Pemiscot site soil is more variable due to the frequent flooding and sedimentation from the Mississippi River.

Wildlife.--The two sites exhibited differences in species richness (Table 4). The exposed, sandy soil of the New Madrid site with its sparse covering of little bluestem grass provides little habitat for wildlife. Local observers report the presence of racoon and rabbit; tracks and scat for both of these were observed. Numerous dog tracks were observed in a dirt path running through the buffer strip.

Numerous wildlife were observed on the Pemiscot County site, including songbirds (especially the black-capped chickadee, which was probably a migrant), red-shouldered hawk, racoon tracks and numerous signs of beaver. It is likely that additional small mammals, amphibians, reptiles and birds inhabit the site, especially in the wetland comprising the proposed dredge spoil pit. The harbor master reported that white-tailed deer inhabit the project area.

Aquatic Resources.--No permanent standing water occurs at either site. All significant aquatic resources are associated with the adjacent harbor for both sites and are typical of slackwater areas of the Mississippi River. Reported fishes in both harbors include sunfish, catfish, carp, buffalo, drum and black bass. Fishing for catfish at the mouth of both harbors is popular with locals, likely because of enhanced catfish production due to grain spillage during loading operations.

Endangered and Threatened Species.--Habitats associated with the proposed projects may support the following threatened or endangered species: bald eagle (*Haliaeetus leucocephalus*), pallid sturgeon (*Scaphirynchus albus*) and interior least tern (*Sterna antillarum athalassos*). None of these species was observed at either site during a total of six visits by Arkansas State University personnel. The U.S. Fish and Wildlife Service and the Policy Coordination office of the

Table 2. Geological and ground water characteristics of potential harbor expansion sites in New Madrid County and Pemiscot County, MO. Both sites are within the upper Mississippi River Embayment.

	New Madrid	Pemiscot
Geologic province	low-relief, braided channel terrace of the Mississippi River alluvial valley	low-relief Mississippi River alluvial valley
Terrace type	Late Pleistocene	Late Pleistocene
Bank height	up to 11 m, varies by flood stage	up to 9 m, varies by flood stage
Surficial materials	Holocene natural levee sands and silts deposited over Late Pleistocene valley train sands/gravels; fill sand	unconsolidated fluvial sediments consisting of lenticular sand units within silty clays
Groundwater	influent regime recharging adjacent shallow alluvial aquifers of 50 - 70 m thickness	influent shallow recharge, auvial aquifer 50 - 65 m thick, locally perched water table above clay
Earthquake potential	lateral spreading of banks during strong earthquakes	liquefaction of shallow saturated sands and lateral spreading

Table 3. Soil types and characteristics for general and wetland evaluations at the New Madrid County and Pemiscot County proposed harbor expansion sites.

	New Madrid	Pemiscot
Soil type series	 fine sandy loam Alfisols Bosket and Broseley	 silt loam Inceptisols Commerce
Soil characteristics thickness general color drainage	 approximately 2 m dark brown well drained	 approximately 1.5 to 2 m dark grayish poorly drained
Wetland evaluations		
horizon and depth	Ap--0 to 2 cm	Ap--0 to 4 cm
color	light brown (10YR 5/2)	dark grayish brown (2.5Y 4/2)
characteristics	very sandy loam fill material; very weak fine granular structure; few fine roots	silty loam; weak, grandular structure; few fine roots
mottles	few light brown (10YR 4/6); very weak wavy boundary	brownish-red (2.5YR 2.5/3); abrupt smooth boundary
horizon and depth	A--2 to 14 cm	Al--4 to 14 cm
color	light brown (10YR 5/2)	dark grayish brown (10YR 3/2)
characteristics	very sandy loam fill material; very weak fine dry granular structure; with numerous 1/25" diameter pea gravel	silty clay loam; thin platy structure breaking into moderate, fine and grandular
mottles	none	numerous, large, brownish red (2.5YR 2.5/3)

Missouri Department of Conservation were contacted regarding their opinions on impacts of the proposed projects to endangered and threatened species. The USFWS response (G. Frazer, pers. comm.) indicated that there are no known bald eagle nests in the vicinity of either proposed project area, and that pallid sturgeon preferred large, turbid, free-flowing, braided-channel riverine habitat, which is not found in either proposed project area. The USFWS indicated that least tern colonies have been observed on an island east of the Pemiscot County project area (river mile 845.2, km 524) and very near or within the New Madrid County project area.

The Missouri Department of Conservation (G. Christoff, pers. comm.) indicated that there were no sensitive species or communities known to occur on the Pemiscot County site or surrounding area. However, the MDC confirmed reports by locals that nesting colonies of the threatened interior least tern were observed on the sandy soil within the New Madrid County project site in June, 1990, when Mississippi River levels were high and preferred sandbar nesting habitats were inundated.

Cultural Resources.--Human occupation of the Mississippi valley in the vicinity of both proposed projects areas began approximately 12,000 years ago and has been continuous ever since (Morse and Morse, 1983). The cultural succession for the region includes the Dalton (12,000 to 8000 years ago), the Archaic (8000 to 3000 years ago), the Hopewell (3000 to 1000 years ago), and the Mississippian

Table 4. Occurrence of major wildlife species at the New Madrid County and Pemiscot County proposed harbor expansion sites.

	New Madrid	Pemiscot
beaver (*Castor canadensis*)		*
eastern cottontail rabbit (*Sylvilagus floridanus*)	*	*
raccoon (*Procyon lotor*)	*	*
swamp rabbit (*Sylvilagus aquaticus*)		*
white-tailed deer (*Odocoileus virginiana*)		*
black-capped chickadee (*Parun atricapillus*)		*
blue jay (*Cyanocitta cristata*)		*
field sparrow (*Spizella pusilla*)		*
indigo bunting (*Passerina cyanea*)		*
interior least tern (*Sterna antillarum athalassos*)	*†	
red-shouldered hawk (*Buteo lineatus*)		*
red-winged blackbird (*Agelaius phoeniceus*)		*
wood duck (*Aix sponsa*)	*	*
mallard duck (*Anas platyrhynchos*)		*

†nesting colonies observed in June, 1990 by harbormaster and Missouri Department of Conservation

(1000 years ago to European settlement). At the time of European contact, areas adjacent to both proposed project sites were occupied by the Pacaha chiefdom of the Mississippian culture (Morse and Morse, 1983). No cultural artifacts have been observed at either port expansion site, however, an extensive archeological clearance was not conducted as a part of this study.

Presence/Extent of Wetlands.--Both proposed project sites were evaluated for three characteristics that define the presence of wetland: (1) hydrophytic vegetation, (2) hydric soils, and (3) wetland hydrology.

Vegetation.--The New Madrid County proposed project area was dominated by a single species of grass (little bluestem grass; Table 1) which is a facultative upland plant. This proposed project area does not meet the wetland vegetation component of the wetland delineation methodology.

All vegetation on the Pemiscot County site occurred within either a tree or herbaceous strata. The tree stratum is composed of black willow (*Salix nigra*) and cottonwood (*Populas deltoides*). The tree cover is dominated (60%) by black willow. The Pemiscot County site meets the vegetation criteria for a wetland.

Soil.--The soil of the New Madrid County site as previously described (Table 3) had no noticeable hydric soil characteristics.

The soil of the Pemiscot County site is comprised of silty clay loam with hydric soil characteristics (mottles). This site meets the soils criteria for a wetland.

Hydrology.--The deep sandy fill that makes up the New Madrid site would make ponding, or standing of water impossible. The relatively high bank above the Mississippi makes inundation unlikely for all but the highest floods. Therefore, wetland hydrology was not present on this site.

The Pemiscot County site is immediately adjacent to the river inside the old mainline levee and thus is subjected to extended periods of inundation. The soil pit had standing water approximately 30 cm below the soil surface. There were large logs and numerous other drift material strewn about the area and water marks present on the trees at a height of 1.8-3 m. Wetland hydrology is present over most of this site.

Hazardous and Toxic Waste.--A search for potential sources of contamination and a risk assessment from construction activities to endangered species were performed within the project area through contacts with appropriate personnel and site visits. For the New Madrid County site this included the U.S. Fish and Wildlife Service, the St. Jude Industrial Park, Noranda Aluminum, Inc., Louis Dreyfus, and Associated Electric Cooperative, Inc. These contacts revealed that no hazardous waste dumps are located on the site, no hazardous waste spills have occurred for at least 11 years, and little hazardous material is shipped by either rail or barge from or to the site. Some hazardous and radioactive material storage and disposal records have been documented by industries adjacent to the project area. A historic county landfill, located 486m south of the project area, has been officially closed, capped, and poses no risk to the project activities. Site visits indicated an absence of apparent site-specific HTRW problems within the project area.

For the Pemiscot County site, the U.S. Fish and Wildlife Service, the Caruthersville Port Authority, and the City of Caruthersville were contacted for HTRW. These contacts indicated that no hazardous waste dumps are located on the site, no hazardous waste spills have occurred for at least five years, and little hazardous materials is shipped by either rail or barge from or to the site. An historic landfill is located approximately 300m northwest of the proposed project area. It is currently at full capacity and awaiting official closure. Site visits revealed an illegal dump within the project area containing non-hazardous residential trash. There are no apparent site-specific HTRW problems within the project area.

Discussion

The information developed above was considered in the following assessment of the likelihood of negative impact on significant resources associated with the local environs that would be affected by the proposed harbor expansions.

Wooded Land.--The Federal Water Project Recreation Act and the Fish and Wildlife Coordination Act are used to protect wooded lands as a resource important to sustaining wildlife populations. There is very little woodland acreage associated with the New Madrid County proposed project. All woodland is contained in a narrow strip (8-10 m) of stream bank buffer lying parallel and immediately adjacent to the expansion site at the top of the Mississippi River stream bank. This strip should be left as undisturbed as possible after harbor expansion to continue to serve as a buffer zone for reducing non-point source runoff and providing habitat for wildlife.

Significant wooded land and associated wildlife habitat would be eliminated by the Pemiscot County proposed project, especially in the inter-levee area to be used as a dredge pit. The existence of similar habitats adjacent to the project site may provide some refugia for wildlife displaced by the expansion.

Agricultural Land.--Agricultural land is recognized as important by the Farmland Protection Policy Act and by the Food Security Act of 1985. The New Madrid County proposed project would not take any farmland out of production because the area is covered with 13-50 cm of sandy fill and would be poorly suited for crop production.

The Pemiscot County proposed project would not take any farmland out of production because approximately 40% of the area is located within the normal seasonal Mississippi River flood plain; 30% is comprised of wetland and the remainder is a dredge pit covered with 50-75 cms of sandy fill and would be poorly suitable for crop production.

Wetlands.--The Clean Water Act and its associated regulations underscore the importance of wetlands to the natural resources and the well-being of the Nation due to their capacity for providing ecosystem services such as water quality improvement, sediment-trapping, flood control and wildlife habitat. Evaluation of the New Madrid County proposed project area indicates that neither vegetation, soils nor hydrology are suggestive of the existence of any wetlands. Conversely, the Pemiscot County site has vegetation, soils and hydrology that are suggestive of the existence of substantial wetlands within the project area. Current construction plans would eliminate all wetlands within this project area.

Wildlife.--The level of impact on wildlife resources in the New Madrid County proposed project area is likely to be low because of the poor to very poor wildlife habitat. In contrast, the level of negative impact on wildlife resources in the Pemiscot County proposed project area is likely to be very high because of the elimination of wetland and upland forest habitat.

Aquatic Resources.--The Clean Water Act is designed to improve, maintain, and protect the aquatic resources of the United States. The proposed projects will enlarge the existing slackwater harbors. During excavation activities it is likely that transient negative impacts, especially on benthic organisms, will occur from increased turbidity and habitat disturbance during drag-line and dredging operations. At both sites the planned stabilization of the newly exposed riverbank with rip-rap should minimize the long-term negative impact of the projects and provide additional high quality habitat for colonizing benthic organisms.

Threatened or Endangered Species.--The Endangered Species Act of 1973 provides legal protection for designated species. On-site inspections, local observers and both the US Fish and Wildlife Service and Missouri Department suggest that bald eagles and pallid sturgeon will probably not be adversely impacted by either of the proposed projects.

On-site inspections at the New Madrid County site revealed no colonies of least terns, but these inspections did not occur during the breeding season (late April to early October). Evidence from three different sources indicates that the site has been used for nesting by interior least terns in the past (1990). Because 1) the preferred nesting habitat for interior least terns is barren sandbars, 2) these preferred habitat types are still common at normal river stages on the Lower Mississippi River (Frazier, pers. comm.) and 3) least tern nesting apparently occurs in the proposed project area only during periods of extreme flooding of the Mississippi, it would be reasonable to conclude that the proposed project site is not preferred by interior least terns. The reported presence of racoons and the apparent high number of visits by dogs on the project site suggests that high predation pressure would occur on this ground-nesting bird, rendering the site marginal breeding habitat at best.

On-site inspections, local observers and both the US Fish and Wildlife Service and Missouri Department of Conservation suggest that bald eagles, pallid sturgeon and interior least terns will probably be minimally or non-impacted by the Pemiscot County proposed project. Several large trees which may be suitable for bald eagle perches will be removed. Interior least terns have been reported to fly as far as six km from a nesting colony to forage so they are likely to occur within the harbor area. Because the planned project is a widening of an existing harbor, no reduction in the availability of foraging habitat or abundance of small forage fish should occur, and the impact on interior least terns should be minimal.

Historic Properties.--There are no dwellings or other structures within either project area that are on the National Register of Historic Places. Thus, no impact will occur as a result of these projects.

Water Quality.--The lower Mississippi River is characterized by high turbidity from suspended solids, moderately elevated levels of nutrients (phosphate, nitrate) from fertilizer, depressed levels of silicate (due to increased diatom populations from elevated nutrients; Turner and Rabalais, 1991) and seasonal extremes in flow. It is not expected that either of the proposed projects will cause long-term changes in any of these variables.

Air Quality.--Long-term changes in the air quality are not expected to occur at either proposed project. It is likely that transient, local air quality degradation will take place because of emissions from drag-line and dredging machinery. It is unlikely that such emissions will greatly exceed those issued by tugboats during normal loading and unloading operations.

Transportation.--Transportation within both proposed project areas would be temporarily impacted while construction occurs. Because a drag line will be used to excavate material from the north bank of the New Madrid County harbor, and the existing facilities are located on the south bank, the impact should be minimal. Similarly, because materials will be excavated from the mouth of the Pemiscot County harbor, and the existing harbor facilities are located further upstream in Gayoso Bend, the impact should be minimal. Overall, transportation of barge-associated goods should increase as a result of each project implementation.

Hazardous, Toxic and Radioactive Wastes.--Based upon site visits and information gathered during the preliminary assessment of both project areas, it is reasonable to assume that no hazardous, toxic, or radioactive wastes would be encountered during the harbor expansions at the New Madrid County or Pemiscot County ports. The illegal dump site at the Pemiscot County site (which should be removed) and the capped municipal landfill nearby should not cause HTRW problems. No additional HTRW investigations are recommended and no further analysis is required.

Summary

From the results of these assessments, it is clear that specific environmental impacts will probably occur as a result of harbor expansions at both the New Madrid County and Pemiscot County ports. The use of the New Madrid site by a federally endangered/threatened species, and the existence of significant forested wetlands on the Pemiscot site may warrant further investigation into the cost vs. benefit of expanding these harbors. It is possible that additional arrangements will be necessary to reduce, eliminate or mitigate the negative enviromnental impacts associated with the projects. This is already underway for the Pemiscot County site, where the wetlands associated with the project, including both the riverine wetland and the interlevee wetland, (a total of 75 acres) are being mitigated by construction of artificial wetlands on a lake near Kennett, MO. If suitable alternative nesting sites are available for Interior least terns then the loss of the marginal site at the New Madrid County port my not be of concern.

The link between the present projects and similar projects likely to occur in regions of Arkansas bordering the Mississippi River is clear. Economic expansion in Arkansas due to industry and agriculture is necessary and inevitable as the regional population increases and becomes more diversified and mechanized. A concomitant increase in transportation needs, including increased use of the Mississippi River waterway as a conduit will result. Careful consideration of the environmental resources and possible impacts of harbor sites should allow economically efficient expansions while minimizing negative impacts on the environment.

ACKNOWLEDGMENTS.—The authors wish to acknowledge the contributions of J. Farris and C. Milam to the Hazardous, Toxic, and Radioactive Waste evaluation used in this report. The assistance of the U.S. Fish and Wildlife Service, Missouri Department of Conservation, the U.S. Army Corps of Engineers and the harbor masters at the New Madrid County and Pemiscot County ports are gratefully acknowledged. This report was funded by the United States Army Corps of Engineers, Memphis office but does not necessarily represent the views and opinions of that agency.

Literature Cited

Brown, B. L. 1977a. Soil Survey of New Madrid County, Missouri: U. S. Dept. Of Agriculture, Missouri Agri. Exper. Station, 70 pp.

Brown, B. L. 1977b. Soil Survey of Pemiscot County, Missouri: U. S. Dept. Of Agriculture, Missouri Agri. Exper. Station, 70 pp.

Bull, J., and **J. Farrand.** 1990. The Audubon Society Field Guide to North American Birds, Eastern Region. Alfred A. Knopf, Inc., NY. 784 pp.

COE. 1987. Department of Defense, Army Corps of Engineers, Corps of Engineers Wetland Delineation Manual. Tech Report Y-87-1.

EHM. 1993. Earthquake Hazard Map of Southeast Missouri, State of Missouri, Division of Geology and Land Survey, scale 1:300,000.

Federal Register. 1969. Regulations for Implementing the Procedural Provisions of the National Environmental Policy Act. 40 CAR Parts 1500-1508.

Frazier, G. Personal communication. United States Fish and Wildlife Service, Columbia, MO.

Jonesboro Sun. 1999. "Bill to reduce steel importing has passed House". Washington (AP) article, 3/18/99 pp.

Little, E. L. 1991. The Audubon Society Field Guide to North American Trees. Alfred A. Knopf, Inc., NY. 714 pp.

Morse, D. F., and **P. A. Morse.** 1983. Archaeology of the central Mississippi Valley: Academic Press, NY.

Munsell. 1994. Munsell® Soil Color Charts. Macbeth Division of Kollmorgen Instruments Corp., New Windsor, NY.

Palmer, E. L., and **S. S. Fowler.** 1975. Fieldbook of Natural History. McGraw-Hill, Inc., NY. 779 pp.

Peterson, R. T., and **M. McKenny.** 1968. A Field Guide to Wildflowers of Northeastern/Northcentral, North America. Houghton Mifflin Company, Boston, 420 pp.

Reed, P. B. Jr. 1988. National List of Plant Species That Occur in Wetlands (Region 5). U. S. Fish and Wildlife Service Biological Report 88.

Saucier, R. T. 1994. Geomorphology and Quaternary Geologic History of the Lower Mississippi Valley: U. S. Army COE, Waterways Experiment Station, Vicksburg, MS, 364 pp.

Suter, G. W. II. 1999. Lessons for small sites from assessments of large sites. Environmental Toxicology and Chemistry. 18:579-580.

Turner, E. R., and **N. N. Rabalais.** 1991. Changes in Mississippi River water quality this century. BioScience. 41:140-147.

U.S.D.A. 1987. U.S. Department of Agriculture. Soil Conservation Service. Hydric Soils of the U.S. as revised 1990.

Effects of Science Crusade in Arkansas

Mostafa Hemmati* and Heath Spillers
Physical Science Department
Arkansas Tech University
Russellville, Arkansas 72801

*Corresponding Author

Abstract

The NSF funded Arkansas Statewide Systemic Initiative (1992), developed with the intent to restructure mathematics and science education in Arkansas, is a recent reform in the Arkansas educational system. The project aimed at changing Arkansas students' attitudes toward science and mathematics, improving student learning and performance, introducing appropriate technology into the classrooms, and allowing for a lasting community involvement in the Arkansas educational system. To implement change through Arkansas Science and Math Crusades, the project has provided large scale teacher training and professional development opportunities to Arkansas school teachers. This reform effort in education started in 1992.

A search of the ERIC Database back to 1992 produces no relevant records relating to Crusades in general nor the Science Crusade in particular. This article presents the results of a study of the effects of the Science Crusade as viewed by Arkansas River Valley science teachers who have participated in the Science Crusade training.

Introduction and Background

During the past few decades, to attract high-tech industries and investment capitol, the Arkansas economical and political leadership has come to the realization that the most crucial factor in such an effort is to prepare an educated and skilled workforce. Comparison of Arkansas public schools students' performance in standardized tests with those of other states had created an unkind national perception. To alter that perception, major improvements in the students' performance had to be made. To achieve better performance results, a fundamental reform in teaching methods and strategies had to be employed to maximize student learning. Major attempts in reforming the Arkansas educational system, particularly during the last fifteen years, have been made. President Clinton, former Governor of Arkansas, has been a leading figure in such reforms.

This article will address one component of the most recent reform in Arkansas education. The Arkansas Statewide Systemic Initiative (1992) made the implementation of the reform possible. Its components, Arkansas Mathematics and Science Crusades, sought improvements in Math and Science. In an effort to achieve the best results, the Crusades were formulated to utilize the most advanced teaching methodologies and the most efficient approaches to students' learning. The Science Crusade is the subject of this study, and the Revised Edition of the Arkansas Science Crusade Trainer's Manual (Arkansas Statewide Systemic Initiative Program, 1996) describes it as follows.

1. A series of modules designed around hands-on science experiences intended to encourage teachers to use hands-on, inquiry-based science; increase their range of assessment alternatives; broaden their teaching strategies; deepen their understanding of important scientific concepts and content; and assess in all informed manner the quality of their schools existing curriculum in the light of the National Science Education Standards and Arkansas Science Frameworks.

2. An opportunity to experience sample activities from existing instructional resources. The resources are intended to reflect a philosophy of teaching that incorporates higher order thinking skills and reflects the intent of the National Science Education Standards. Activities range from a very open-ended constructivist style to the more traditional guided format. The activities are designed to reinforce basic science concepts and skills; encourage the application of concepts in problem solving and decision-making; and stimulate class discussions on curriculum, reform and equity. Teachers are encouraged to compare the different resources with regard to effectiveness and student engagement.

3. A catalyst for reform in science education (curriculum, teaching strategies, etc.) and a motivation for further professional development.

4. An opportunity to investigate a broad range of assessment strategies (including but not limited to performance based assessment and portfolios) to better determine their students' progress and understanding.

5. An opportunity to look at strategies to engage all students (traditionally served and underserved) in a meaningful science curriculum.

6. An opportunity for teachers and administrators from the 5-12 science community (public and private) to net-

work/interact with each other as well as faculty members from our colleges and universities.

The reforms were initiated to address identified shortcomings and; therefore, were expected to achieve certain goals. This article intends to measure the degree of success of the Science Crusade as viewed by instructors who have been involved in the reform.

To fund the Arkansas Statewide Systemic Initiative of which the Science Crusade was a part, in October of 1992, the Arkansas Department of Higher Education submitted a grant proposal to the National Science Foundation for the amount of $10,000,000.00. The following is an excerpt from President Clinton's (former Governor of Arkansas) letter of support included in the proposal (Arkansas Department of Higher Education, 1992):

"Arkansas has a vision of economic growth and human progress which depends on the ability of every child to reach his or her full potential. Systemic change at every level of our education system is the means by which we intend to realize this vision. The proposed Arkansas Systemic Initiative Project makes substantial commitments of time, energy and resources from key state agencies and other important participants in this effort.

Systemic educational change in Arkansas has been under way for most of the past decade and will extend beyond the life of the NSF support we hope to receive. Our vision means that we fully expect to see the day when it is a routine outcome of the education system for all children to achieve at their full potential as human beings. I hope you will join us in this endeavor."

The proposal described the MISSION of the project as follows: "The mission of the Arkansas Science Crusade is to help teachers of science create successful learning environments for every student, and to promote professional growth for teachers involving science content, and instructional strategies, and to provide access to adequate instructional materials including science equipment and technology in all Arkansas science classrooms", and intended to create a vision of:

1. Science literacy for all in an evolving technological society
2. Science as an active, constructive, cooperative process
3. Science involving experimentation, investigation of scientific phenomena, analysis, inquiry and problem solving
4. A science curriculum that includes interdisciplinary content connections and real-world applications.

The goals of the Arkansas Science Crusade, reflecting it's mission and vision, are listed in the proposal (Arkansas Department of Higher Education, 1992).

Method of Study

During the summer of 1994, to be certified as trainers, the author and another faculty member from Arkansas Tech University took part in the initial training of the Science Crusade. The training included over 100 hours of science content, and methodology and lasted until the end of the fall 1994 semester. After receiving the required grant, funds to conduct Science Crusade classes, we were able to offer three Science Crusade classes during the following two years. The science teachers participating in the classes completed seventeen three-hour training sessions followed by three follow-up sessions. A total of 54 science teachers from grades 4 through 12 representing school districts in the Arkansas River Valley area participated in the three Science Crusade classes.

To meet the goals as specified in the introduction, the seventeen Science Crusade training modules followed procedures envisioned by the Arkansas Statewide Systemic Initiative leadership. Prior to conducting training sessions, services of many science faculty from around the State were utilized to prepare a Trainer's Manual. The manual included seventeen modules which covered most areas of the physical and life sciences. The module's material was prepared with an interdisciplinary approach, and the subject delivery was intended to utilize progressive national trends in teaching methodologies and the most up-to-date teaching technology tools available. In three years following the start of the Science Crusade, the training modules evolved substantially and the training sessions and the number of modules were cut to fifteen.

During the spring of 1997 in an attempt to measure the effects of the Science Crusade on participating science teachers' approach to teaching science, a survey was drafted. The survey included fifteen questions tailored to parallel the goals of the Science Crusade. The survey was mailed to fifty-four science teachers who had participated in the three Science Crusade classes offered through the University. The science teachers had three weeks to return the survey. By the deadline indicated in the attached letter, we received 30 of the fifty-four surveys that had been mailed to the science teachers. This represented a 56% survey response. The method of response and the fifteen survey questions are as follows.

Strongly Disagree ① ② ③ ④ ⑤ Strongly Agree

1. The Science Crusade has effected my approach to the teaching of science as inquiry.
2. The Science Crusade directly effected the frequency I employ experimentation in my classes.
3. The Science Crusade has effected the implementation of a more standards based curriculum in my classroom

/ science department, (National Science Education Science Literacy).

4. The Science Crusade has effected the implementation of an integrated curriculum in my classroom / science department.

5. The Science Crusade introduced me to new science content and/or effective teaching strategies.

6. The Science Crusade has enabled me to more effectively incorporate critical thinking activities into my daily routine.

7. The Science Crusade introduced me to new technologies, manipulative.

8. The Science Crusade introduced me to investigative and instructional materials such as FOSS, GEMS, etc.

9. My school districts participation in the Arkansas Math and Science Crusade School/College Collaboration (50/50) matching grant has enabled me to better equip my classroom with the appropriate equipment and manipulative needed to develop scientific literacy.

10. The Science Crusade has effected my teaching strategies in such a way that student interest in science has increased.

11. The Science Crusade has increased interest in students who in the past tried to avoid science, particularly females and minorities.

12. The Science Crusade experience has enabled me to employ strategies that engage traditionally under-represented groups (females and minorities).

13. The Science Crusade experience influenced my decision to continue my education toward a Master Degree or additional certification areas.

14. The Science Crusade increased the partnerships between our local school district and our local businesses.

15. I have experienced an increase in support from the administration since the Science Crusade, for example asked for supplies and equipment and received funding.

Table 1. Summary of the data analysis

Sample Size	Question Number	X (Mean Value)	σ (Standard Deviation)
30	1	3.83	0.64
30	2	3.67	1.06
30	3	3.10	0.96
30	4	3.43	0.86
30	5	4.03	0.93
30	6	3.66	0.71
30	7	4.37	0.81
30	8	3.50	1.04
29	10	4.00	0.60
29	11	3.34	1.04
28	12	2.82	0.98
28	13	2.61	1.34
28	14	2.53	1.23
28	15	3.21	1.17

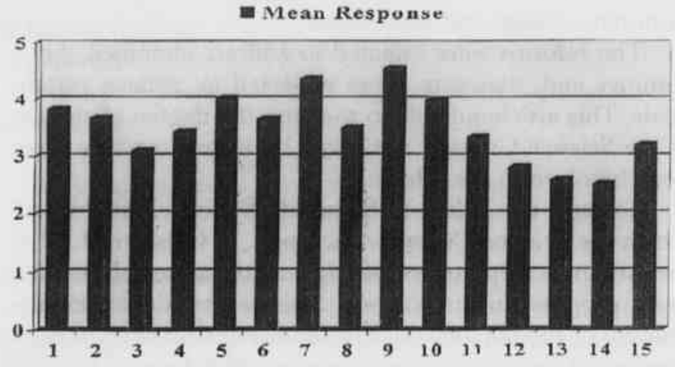


Fig. 1. Plot of the mean responses to the survey questions.

Table 2. Comparison of the means at $\alpha < 0.05$

AT $\alpha < 0.05$
$\bar{X}_1$ is greater than $\bar{X}_{12}$, $\bar{X}_{13}$, $\bar{X}_{14}$
$\bar{X}_2$ is lower than $\bar{X}_9$, and greater than $\bar{X}_{13}$ and $\bar{X}_{14}$
$\bar{X}_3$ is less than $\bar{X}_5$, $\bar{X}_7$, $\bar{X}_9$, and $\bar{X}_{10}$
$\bar{X}_4$ is less than $\bar{X}_7$, $\bar{X}_9$ and greater than $\bar{X}_{14}$
$\bar{X}_5$ is greater than $\bar{X}_3$, $\bar{X}_{12}$, $\bar{X}_{13}$, and $\bar{X}_{14}$
$\bar{X}_6$ is less than $\bar{X}_9$, and greater than $\bar{X}_{13}$ and $\bar{X}_{14}$
$\bar{X}_7$ is greater than $\bar{X}_3$, $\bar{X}_4$, $\bar{X}_8$, $\bar{X}_{11}$, $\bar{X}_{12}$, $\bar{X}_{13}$, $\bar{X}_{14}$, and $\bar{X}_{15}$
$\bar{X}_8$ is less than $\bar{X}_7$, $\bar{X}_9$ and greater than $\bar{X}_{13}$, and $\bar{X}_{14}$
$\bar{X}_9$ is greater than $\bar{X}_2$, $\bar{X}_3$, $\bar{X}_4$, $\bar{X}_6$, $\bar{X}_8$, $\bar{X}_{11}$, $\bar{X}_{12}$, $\bar{X}_{13}$, $\bar{X}_{14}$ and $\bar{X}_{15}$
$\bar{X}_{10}$ is greater than $\bar{X}_3$, $\bar{X}_{12}$, $\bar{X}_{13}$ and $\bar{X}_{14}$
$\bar{X}_{11}$ is less than $\bar{X}_7$, and $\bar{X}_9$
$\bar{X}_{12}$ is less than $\bar{X}_1$, $\bar{X}_5$, $\bar{X}_7$, $\bar{X}_9$, and $\bar{X}_{10}$
$\bar{X}_{13}$ is less than $\bar{X}_1$, $\bar{X}_2$, $\bar{X}_5$, $\bar{X}_6$, $\bar{X}_7$, $\bar{X}_8$, $\bar{X}_9$, and $\bar{X}_{10}$
$\bar{X}_{14}$ is less than $\bar{X}_1$, $\bar{X}_2$, $\bar{X}_4$, $\bar{X}_5$, $\bar{X}_6$, $\bar{X}_7$, $\bar{X}_8$, $\bar{X}_9$, and $\bar{X}_{10}$
$\bar{X}_{15}$ is less than $\bar{X}_7$, and $\bar{X}_9$

Data Analysis and Results

An IBM Model 9221 using SAS (1989) system was utilized for analysis of variance. Also, a Tukey multiple comparison was utilized to find differences among means ($\alpha \leq 0.05$). Table 1 represents the summary of the data analysis, Figure 1 is a plot of the mean responses to the survey questions, and Table 2 shows a comparison of the means at $\alpha <$

0.05.

A review of the Tables 1 and 2 indicates that five questions had five or more significant differences. Questions number seven ($X = 4.37$) and nine ($X = 4.55$) had high responses, indicating that the Science Crusade goals that science teachers become literate with the appropriate technology and their students have access to relevant science equipment have been met. The mean responses to question numbers 12, 13, and 14 indicate that the goals connected with science teachers use of strategies that engage traditionally under-represented groups; influence on science teachers' decision to continue their education toward a Master Degree or additional certification area; and increase the partnership between the science teachers' school district and their local businesses have not been achieved.

Conclusions

The analysis of survey responses indicates that, as viewed by the participants in the Science Crusade in the Arkansas River Valley area, a good number of the goals of the Science Crusade have been met. The Crusades have had precise planning and sought very progressive goals; therefore we believe that positive results indicate improvement in Arkansas science education.

In addition to the results of the collected data, there are other positive aspects of this reform. Some of the most energetic, optimistic, and reform minded science teachers and college science faculty from across Arkansas were recruited to implement the Crusade's vision. Those who were initially trained have been very active in training hundreds of Arkansas science teachers and numerous college faculty to implement this reform. The training processes and other organized activities after that training connected with the Arkansas Systemic Initiative Project have organized hundreds of concerned science teachers in professional meetings. These organizations have become the driving force which will sustain the continuation of reform and make it a lasting process.

ACKNOWLEDGMENTS.—The authors would like to express their gratitude to the Arkansas Statewide Systemic Initiative for its financial support of this study and Dr. Charles Gagen for his assistance with data analysis.

Literature Cited

Arkansas Department of Higher Education. 1992. A proposal entitled "Arkansas Statewide Systemic Initiative Program" submitted to the National Science Foundation.

Arkansas Statewide Systemic Initiative Program. 1996. Arkansas Science Crusade Trainer's Manual, 1996 Revised Edition.

SAS Institute Inc. 1989. SAS User's Guide; Basics, Version 5 Edition. Cary, NC: SAS Institute Inc., 1989.

Speed Range for Breakdown Waves

Mostafa Hemmati*, Eric George, and Frances Terry
Physical Science Department
Arkansas Tech University
Russellville, AR 72801

*Corresponding Author

Abstract

Considering the electrons as the main element in breakdown wave propagation and using a one-dimensional, steady-state, three-fluid, hydrodynamical model, previous investigations have resulted in the completion of a set of equations for conservation of mass, momentum, and energy. We will use the terms proforce and antiforce waves, depending on whether the applied electric field force on electrons is with or against the direction of wave propagation. In the case of antiforce waves, the electron gas temperature and therefore the electron fluid pressure is assumed to be large enough to sustain the wave propagation down the discharge tube.

For strong discontinuity and based on the conditions existent at the leading edge of the wave, previous investigations have concluded a minimum wave velocity condition for breakdown waves. However, allowing for a temperature derivative discontinuity at the shock front, we have been able to derive a new set of conditions at the shock front and therefore a lower range of electron drift velocity. This conforms with the experimentally observed wave speeds. The solution to the set of electron fluid-dynamical equations involves a previously discovered method of integration of the equations through the sheath (dynamical transition) region. For a wide range of wave speeds, the appropriate set of electron fluid-dynamical equations has been integrated through the sheath region.

Introduction

Shelton and Fowler (1968) argued that a fluid phenomenon involving no mass motion must be due to electron-fluid action. Therefore, they thought that the name "Electron Fluid-Dynamical Wave" represented a better description of the basic nature of the event. Owing to the smallness of the velocity changes of the heavy particles as the wave passes over them, a set of conservation equations applying only to the electron fluid could be derived. Using the principle of frame invariance, Shelton and Fowler (1968) found analytical forms for both the elastic and inelastic collision terms in the equations of conservation of momentum and energy. From the conservation of energy equation, they derived the conditions existent at the leading edge of the wave. Based on these conditions and for strong discontinuity, they found a minimum wave velocity condition ($\frac{1}{2}mV_0^2 \geq e\phi_i$), where ϕ_i, V_0, m, and e are ionization potential, wave velocity, and electron mass and charge respectively. To achieve a solution to the electron fluid dynamical equations, Shelton and Fowler had to resort to approximation methods.

For successful integration of the set of equations through the dynamical region, Fowler et al. (1984) had to modify Shelton's three component fluid equations for conservation of mass flux, momentum, and energy. With Poisson's equation included and for proforce waves, their set of equations which have proved to be successful are

$$\frac{dE}{dx} = \frac{e}{\epsilon_0} n\left(\frac{v}{V} - 1\right), \tag{1}$$

$$\frac{d(nv)}{dx} = \beta n, \tag{2}$$

$$\frac{d}{dx}\left\{ mnv(v - V) + nkT_e \right\} = - enE - Kmn(v - V), \tag{3}$$

$$\frac{d}{dx}\left\{ mnv(v - V)^2 + nkT_e(5v - 2V) + 2e\phi_i nv - \frac{5nk^2T_e}{mK}\frac{dT_e}{dx} \right\} = - 3\left(\frac{m}{M}\right)nkKT_e - \left(\frac{m}{M}\right)Kmn(v - V)^2. \tag{4}$$

Where the variables are electric field E, electron temperature T_e, electron concentration n, electron velocity v, and position in the wave profile x. Also, β and K are the ionization frequency and elastic collision frequency, respectively.

In the case of proforce waves, to reduce equations (1) through (4) to nondimensional form, Shelton and Fowler (1968) introduced a set of dimensionless variables. We have slightly modified the dimensionless variables and they are

$$\omega = \frac{2m}{M},\ \kappa = \frac{mVK}{eE_0},\ \mu = \frac{\beta}{K},\ \alpha = \frac{2e\phi}{mV^2},\ v = V\psi,\ n = \frac{\epsilon_0 E_0^2}{2e\phi}\nu,\ T_e = \frac{2e\phi}{k}\theta,\ E = \eta E_0,\ x = \frac{mV^2}{eE_0}\xi.$$

In the above equations, υ, ψ, θ, μ, κ, η, and ξ are the dimensionless electron concentration, electron velocity, electron temperature, ionization rate, elastic collision frequency, electric field, and position inside the wave, respectively. The symbols n and T_e represent electron number density and temperature inside the sheath, and β, ϕ, V, M, E_0 are ionization frequency, ionization potential, wave velocity, neutral particle mass, and electric field at the wave front. In terms of dimensionless variables the electron fluid dynamical equations become

$$\frac{d\eta}{d\xi} = \frac{\nu}{\alpha}(\psi - 1). \tag{5}$$

$$\frac{d(\nu\psi)}{d\xi} = \kappa\mu\nu, \tag{6}$$

$$\frac{d}{d\xi}\{\nu\psi(\psi-1) + \alpha\nu\theta\} = -\nu\eta - \kappa\nu(\psi - 1), \tag{7}$$

$$\frac{d}{d\xi}\{\nu\psi(\psi-1)^2 + \alpha\nu\theta(5\psi - 2) + \alpha\nu\psi + \alpha\eta^2 - \frac{5\alpha^2\nu\theta}{\kappa}\frac{d\theta}{d\xi}\} = -\omega\kappa\nu\{3\alpha\theta + (\psi-1)^2\}. \tag{8}$$

Solution of the Equations

For strong discontinuity, Shelton and Fowler (1968) derived the following conditions for electron velocity and temperature at the leading edge of the wave.

$$\psi_1 = \frac{5 - \sqrt{9 + 16\alpha}}{8}, \tag{9}$$

$$\theta_1 = \frac{\psi_1(1 - \psi_1)}{\alpha}. \tag{10}$$

Based on these conditions, he concluded a minimum wave velocity condition $(v_0 \geq \sqrt{\frac{2e\phi_i}{m}})$. However, allowing for a temperature derivative discontinuity at the shock front, introducing the initial condition on electron temperature from equation (10), and substituting the values of the other variables at the leading edge of the wave ($\xi_1 = 0$, $\eta_1 = 1$) into the energy equation with the heat conduction term included results in

$$\nu_1\psi_1(\psi_1 - 1)^2 + \nu_1\psi_1(1-\psi_1)(5\psi_1 - 2) + \alpha\nu_1\psi_1 + \alpha(\eta_1^2 - 1) - \frac{5\alpha\nu_1\psi_1}{\kappa}(1-\psi_1)\theta_1' = 0. \tag{11}$$

This equation reduces to

$$-4\psi_1^2 + 5\psi_1 - 1 + \frac{5\alpha\psi_1}{\kappa}\theta_1' + \alpha - \frac{5\alpha\theta_1'}{\kappa} = 0. \tag{12}$$

Solving this quadratic equation for ψ_1, one can find the initial condition on electron velocity to be

$$\psi_1 = \frac{5(1 + \frac{\alpha\theta_1'}{\kappa}) - \sqrt{(3 - \frac{5\alpha\theta_1'}{\kappa})^2 + 16\alpha}}{8}. \tag{13}$$

From Poisson's equation and for waves moving into an unionized medium, one can conclude $e(N_iV - nv) = 0$. This is called the zero current condition, and it requires that V and v be of the same sign. Therefore, $\psi_1 = \frac{v_1}{V}$ has to be positive. From equation (13) one can conclude

$$5(1 + \frac{\alpha\theta_1'}{\kappa}) - \sqrt{(3 - \frac{5\alpha\theta_1'}{\kappa})^2 + 16\alpha} > 0 \tag{14}$$

or

$$0 < \alpha < (1 - \frac{5\theta_1'}{2\kappa})^{-1} \tag{15}$$

With positive values of θ_1', α can have values larger than one, and we have been able to find solutions for α as large as 2. This conforms with experimentally observed wave speeds (Uman, 1993).

To integrate the equation set through the sheath region, one has to place the singularity inherent in the equation set in the denominator of the momentum integral. If we solve the momentum equation (7) for $\frac{d\psi}{d\xi}$ it will become:

$$\frac{d\psi}{d\xi} = \frac{\kappa\psi(1-\psi)(1+\mu) - \alpha\theta'\psi + \eta\psi - \alpha\kappa\mu\theta}{\psi^2 - \alpha\theta}. \tag{18}$$

A zero denominator in the momentum integral represents an infinite value for the derivative of electron velocity with respect to the position inside the sheath. This condition requires the existence of a shock inside the sheath region, which is not allowed. The numerator in the momentum integral, therefore, has to become zero at the same time that the denominator becomes zero. In the process of integration of the equations through the sheath region, comparing the numerator and denominator values will allow one to choose the required initial parameters by trial and error. A successful solution has to allow passage through the singularity and satisfy the physically acceptable conditions at the trailing edge of the sheath. The expected conditions at the end of the sheath are a) the electrons have to come to rest relative to neutral particles ($\psi \rightarrow 1$), and b) the net electric field has to reduce to a negligible value ($\eta \rightarrow 0$). The method of integration of the set of electron fluid dynamical equations is identical to the one adopted previously (Hemmati et al., 1998).

For a wide range of wave speeds and for proforce waves moving into a nonionized medium, we have integrated the set of electron fluid-dynamical equations through the sheath region. The solutions meet the expected conditions at the trailing edge of the wave ($\psi \rightarrow 1$, $\eta \rightarrow 0$). Successful integration of the set of equations through the sheath region required the use of the following values for κ, ψ_1, and υ_1.

$\alpha = 0.01$, $\kappa = 1.239718$, $\psi_1 = 0.327$, $\upsilon_1 = 0.023$
$\alpha = 0.1$, $\kappa = 1.071818$, $\psi_1 = 0.29125$, $\upsilon_1 = 0.235$
$\alpha = 0.25$, $\kappa = 0.959363$, $\psi_1 = 0.26016$, $\upsilon_1 = 0.666$
$\alpha = 0.5$, $\kappa = 1.08576$, $\psi_1 = 0.25375$, $\upsilon_1 = 1.05$
$\alpha = 1$, $\kappa = 1.0426635$, $\psi_1 = 0.2071$, $\upsilon_1 = 2.1$

Figure 1 is a plot of the electric field, η, as a function of electron velocity, ψ, inside the sheath for five values of α. $\alpha = 0.01$ represents a fast wave speed ($V = 3 \times 10^7$ m/s) and $\alpha = 1$ represents a slow wave speed ($V = 3 \times 10^6$ m/s). The graph shows that for all five values of α the solutions to the electron fluid dynamical equations conform to the expected physical conditions at the trailing edge of the wave.

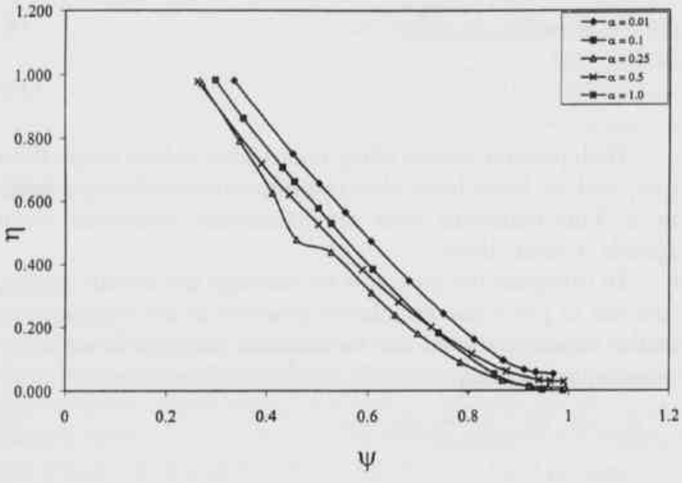


Fig. 1. Electric field, η, as a function of electron velocity, ψ, for five values of α. α = 0.01, 0.1, 0.25, 0.5, and 1. α represents wave speed.

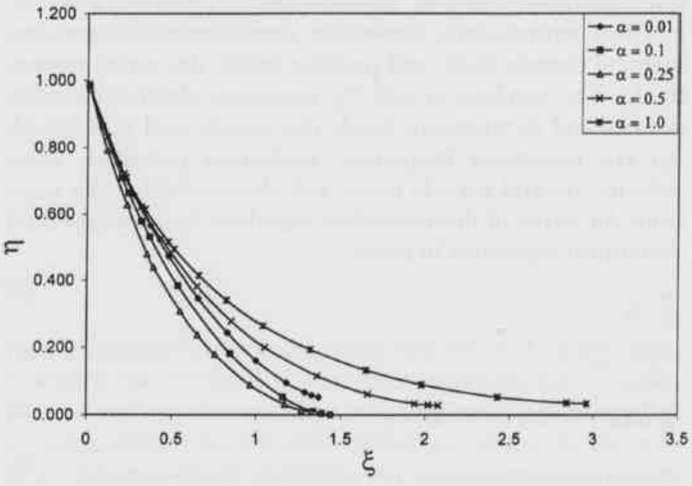


Fig. 2. Electric field, η, as a function of position inside the sheath, ξ, for five values of α. α = 0.01, 0.1, 0.25, 0.5, and 1. α represents wave speed.

Figure 2 shows graphs of electric field, η, as a function of position inside the sheath, ξ, for five values of wave speed. As the value of the wave speed decreases (α increases), the integration of the equations becomes more difficult and time consuming. $\alpha = 4$ seems to be the cut-off point, representing a minimum wave speed. For $\alpha > 4$, the integration of the set of equations through the sheath region becomes impossible. The present limit on the values of wave speed conforms with the experimentally measured values (Uman, 1993). For $\alpha = 0.01$, the nondimensional sheath thickness is $\xi = 1.4$. To connect to the physical world, this represents a sheath thickness of $x = 0.0007$ m.

Conclusions

For proforce waves, the electron fluid dynamical equations have successfully been integrated for five different values of wave speeds. Allowing for a temperature derivative discontinuity at the shock front results in a lower limit on breakdown wave speeds. Our newly derived limit on wave velocity conforms with the experimentally observed wave speeds.

ACKNOWLEDGMENTS.—The authors would like to express their gratitude to the Scientific Information Liaison Office for their financial support of this research project.

Literature Cited

Fowler, R. G., M. Hemmati, R. P. Scott, and **Parsenajadh.** 1984. Electric breakdown waves: Exact numerical solutions. Part 1., Phys. Fluids. 27:1521-1526.

Hemmati, M., M. S. Doss, and **E. L. George.** 1998. Speed cut-off point for antiforce waves. J. Arkansas Acad. Sci. 52:63-66.

Shelton, G. A., and **R. G. Fowler.** 1968. Nature of electron-fluid-dynamical waves. Phys. Fluids. 11:740-746.

Uman, M. A. 1993. Natural Lightning. Proc. IEEE Industrial and Commercial Power Systems Technical Conference. Vol. 93ch3255-7 pp. 1-7.

Microlevel Climate Change due to Changes in Surface Features in the Ganges Delta

M. M. Adel
Interdisciplinary Sciences Research Center
Department of Chemistry & Physics
P. 0. Box 4941
University of Arkansas at Pine Bluff
Pine Bluff, AR 71611

Abstract

The Ganges had been the world's 8th largest river in terms of the volume of water discharge of 490 km^3/yr to the ocean prior to 1975. Since that time, over a period of two decades, India has reduced the Ganges discharge through Bangladesh to 40% from its original annual average discharge of 1,932+/-223 m^3/s by diverting water for irrigation in her upper states. The resulting consequences have been disastrous due to the depletion of the surface water resources. One of the devastating consequences has been the generation of extreme climate. The summertime maximum temperature has risen to about 43.33°C (110°F) from about 37.22°C (99°F). The heating degree days (HDDs) calculated with the base temperature of 30°C (86°F) show that the average value of HDD after the generation of extreme climate is 637C° (1146.6F°) more than the value before the generation of the climatic extremity. During the era of the pre-diversion of water the relative humidity had to rise to 75% to generate heatstroke conditions at the then summertime maximum temperature of 37.22°C (99°F), whereas under the current summertime maximum temperature, the same conditions begin at a relative humidity value of 45%. This results in prolonged exposure to heatstroke conditions for 40 million of the world's poorest people. Further, the wintertime minimum temperature has dropped from about 8.33°C (47°F) to about 4.44°C (40°F), and it still shows a dropping trend. This low temperature along with a wind speed of 16 to 24 km/hr creates hypothermal conditions, particularly for the oldest and the youngest persons and takes a heavy death toll. Cooling Degree Days (CDDs) calculated from a base temperature of 15°C (59°F) show that there are more fluctuations in CDDs in post-diversion time than in pre-diversion time. An estimation shows that at least 20 million trillion calories of heat are generated during the summertime in the Gangetic Bangladesh because of early drying of the surface water resources. Since water and the wet soil used to retain that heat due to the highest thermal capacity of water, there is a shortfall of the same amount of heat creating an environmental heat deficit during the wintertime in the absence of the surface water resources. To improve length and quality of life for the people of Biosphere III, the Farakka Barrage has to be demolished, and the original flow of the Ganges through itself and its distributaries in the delta must be restored.

Introduction

The Ganges basin in Bangladesh, hereafter called Biosphere III because of the unique ecodisastrous effects it has been suffering, has had an almost continuous shortage of water for more than two decades beginning in 1975. While Biosphere II is an artificially enclosed environment to simulate the living conditions is space, the term Biosphere III is introduced for this region marked with artificially created critical shortage of water and subsequent evolution of a series of situations like climatic extremes, fading tolerance of different species of living beings, arsenic poisoning of groundwater, epidemic form of environmental diseases, etc. In 1975, India started withdrawing the Ganges water by the operation of the Farakka Barrage, which is built over the Ganges about 18 km upstream from the Indo-Bangladesh common border. Although its stated purpose was to maintain navigability of the Calcutta Port located about 260 km downstream from the barrage point, its main use so far has been to provide the Ganges water for irrigation for the upper states of India (Crow, 1981; Bindra, 1982; Begum, 1988; Crow et al., 1995; Sattar, 1996; New York Times; 1997).

Figure 1 illustrates the Ganges-Brahmaputra basin in the Indian Subcontinent. The Ganges starts in the Himalayas, passes through the upper states of India and enters Bangladesh through the north-west side. Biosphere III, the study area, is the region to the west side of the river through the delta. Figure 2 illustrates the river systems in Bangladesh - the Ganges enters from the northwest, the Brahmaputra from the north, and the Meghna from the northeast. All these rivers join together before falling to the Bay of Bengal. The Biosphere III is shown by cross-hatched lines. The Ganges water had been the sustainer of life for the ecosystems that flourished in the basin for thousands of years. The Ganges water along with the monsoon runoffs

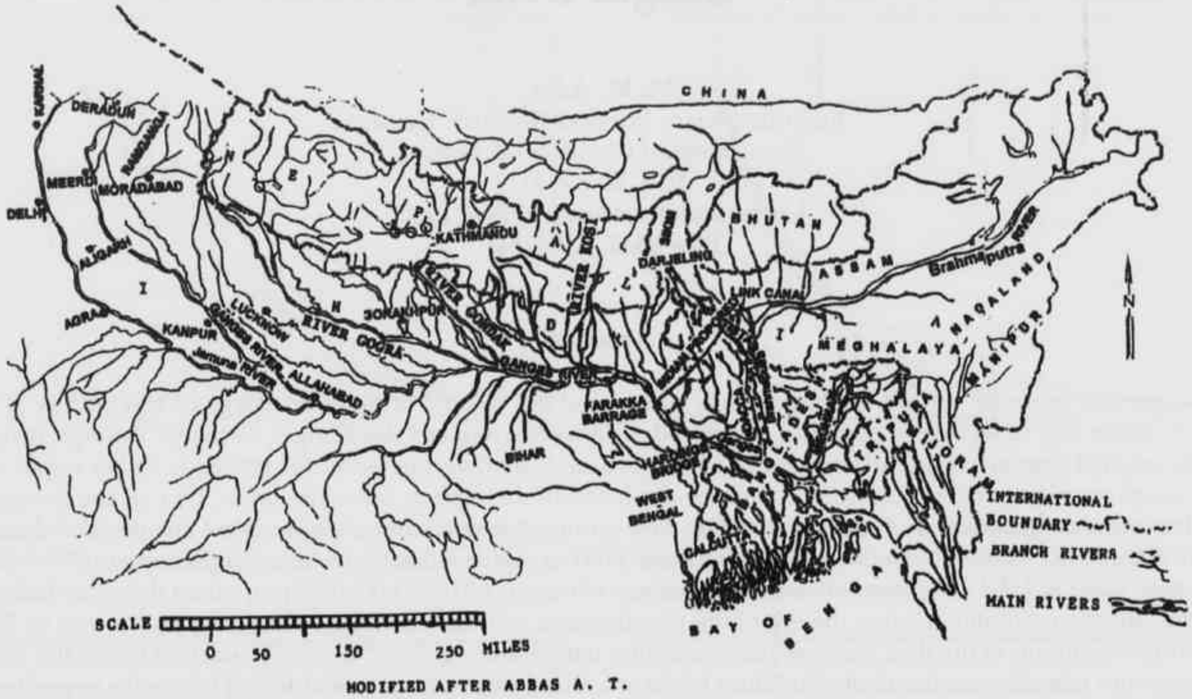
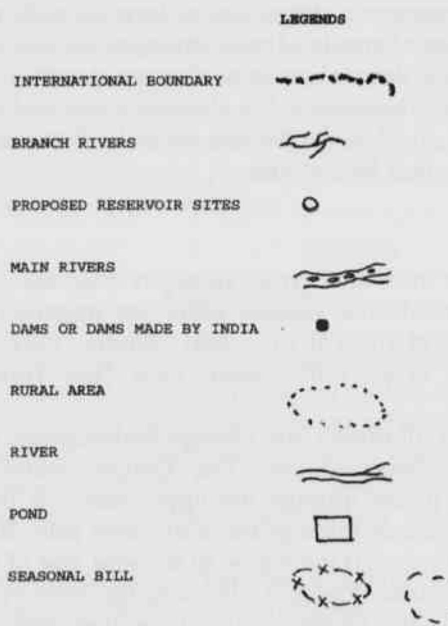


Fig. 1. Illustration of the course of the Ganges from the Himalayas through the upper states of India, Bangladesh, and then to the Bay of Bengal (modified after Abbas A. T.)



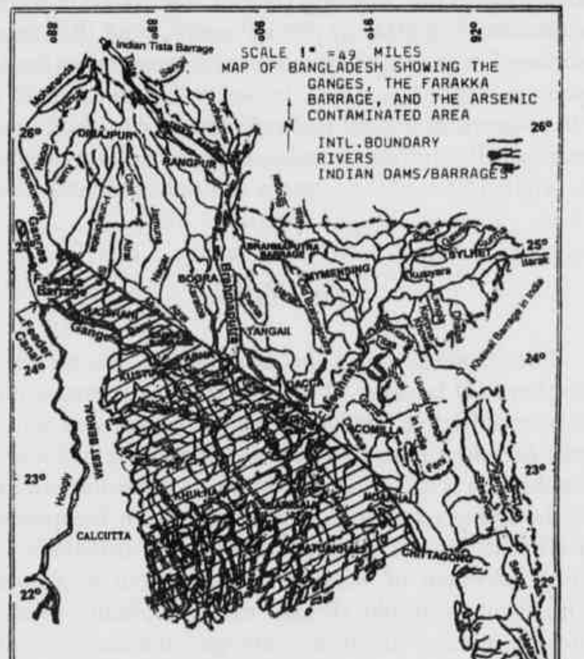


Fig. 2. Illustration of the river systems in Bangladesh. The cross-hatched part is the Ganges basin called Biosphere III. It also illustrates the locations of the Farakka Barrage, the Hoogly river, and the Calcutta Port (modified after Abbas A. T.)

had been the source of the surface and groundwater resources. The surface water resources included the distributaries of the Ganges, canals, floodplains, ponds, and ditches. The pre-dam Ganges discharge of 490 kM^3/yr had been equivalent to 455 mm/yr (Dingman, 1994); the latter unit (equals the volume discharge per year divided by the area under consideration) is introduced for comparison with the monsoon rainfall that ranged from 1500 mm/yr on the north to 2750 mm/yr on the south over the Ganges delta (Huq, 1974). While the flood season Ganges discharge in the distributaries currently varies from zero to about one-quarter of the original discharge in quantity and about one-half of the original duration, the post-Farakka monsoon rainfall is reduced to about 70% of the pre-Farakka rainfall (Miah, 1999a) because of the depletion of the surface water resources that used to supply additional moisture on land by evapotranspiration from surface water resources to the incoming saturated air from the sea in the south to meet some critical condition to cause precipitation. As to the dry season condition of the Ganges, Hillary (1979) writes in his travel account on the Ganges that during this season (November - May) nearly all the water from the Ganges is diverted by India through the Ganges canal. Further, the depletion of the surface water has led to a big impact upon the groundwater resource. While the groundwater extraction previously in Bangladesh had been about 5 mm/yr and was for drinking alone, the extraction in post-Farakka years is about 325 mm/yr for domestic, 133 to 246 mm/yr for irrigation, and about 40 mm/yr for fish farming. The volume extraction of groundwater can be obtained multiplying the figures by the area factor under consideration. Once again, this way of expressing the unit of groundwater extraction can be related to the depth of the sinking groundwater table and the monsoon rainfall. Following the weak discharge from the Ganges, the sedimentation rate of about 1.2 kg-m^{-2}-yr^{-1} in the Ganges water has formed large shoals in the Ganges itself blocking the discharge in the distributaries (Miah, 1996a). The monthly average discharge for pre- and post-Farakka years is illustrated in Fig. 3 (Miah and Samad, 1999). The top three curves corresponding to 1850, 1900, and 1980 apply to the Farakka point (Schwarz et al., 1993) in India. The bottom two curves corresponding to 1963 and 1993 are applicable to the Hardinge Bridge point located near the proposed Ganges Barrage site in the delta shown in Fig. 2. The dry season flow at the Hardinge Bridge point had been 2,000 m^3-s^{-1} or more as found from the hydrograph for 1963. However, the hydrograph for 1993 in the post-diversion era shows about 45% reduction all the year round.

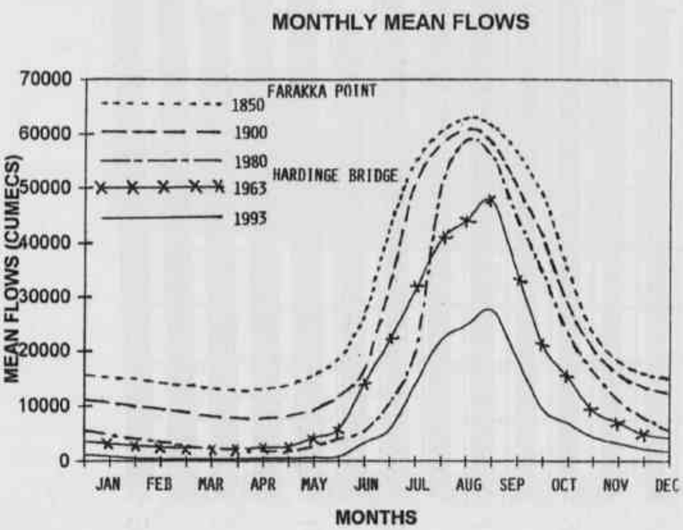


Fig. 3. Illustration of the monthly average flow rate of the Ganges for the years 1850, 1900, and 1980 at the Farakka point, and for 1963 and 1993 at the Hardinge Bridge point located near the proposed Ganges Barrage in Biosphere III.

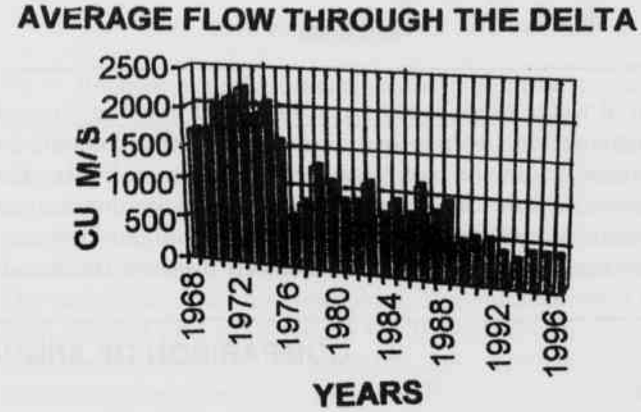


Fig. 4. Illustration of the average annual discharge rate of the Ganges through Biosphere III (courtesy of Hebblethwaite, 1997).

The average annual discharge in pre- and post-Farakka years is illustrated in Fig. 4 (courtesy of Hebblethwaite, 1997). The average flow (770+/-285 m^3-s^{-1}) in the post-Farakka years is 40% of the average flow (1932+/-223 m^3-s^{-1}) in pre-Farakka years. Figure 5 shows the resulting condition of the Ganges at the Hardinge Bridge point, the observation point for the Water and Power Development Authority of Bangladesh, following the water diversion. The dry and fissured bed reflects, absorbs, and radiates heat instead of almost totally absorbing heat when the bed is covered with water.

A multitude of effects including the depletion of surface water resources, a loss of professions, the obstruction of irrigation, a drop in cash crop production, the extinction and near-extinction of an unknown number of aquatics and amphibians, an increase in malnutrition, a drop in horticultural production, the closure of navigable routes, the deple-

Fig. 5. The dry and fissured Ganges bed.

tion of water sports facilities, an increased pressure on land transportation, a drop in soil organic matter content, an increase in inland intrusion of saline water fronts, the overextraction of groundwater, the contamination of groundwater by arsenic, an outbreak of skin and lung cancers, the occurrence of environmental diseases, the development of extreme climate, the occurrence of strokes and asthma, and the feedback effects have occurred since the water shortage began (Miah, 1994a, 1994b, 1995a, 1995b, 1995c, 1995d, 1995e, 1996a, 1996b, 1996c, 1996d, 1996e, 1996f, 1996g, 1997a, 1997b, 1997c, 1997d, 1997e, 1998a, 1998b, 1998c, 1998d, 1998e, 1998f, 1999b, 1999c, 1999d, 1999e, 1999g; Miah and Samad, 1996, 1999). These said effects surpass the ones created by the diversion of water from the Amudarya and the Sirdarya, the two feeder rivers for the Aral Sea, for the cultivation of cotton in the former Soviet Union (Micklin, 1988; Brown, 1991; Sneider, 1992). One of the disastrous effects is the generation of extreme climate leading to human sufferings and even fatalities. This is the focus of this paper. Although the name of India is involved in the construction of the Farakka Barrage, the paper unveils science for the suffering humanity and does not take any political stance against anything.

Materials and Methods

The climate data for Biosphere III were supplied by the Meteorological Office in Dhaka, Bangladesh for pre- and post-Farakka years. Due to the time lag of a few years in archiving data, any year's data are not available until 4 to 5 years later. The supplied data were analyzed to see if there

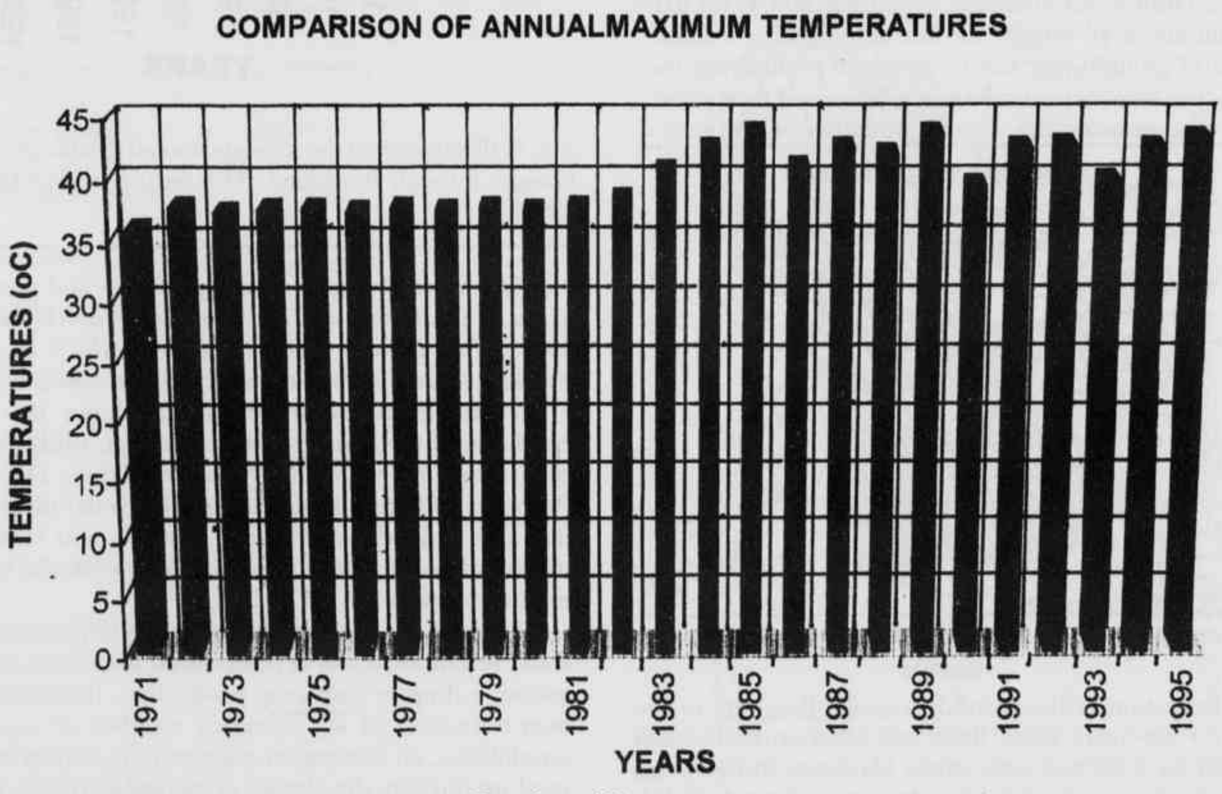


Fig. 6. The summertime maximum temperature in Biosphere III.

have been any changes in the climate following water diversion. Although the pre-dam data spanned decades back beyond the beginning year of water diversion, only a few years up to 1971 have been included in the analysis because of finding no changes in the data trend. The maximum temperatures for the years 1971 through 1995 were plotted. This is illustrated in Fig. 6. The illustration shows that the increase in maximum temperature started after 1981. It can be said that the pre-Farakka maximum temperature of about 37.22°C (99°F) has increased to about 43.33°C (110°F) in post-Farakka years.

Further, Heating Degree Days (HDDs) were calculated with the base temperature of 30°C (86°F) (Mitchell, et al., 1973) In that part of the world where the people live in open-windowed houses and work in open air, the base temperature is assumed not to be uncomfortable for them. For an average temperature larger than the base temperature, the difference between the average and the base temperature was calculated. This calculation was done for the days in March through November of every year. An average temperature equal to or lower than the base temperature contributed nothing to HDD. Afterwards, these differences were added to get the HDD for every year in the interval 1971-95. HDDs have been plotted in Fig. 7. It shows HDDs are larger beginning in 1983. Average values of HDDs from 1983 onward are 637°C (1146.6°F) more than that for previous years for Biosphere III.

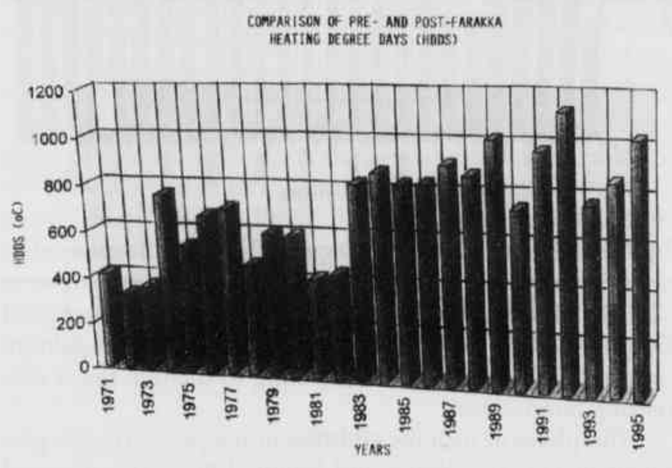


Fig. 7. The Heating Degree Days (HDDs) for Biosphere III.

An evidence of a dangerous environmental condition has been revealed in this study as discussed below. Since that condition is the result of the maximum temperature and humidity, and having discussed the maximum temperature, the variation of relative humidity is now examined by a plot of the comfort index. The monthly averages of the daily maximum and minimum values of the relative humidity for 1990 have been plotted in Fig. 8. The maximum value stays above 95% and the minimum stays above 40%. A relative humidity value above 45% is dangerous in conjunction with the current maximum temperature as is evident from the plot in Fig. 9 (Pearce and Smith, 1984). This figure shows the comfort index as a function of temperature and humidity. The oblique lines are humidity lines. The comfort index has been divided into six divisions by drawing five horizontal lines that pass through the humidity lines. The level of discomfort for each division is indicated to the left of the 100% humidity line. The combination of temperature and relative humidity results in distinct stress, great discomfort, and high danger of heatstroke. Two dotted vertical lines have been drawn. One corresponds to the maximum temperature in the pre-Farakka period, and the other corresponds to the current maximum temperature. In pre-Farakka days, distinct stress would start at about 40% relative humidity and heatstroke at about 75%. In post-Farakka days, the distinct stress starts at lower than 20% relative humidity, and heat stroke condition starts at about 46% relative humidity. What the comparison of Figs. 8 and 9 reveals is that from mid-April to mid-November 40,000,000 of the world's poorest people live under heat stroke conditions. This condition becomes unbearable for cardiovascular and asthma patients, which are comparatively more numerous in Biosphere III than in any other part of the country (Miah and Samad, 1999). Also, infants and elderly persons suffer from dangerous heat stress. There are reports that under these climatic conditions, occurrences of hypertension, apoplexy, etc. become common (Hays and Hussain, 1995; Hussain and Hays, 1993, 1997; Rogot, 1973; Rogot and Padgett, 1976). Kalkstein and Valimont (1987) give many examples of mortality and morbidity due to high temperatures. For

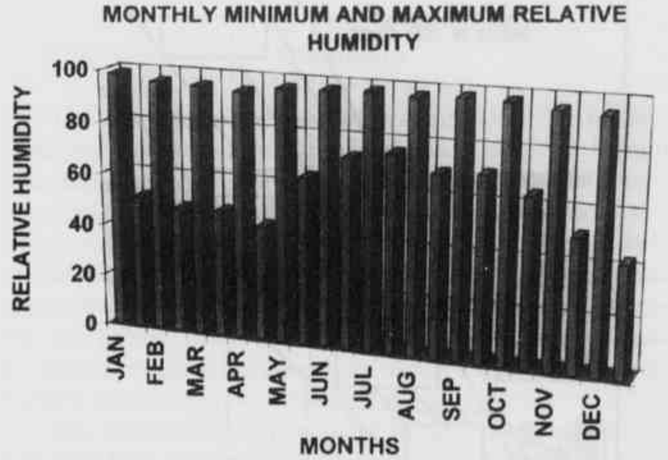


Fig. 8. Illustration of the monthly average relative humidity.

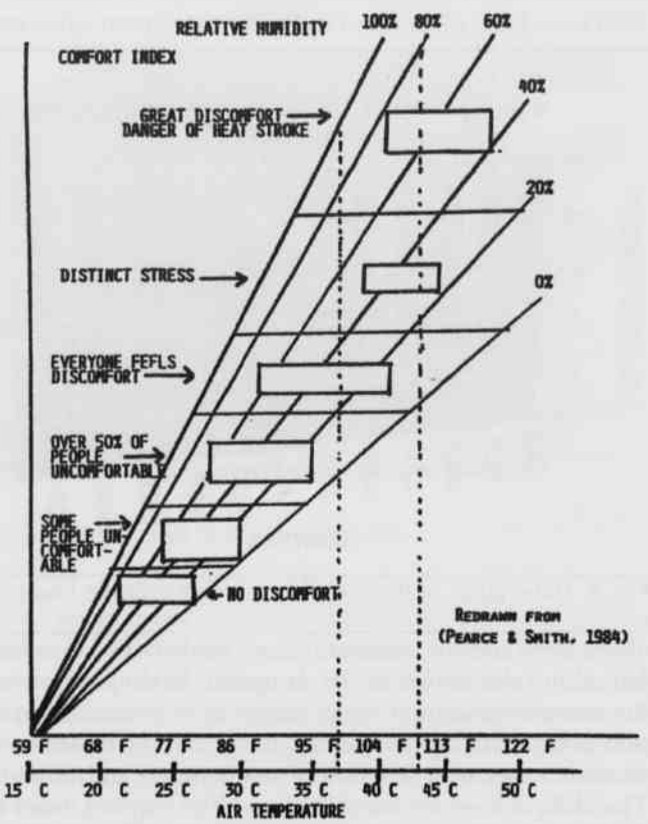


Fig. 9. Illustration of the comfort index as a function of relative humidity and temperature (Pearce and Smith, 1984).

Biosphere III, such statistics have yet to be prepared.

In addition to plotting the summertime maximum temperatures, wintertime minimum temperatures have been plotted in Fig. 10. The minimum temperature of about 8.33 °C (47°F) of pre-Farakka days has dropped to 4.44°C (40°F) or below. The curve still shows a dropping trend. The dropping trend is just an indication of a continuous heat loss by Biosphere III. Like HDDs, CDDs (Cooling Degree Days) were calculated with a base temperature of 15°C (59°F) (Mitchell et al., 1973) . It was assumed that the people of Biosphere III could tolerate this temperature because they work under natural conditions and live in open-windowed houses. The plot of CDDs in Fig. 11 shows that there is great variation in the number of CDDs per year. The number of CDDs in 1983 and 1989 is particularly high. The pre-Farakka highest CDD was 281.3°C (506.34°F) in 1972. As the plot shows, the post-Farakka highest CDDs have been 372.4°C (670.32°F) in 1983 and 475.7°C (856.26°F) in 1989.

If the wind chill is taken into account, the equivalent temperature will be even lower. In the delta, the wintertime wind speed may reach about 27 Km/hr. For a temperature of 4.44°C (40°F), the equivalent wind chill temperature is -

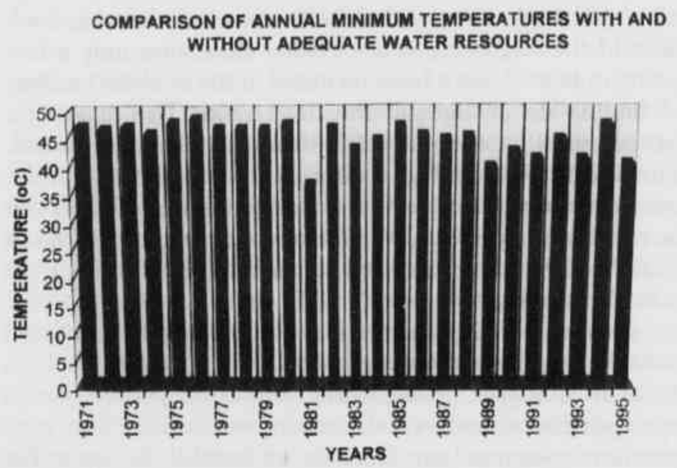


Fig. 10. The wintertime minimum temperature for Biosphere III.

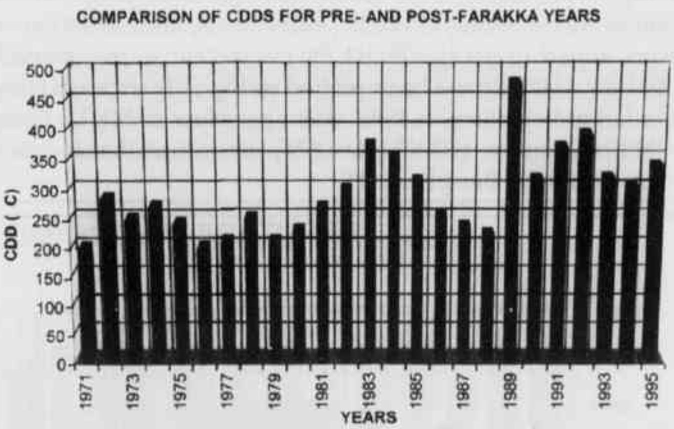


Fig. 11. The Cooling Degree Days (CDDs) for Biosphere III.

5.28°C (22.5°F) (Ruffner and Bair, 1987). The people of Biosphere III do not have the wintertime heating capability nor do they have the winter clothing to tolerate these subfreezing temperature.

The physical feelings at different temperatures are presented in Fig. 12 (Pearce and Smith, 1984). The diagonal lines are the wind speeds. Along the vertical axis are plotted the wind chill indices. The horizontal axis represents the wind chill temperature. The horizontal lines through the wind speed lines divide the wind chill index into, beginning from the bottom, cool, very cool, cold, very cold, bitterly cold, dangerous conditions when exposed flesh freezes, and very dangerous conditions when exposed flesh freezes in 60 seconds. Two dotted vertical lines have been drawn to show the post-diversion period minimum wind chill temperatures of -2.22°C (28°F) and -5.28°C (22.5°F) corresponding to the

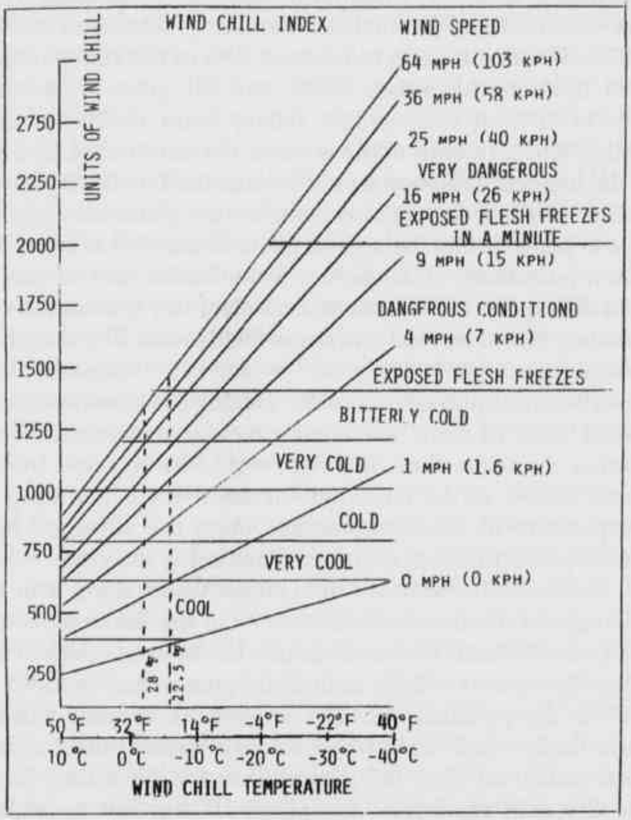


Fig. 12. Illustration of physical feelings as a function of temperature and wind speed (Pearce and Smith, 1984).

wind speeds of 16 km/hr (10 mi/hr) and 24 km/hr (15 mi/hr) respectively. These temperatures are below the freezing point of water and flesh. A dangerous condition existed in 1998. By the first week of January, government reported 500 deaths (Bangla Barta, 1998). It is not unlikely that the death toll rose over 2,000 by the end of the winter. Countries, such as Germany, donated thousands of blankets to the people of Biosphere III. Also, a few hundred people died in 1997 from the extreme cold (Sonardesh, 1997).

Results

The summertime maximum temperatures in Biosphere III rose sharply after 1981 from about 37.22°C (99°F) to about 43.33°C (110°F). The maximum temperature shows a very steep gradient during 1981-85. The HDDs are almost the same after the maximum temperature reached 37.77°C (100°F) . The average value of HDD is 637°C (1146.6°F) more in post-Farakka days than it was in pre-Farakka days. People of Biosphere III are exposed to heat stroke conditions for a longer time since the water shortage started. The wintertime minimum temperature has dropped from 8.33°C (47°F) to 4.44°C (40°F) following the water shortage and still shows a dropping trend. Calculation of CDDs shows that the wintertime minimum temperature has fluctuated greatly.

Discussion

The climatic severity in Biosphere III is the result of changing the land-cover and land-use. This is in keeping with the findings reported earlier (Salati and Vose, 1984; Bouwman, 1990). Lands that were under water more than two decades ago can accumulate little water for much shorter duration today. The latent heat sources (i.e., the water reservoirs) have been converted to sensible heat sources (i.e., dry lands). Water has an extremely high thermal capacity, which causes water reservoirs to serve as heat reservoirs. Today's dry lands have increased the albedo.

The amount of excess heat in the summer and the deficit of heat during the winter can be calculated from the information on the land areas that would remain inundated during the rainy season (July through October). Only the rural areas will be considered in this calculation because of their vast aggregate expanse. There are about 28,000 villages in rural Biosphere III. The number of urban areas is about 28. Figure 13 is a map of the rural Biosphere III adapted from the infrared color aerial photographic survey

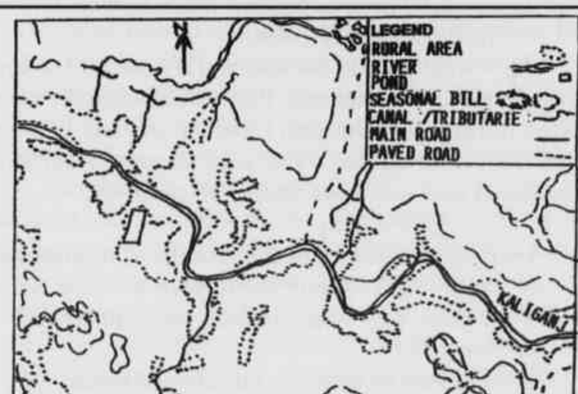


Fig. 13. A glimpse of the rural Biosphere III (SPARSO, 1993)

done during February 1983 and updated with SPOT satellite-acquired data in February and March 1989 by Bangladesh Space Research and Remote Sensing Organization (SPARSO, 1993). The figure shows many features including floodplains (*bills*) up to large ponds. In the pre-Farakka days, the land area between rural units would remain watersoaked and/or water-logged during July through November. Each village is located on a high land area. In each of these high land areas, there are ponds and ditches which may be called the permanent and seasonal surface water bodies of rural Biosphere III. Further, every two to six villages surround a floodplain which may be a shallow one or a deep one. In pre-Farakka days, significant parts of the deep ones held water almost the year around. Total area occupied by floodplains, ponds, and ditches that used to be under water, i. e., the area occupied by the permanent and seasonal water bodies, can be found from the following relations:

$$A_H = n_V A_V - n_V A_{PD}$$

$$A_{SW} = A_B - A_H$$

where A_H = total area of homesteads in Biosphere III
n_V = total number of villages in Biosphere III = 28,000
A_V = average area of a single village = 0.07 sq km
A_{PD}= average areas of ponds and ditches per village = 0.027 sq km
A_{SW} = total area of surface water bodies in Biosphere III, and
A_B = total area of Biosphere III = 46,080 sq km

Prior to 1975, the total area that would annually remain inundated during July through October and wet later on is found to be 44,876 sq km. The solar energy absorbed by this inundated and wet areas would be given by

$$Q = A_{sw}tq$$

where t = time in minutes of the months (6 months per year and 12 hours per day) of the year during which A_{sw} would remain water-filled and wet, and
q = calories of heat per minute per sq km (calculated from the standard value of 0.44 cal/min of solar radiation) of Biosphere III = 4.4×10^9 cal/sq km/min

This yields 2.6×10^{19} calories for Q. Whereas the floodplains, the major source of seasonal and perennial surface water resources, would have rice plants in them, the above calculation is done for the lost water bodies that did not have anything else other than water. We need to apply some corrections to this estimated figure. The floodplain arable areas and other arable land areas had been the rice growing fields. Before the harvest season (end of November), there would be green rice plants in water or in wetlands. After harvest there would be rice straws in water or in wetlands. Several facts relate to the amount of heat absorbed. (1) Lake water reflects less than 10% of the sunlight falling upon it (Mirinova, 1973). (2) Maximum reflection of sunlight from wet soil is 20% of the incident amount (Tucker and Miller, 1977). (3) Straw reflects more than 40% of the sunlight incident upon it (Mirinova, 1973), and (4) green vegetation reflects 30% of the sunlight falling upon it (Tucker and Miller, 1977). In each of those cases, the unreflected amount of the incident radiation would be absorbed by the bodies of water. Further, floodplains without rice plants are equivalent to lakes. It may be a good guess to take 0.3 as the maximum reflectivity of the surface water bodies and 0.7 as the least absorptivity. The maximum reflectivity is chosen to be between that of wet soil and straw-filled lands. The absorbed heat is then $0.7 \times 2.6 \times 10^{19} = 1.8 \times 10^{19}$ calories. This absorbed heat played two roles. During the summertime, it would help to keep the environmental temperature low. During the wintertime, this heat would be released by the water bodies to the environment when there is a drop of temperature in the environment. Thus, the absorbed heat would protect the environment from being too cold.

Today, the absence of the Ganges water along with the shortage of the monsoon rain water in the floodplains and other arable lands leaves the arable lands water-soaked only after downpours whose annual frequency has reduced to 50% in the postdam era. The floodplains are now agricultural lands which absorb, reflect, and radiate the incident solar radiation. They fail to store heat for the winter. So do the dry soils elsewhere. Biosphere III has lost its highest thermal capacity material, water. With ditches no longer in existence and deaths of shallow ponds, A_{PD} is estimated to be reduced by 50% to the new value of 0.0135. The rural areas have increased, at least by 10%. This gives A_V value as 0.077. The time factor t has to be given some equivalent value on the ground that the distributaries with clogged mouths either cannot flow water to floodplains or has reduced the flow to the floodplain both in duration and quantity by about one-quarter. The equivalent value may be estimated, assuming a proportionality, by the consideration of a 60% (40% of the original) decrease in the Ganges flow and a 70% decrease in the monsoon rainfall. Thus 6 months' time of the pre-dam period is reduced to 1.68 (= $6 \times 0.40 \times 0.70$) months. The new Q value, the heat retained by water and wet soil mass is then 4.95×10^{18} calories which is less than 30% of the pre-Farakka value.

Though the water diversion that led to the creation of Biosphere III started in 1975, the summertime rise of the maximum temperature and the wintertime drop of the minimum temperature started after 1981. This is probably due to the fact that it took a few years at the beginning for depletion of the surface water resources and for nature to react.

Conclusions

The generation of extreme climate leading to the summertime higher maximum and the wintertime lower minimum temperatures in the post-diversion era of the Ganges water compared to the prediversion era shows a close temporal correlation to the depletion of surface water resources following the water diversion. The climatic extremity has increased the suffering of the people of Biosphere III. To alleviate the suffering and restore the original climatic conditions, the Farakka Barrage has to be demolished with the assurance of a minimum flow at the Farakka point for adequate discharge through the Ganges and its distributaries in Biosphere III to revitalize the original surface water resources and to facilitate the groundwater recharging. International agencies should take urgent steps to resolve water disputes among riparian countries in the light of the global environmental awareness.

ACKNOWLEDGMENTS.—The author is thankful to ERDA/NIH. The author is also thankful to Arkansas Space Grant Consortium for partial funding of the project. Thanks are also due to the Ministry of Defense, Government of the People's Republic of Bangladesh, particularly the Agriculture Secretary M. N. Islam and Defense Secretary M. H. Rahman for supplying the climate data from the Bangladesh Meteorology Office in expectation of benefits for the nation from the research results. Thanks are also due to the staff members of the Meteorology Office for making the data available in time and also to M. A. Samad, who frequently visits the government offices in Dhaka from Biosphere III, for getting the appropriate data. Further, thanks are due to the Bangladesh Water and Power Development Authority for supplying the Ganges discharge rate at the Hardinge Bridge observation point and to the Bangladesh Space Research and Remote Sensing Organization for supplying the aerial observation map of part of Biosphere III.

Literature Cited

Abbas, A. T. 1993. Cited in Farakka Barrage - An overview, paper presented by S. A. Khondoker in the International Seminar on Farakka Barrage, Columbia University, October 10, 1993

Bangla, Barta. 1998. Unprecedented cold wave over the entire Bangladesh (in Bengali), 3:1, January 9, Los Angeles.

Begum, K. 1988. Tension over the Farakka Barrage, The University Press Ltd., Dhaka, Bangladesh.

Bindra, S. S. 1982. Indo-Bangladesh relations, Deep and Deep Publications, New Delhi, India.

Bouwman, A. F. 1990. Estimating the effect of changing land use on transpiration and evaporation, pp. 129-142, *In* A. F. Bouwman (Ed.) Soils and greenhouse effect, John Wiley and Sons Ltd.

Brown, L. R. 1991. The aral sea: going, going ... Worldwatch 4 (Jan/Feb), 24-35.

Crow, B. 1981. Why are the Ganges and the Brahmaputra undeveloped? : politics and stagnation in the rivers of South-Asia. Bull. Conc. Asian Schol. 13: 35-48.

Crow, B., A. Liquist and **D. Wilson.** 1995. Sharing the Ganges - the politics and technology of river development, University Press, Ltd., Dhaka, Bangladesh.

Dingman, S. L. 1994. Physical hydrology, Prentice Hall, Englewood Cliffs, NJ.

Hays, R. L., and **S. T. Hussain.** 1995. Public health and forced climate change: Extreme temperature exposure and infectious diseases. World Res. Rev. 7: 63-76.

Hebblethwaite, G. 1997. The impacts and implications of the Farakka Barrage upon Bangladesh, B. S. Thesis, University of New Castle Upon Tyne, United Kingdom.

Hillary, E. S. 1979. From Ocean to the Sky, p. 35. Viking Publisher, NY.

Huq, M. S. 1974. Climate of Bangladesh, *In* A. F. M. Kalimuddin (Ed.) Studies in Bangladesh Geography, Jahangir Nagar University, Savar (Dhaka), Bangladesh, pp. 15-20.

Hussain, S. T., and **R. L. Hays.** 1993. Global warming and public health: an appeal for coordinated and early action, World Res. Rev. 5:424-429.

Hussain, S. T., and **R. L. Hays.** 1997. Climate Changes and Threaten Health as Consequences of Farakka Barrage (abs.). p. 11, *In* Shaheen et al. (ed.) A publication of the International Farakka Committee for the International Seminar on Farakka Agreement, Arsenic Problem, Natural Gas, Transit and other Related National Issues of Bangladesh, September 28, NY.

Kalkstein, L. S., and **K. M. Valimont.** 1987. Climatic effects on human health in potential effects of future climate changes on forests and vegetation, agriculture, water resources, and human health. EPA Science and Advisory Committee Monograph No. 25389, 122-52, Washington, DC: U. S. Environmental Protection Agency.

Miah, M. A. 1994a. A narrative from a native living Abroad (in Bengali), Daily Sonar Desh, July 28, Rajshahi, Bangladesh.

Miah, M. A. 1994b. Farakka Barrage and the Political Situation (in Bengali). Weekly Thikana, September 13, NY.

Miah, M. A. 1995a. About the extreme climate in northwest Bangladesh (in Bengali). Rotary Club Published, Joypurhat, Bangladesh.

Miah, M. A. 1995b. The climate crisis in Bangladesh (in Bengali). Daily Sonar Desh, September 2, Rajshahi, Bangladesh.

Miah, M. A. 1995c. Nobody has the right to build a barrage on an international river: Farakka Barrage was built without prior thinking (in Bengali). Weekly Thikana, August 4, NY.

Miah, M. A. 1995d. Is the climate of Bangladesh changing? (in Bengali). Bitchitra 24:25-30

Miah, M. A. 1995e. The lost water resources and the developing economy of Bangladesh, International Association of Geophysics and Aeronomy and the International Association on Hydrological Sciences, University of Colorado, Boulder, July 4, 1995.

Miah, M. A. 1996a. The Water Crisis in Bangladesh: A Challenge to integrated water management. *In* J. Niemczywics (ed.) Challenge to integrated water management in urban areas of the developing countries, Environ. Res. Forums 3-4:49-86. Transtec Publications, Switzerland.

Miah, M. A. 1996b. In the perspective of thirty-year water-sharing agreement (in Bengali). Daily Sonar Desh, December 17, Rajshahi, Bangladesh.

Miah, M. A. 1996c. Signs of thunderings in Bangladesh sky (in Bengali). Weekly Thikana, November 8, LIC, NY.

Miah, M. A. 1996d. Does the mother miss the funeral pyre or the child miss the property share (in Bengali). Bangla Patrika, December 15, NY.

Miah, M. A. 1996e. Farakka Barrage: An unprecedented environmental disaster in the Ganges Basin (in Bengali). p. 18-30. *In* T. S. Rahman (ed.) In the perspective of the Ganges Water Treaty (in Bengali). Bangla Bazar Publishers, Dhaka, Bangladesh.

Miah, M. A. 1996f, Environmental changes due to Farakka. The Message, September 20, NY.

Miah, M. A. 1996g, Farakka the Death Trap. Biosphere III, Advanced Micro Devices, Texas. [...a-u.ac.jp:8080/med2/26/farakkah.html.

Miah, M. A. 1997a. UNESCO's proposal against creation of water shortage and environmental damage: an upstream country's water use must not affect a downstream country (in Bengali). Daily Sonar Desh, January 18-21, Rajshahi, Bangladesh.

Miah, M. A. 1997b. Farakka facts: water diversion, water division, and water-sharing agreement (in Bengali). Weekly Thikana, September 22, LIC, NY.

Miah, M. A. 1997c. Farakka facts: water diversion, water division, and water-sharing agreement (in Bengali). Weekly Thikana, September 29, LIC, NY.

Miah, M. A. 1997d. Farakka Barrage, the Octopus for Bangladesh (Abst.). p. 9. *In* Shaheen et al. (ed.) A publication of the International Farakka Committee for the international seminar on Farakka Agreement, Arsenic Problem, Natural Gas, Transit and Other Related National Issues of Bangladesh, September 28, NY.

Miah, M. A. 1997e. Biosphere III and the poisonous activities of the Farakka Barrage. Bitchitra 22:25-30, Dhaka, Bangladesh.

Miah, M. A. 1998a. Arsenic excess in the Gangetic Delta's groundwater: causes and remedial lessons, Abst. international conference on arsenic pollution of groundwater in Bangladesh: causes, effects, and remedies. Dhaka, Bangladesh.

Miah, M. A. 1998b. Groundwater contamination in the Ganges Delta, in IAHS Proceedings: GQ 98-Groundwater Quality: Remediation and Protection.

Miah, M. A. 1998c. Some dire environmental consequences of water depletion in the Ganges Basin. Abst. 7th International Symposium on Society and Resource Management. Univ. Missouri-Columbia.

Miah, M. A. 1998d. The ultimate fate of the depletion of surface water resources. Abst. 9th International Conference on Global Warming, Hong Kong.

Miah, M. A. 1998e. Health risks assessment due to arsenic contamination in groundwater in the Ganges Delta, IAHS Proc. International Conference on Groundwater Contamination, Santiago, Chile.

Miah, M. A. 1998f. Farakka Facts: The lost heat energy and its consequences. Weekly Thikana, February 21, 1998, LIC, NY.

Miah, M. A. 1999a. The impact of water diversion upon water resources. Water Resources Research (in press).

Miah, M. A. 1999b. Biosphere III: The site of unprecedented ecocide in the Ganges Basin. Proc. International Conference on Water Management, Arsenic Contamination, and Desertification Problems in Bangladesh (in press), held in July, 1998, Dhaka, Bangladesh.

Miah, M. A. 1999c. The arsenic episode in Bangladesh, Ground Water (submitted).

Miah, M. A. 1999d. The arsenic disaster in Bangladesh: causes and remedies. International Conference on arsenic in groundwater of Bangladesh, February 27-28, 1999, Wagner College, NY.

Miah, M. A. 1999e. Groundwater poisoning in the Ganges Delta. Student-Teacher Research Forum at UAPB, March 17, 1999.

Miah, M. A. 1999g. Water diversion and climatic extremes in Biosphere III, Climate Change (submitted).

Miah, M. A., and **M. A. Samad.** 1996. History of the environment of Bangladesh. p. 214-227. *In* W. Schroder and M. Colacino (ed.) Global change and history of geophysics, Bremen-Roennebeck, Germany.

Miah, M. A., and **M. A. Samad.** 1999. The impact of climatic extremes and water shortages upon human health. Global Res. Rev. (in press).

Micklin, M. 1988. Desiccation of the Aral Sea: A water management disaster in the Soviet Union. Science 241:1170-1176.

Mirinova, Z. F. 1973. Albedo of the Earth's surface and clouds. *In* Radiation Characteristics of the Atmosphere and the Earth's Surface, (I. A. Kondratev, ed.) NASA, Springfield, VA, 580 pp.

Mitchell, J. M., R. E. Felch, D. L. Gilman, F. T. Quinlan, and **R. M. Rotty.** 1973. Variability of seasonal total heating fuel demand in the United States. Report to the Energy Policy Office, Washington, DC.

New York Times. 1997. Reported by J. F. Burns, New York.

Pearce, E. A., and **C. G. Smith.** 1984. The Times Book World Weather Guide, p. 7-15, Times Book, NY.

Rogot, E. 1973. Association of Cardiovascular Mortality with Weather-Chicago 1967. Proc. ASHRAE Symposium on Air-Conditioning, Climatol. Public Health. 11-25 August 1971.

Rogot, E., and **S. J. Padgett.** 1976. Association of coronary and stroke mortality with temperature and snowfall in selected areas of the United States. Amer. J. Epidemiol. 1037:565-475.

Ruffner, J. A., and **F. E. Bair** (ed). 1987. The weather almanac. 5th ed., pp. 110-115, Gale Res. Co. Book Tower, Detroit, MI.

Salati, E., and **P. B. Vose.** 1984. Amazon Basin: a system in equilibrium. Science 225:129-138.

Sattar, A. 1996. The Farakka where lies the fate of Bangladesh in captivity (in Bengali), p. 81-111, Padma Prakashani (Publisher), Dhaka, Bangladesh.

Schwarz, H. E., J. Emel, W. J. Dickens, P. Rogers, and **J. Thompson.** 1993. Water Quality and Flows. p. 253-270. *In* B. L. Turner II, W. C. Clark, R. W. Kates, J. F. Richards, J. T. Mathews, and W. B. Meyer (ed.) The Earth as Transformed by Human Action, Cambridge University Press, NY.

Sneider, E. 1992. Christian Science Monitor. The Christian Science Publishing House.

SPARSO. 1993. Report on Sectoral Study E, monitoring of Changes in River Courses Based on Landsat MSS/TM Data, Bangladesh Space Research and Remote Sensing Organization, Dhaka, Bangladesh.

Tucker, C. J., and **L. D. Miller.** 1977. Soil spectra contributions to grass canopy spectral reflectance, Photogram. Eng. Remote Sens. 43:721-726.

The Effects of Varied Intensity Resistance Training in Combination with Extra Mass-bearing Exercise on Bone Adaptations in Ovariectomized and Sham Operated Sprague Dawley Rats

Donna Quimby*
Health Sciences
University of Arkansas at Little Rock
2801 S. University Ave.
Little Rock, Arkansas 72204

Kathy Hall
Department of Kinesiology
University of Arkansas
Fayetteville, Arkansas 72701

*Correspondence Author

Abstract

This experiment was designed to study the effects of intensity of exercise on bone adaptations in ovariectomized and sham operated 12 week old rats. Eighty Sprague Dawley rats were divided by mass into two equal groups (mean = 197 g). One group was ovariectomized (OVX); the other sham (S) operated. Each surgery group was then subdivided by mass into four exercise intensity groups. The exercise intensity groups were created by loading additional mass (percent of animals body mass, 0%, 3%, 6% and 9%) on each animal in combination with treadmill running (10 m/min.; 30 min./day; 4 days/wk.; for 7 weeks). Intensity of exercise and OVX had a significant effect on bone integrity (BI) ($P<.001$), a construct that consisted of bone breaking strength, apparent bone density and % ash wt. OVX seemed to influence BI more than intensity of exercise. Breaking strength was significantly affected by OVX ($P<.001$). Upon further analysis, OVX had the most significant effect on breaking strength and ASH% ($P = .023$; $P = .000$; respectively) whereas intensity of exercise did not have a significant effect on any of the construct variables. When the construct variables were compared between groups, bone breaking strength was significantly greater in the OVX than the S ($P = .024$). There was no effect on bone density between the groups, and ASH% was significantly less in the OVX than the S.

Introduction

The magnitude of the effects of involutional or osteoporotic bone loss in postmenopausal women is devastating. Osteoporosis affects half the female population over age 45. By age 75, nine out of ten women are afflicted. Bone loss compromises the integrity of the skeletal structure leaving it most vulnerable to spontaneous fractures of the vertebrae, wrist and hip. In 1992 the U.S. estimated annual cost of hip fractures was 7.3 billion dollars in direct costs with a total of 12 billion when indirect costs were included (Clark, 1992). The monetary costs are exorbitant, but they pale when compared to the personal cost of this disease.

There is a 12-20% mortality rate among the 250,000 hip fractures annually (Levin, 1991). Of those patients who survive, about 50% will dramatically change their lifestyles as a result of loss of mobility. The ability to live independently often ends, and they become nursing home bound (Levin, 1991). Despair and a loss of the will to live may develop as a result of diminished quality of life. Mortality, morbidity, and monetary loss, coupled with psycho-social issues as a result of osteoporosis, are devastating.

Reaching peak bone mass with as much bone as possible and maintaining that mass can help prevent early onset of osteoporosis. According to Papazian (1994), estrogen in combination with a growth hormone is responsible for bone growth in young women during puberty, and it is irrefutable that estrogen deficiency in women results in bone loss. The need for estrogen to maintain bone mineral density cannot be completely abated by exercise. Substantial research, however, supports exercise as a means of increasing bone integrity. According to Frost (1997) and Skerry, (1997) bone strain magnitude and rate of change in strain magnitude are the two most important exercise factors. Frost (1997) quantifies the strain magnitude necessary to elicit bone modeling (adults 800-1200 microstrains; youth 2000-4000 microstrains). Bone modeling dictates bone strength because it influences the amount of tissue and its architecture. Decreased estrogen levels increase the threshold for bone modeling to occur (Westerlind et al., 1997). The definition of an exercise protocol that best promotes bone modeling so that individuals reach peak bone mass and maintain that mass could help facilitate the reduction of osteoporotic injuries.

Materials and Methods

Eighty female Sprague Dawley rats with a mean mass of 197 grams (approximately 12 weeks of age) were used to conduct this seven week exercise intervention study. The animals were massed and divided into two groups of equal mean mass. One group was ovariectomised (O) the other sham (S) operated.

After surgery, the animals were given a 10-day recovery period. Thereafter, all animals started treadmill training at a speed of 10 meters per minute for 5 minutes. Appropriate additional mass was added to each animal (extra mass pouch with lead shot) to correspond with their intensity grouping. The four levels of intensity groupings were accomplished by adding 0%, 3%, 6% and 9% of the animals' body mass. The initial training run was 5 minutes. The duration of subsequent exercise bouts was increased by two minutes until the animals could run for 15 minutes. Exercise period length was then increased by 5 minutes after each two bouts until the animals could run for 30 minutes. The animals were weighed once a week, and the incremental mass gain of the animal was reflected by additional mass being placed in the extra mass pouch. This additional mass corresponded to the appropriate exercise intensity percentage. The animals exercised 4 days per week, 2 consecutive days with one or two days between bouts for 7 weeks. Throughout the study the animals were allowed to eat and drink ad libitum.

At the end of the seven week training period, the animals were euthanised and the right femur was resected. Bone density (d=m/v), anthropometric measurements (femur length, epiphyseal plate width, mid-shaft width, beginning body mass, ending body mass, mass gain), breaking strength (810 Material Test System (MTS) actuator descent rate .1 mm per sec) and bone mineral ash (ashing protocol: Association of Official Analytical Chemists) were collected.

The experimental design was a 2X4 factorial with the two groups being ovariectomized (OVX) and sham (S) operated Sprague Dawley female rats. The factor was intensity of training, altered by adding one of four levels of additional mass (0%, 3%, 6% and 9% of animals body mass). The groups are differentiated as OVX0, OVX3, OVX6 or OVX9 and S0, S3, S6 or S9 to indicate intensity levels.

Results

Bone Integrity Construct.--A bone integrity construct (BI) was developed by grouping bone breaking strength, bone density and ASH%. The three variables were massed equally. The BI was analyzed using SPSS Multiple Analysis of Covariance (MANCOVA) with final body mass being the covariate. Individual analyses of variance (ANOVA) were calculated for bone breaking strength, ASH% and bone density with respect to surgery and intensity of exercise. Descriptive statistics and correlations were calculated for the dependent variables.

When BI and intensity of exercise and surgery were compared, Wilks multivariate test yielded a value of .61989 which was significant ($P<.001$). Surgery had more influence on BI than exercise intensity although in combination they significantly affected BI. Further analysis suggested that ovariectomy significantly influenced BI and two of the dependent variables, breaking strength and ASH% ($P = .023$; $P<.001$ respectively). Intensity of exercise had no significant influence on BI or the variables individually.

Individual Bone Variables.--The results of the statistical analyses are shown in Tables 1, 2 and 3. Bone density for S rats when compared by intensity of exercise (0%, 3%, 6%, 9%) was not significantly different. Mean bone density of the S rats exhibited a numerically curvilinear trend to exercise intensity (S0, 1.62g; S3, 1.64g; S6, 1.70g and S9, 1.54 g). Bone density within the OVX group did not differ. When bone density was compared between the S and OVX groups, the OVX bone density was 3.9% less than that of the S animals (1.55g and 1.61g, respectively) but was not statistically different. An ANOVA was computed in order to further clarify the effects of intensity of exercise and surgery on bone density (Table 3). Neither intensity of exercise nor surgery influenced bone density.

In both the S and OVX groups, bone breaking strength did not follow a linear path relative to intensity of exercise. Bone breaking strength in the OVX animals was significantly higher than that of the S animals (157.5 n and 146.3 n, respectively; $P = .024$). The correlations suggest that bone anthropometric measures and animal mass were variables that affected bone breaking strength (Table 1 and 2). The combined effects of intensity of exercise and surgery or intensity alone did not influence bone breaking strength (Table 3).

ASH% was significantly influenced by the main effects of intensity and surgery. When considered individually, surgery produced a significant effect and intensity of exercise had no effect (Table 3). ASH % of the femur was significantly greater in the S than OVX group (.6918 g and .6722 g, respectively; $P \leq .001$). The .0196 g difference in Ash represents a 2.9% greater bone mineral content in the S group when compared to the OVX group.

Bone Anthropometric Measurements.--Femoral length, mass and volume further define bone characteristics with respect to exercise intensity and ovariectomy. Femoral length was significantly greater in the OVX group than the S group, a difference of 2.89% (36.66 mm vs. 35.63 mm; $P \leq .001$). Femoral length had a significant positive correlation to bone breaking strength in both the OVX and S groups (Tables 1 and 2). Mass had a greater relationship to femoral length for the S group than the OVX group (Table 1 and 2). ASH% also had a significant positive correlation to femoral length for the S group but not the OVX group.

Table 1. Correlation matrix for breaking strength, body mass plus mass, femur volume, femur mass, initial mass, femur length, ash%, final mass and mass gain in S rats

	Breaking Strength (n/m^2)	Body mass plus mass (g)	Femur volume (ml)	Femur mass (g)	Initial mass (9g)	femur length (mm)	Ash % (g)	Final mass (g)	Mass gain (g)
Breaking strength	1.00	.62 P=.000	.29 P=.123	.81 P=.000	.54 P=.003	.58 P=.001	.38 P=.048	.70 P=.000	.60 P=.001
Body mass plus mass	.62 P=.000	1.00	.48 P=.007	.56 P=.001	.60 P=.000	.61 P=.000	.46 P=.015	.91 P=.000	.82 P=.000
Femur volume	.29 P=. 123	.48 P=.007	1.00	.51 P=.004	.28 P=.135	.12 P=.531	.33 P=.091	.40 P=.028	.35 P=.058
Femur mass	81 P=.000	.56 P=.00 I	.51 P=.004	1.00	.47 P=.009	.60 P=.001	.41 P=.029	.55 P=.003	.39 P=.033
Initial mass	.54 P=.003	.60 P=.000	.28 P=.135	.47 P=.009	1.00	.59 P=.001	.24 P=.217	.69 P=.000	.26 P=.167
Femur length	.58 P=.001	.61 P=.000	.12 P=.531	.60 P=.001	.59 P=.001	1.00	.41 P=.033	.60 P=.001	.42 P=.024
Ash %	.38 P=.048	.46 P=.015	.33 P=.091	.42 P=.029	.24 P=.217	.41 P=.033	1.00	.46 P=.014	.47 P=.013
Final mass	.70 P=.000	.91 P=.000	.40 P=.028	.53 P=.003	.69 P=.000	.60 P=.001	.46 P=.014	1.00	.88 P=.000
Mass gain	.60 P=.001	.82 P=.000	.35 P=.058	.39 P=.033	.26 P=167	.42 P=.024	.47 P=.013	.88 P=.000	1.00

Table 2. Correlation matrix for bone density, breaking strength, femur volume, femur mass, femur length and initial mass in OVX rats.

	Bone Density (wt/vol)	Bone Strength (n/m^2)	Femur Volume (ml)	Femur Mass (g)	Femur Length	Initial Mass (ml) (g)
Bone Density	1.00	.04 P=.820	-.77 P=.000	.06 P=.748	.29 P=.134	-.11 P=.575
Bone Strength	.04 P=.820	1.00	.43 P=.018	.78 P=.000	.48 P=.010	.53 P=.003
Femur Volume	-.77 P=.000	.43 P=.018	1.00	.58 P=.001	.11 P=.580	.39 P=.033
Femur Mass	.06 P=.748	.78 P=.000	.58 P=.001	1.00	.67 P=.000	.49 P=.006
Femur Length	.29 P=.134	.48 P=.010	.11 P=.580	.67 P=.000	1.00	.11 P=.597
Initial Mass	-.13 P=.575	.53 P=.003	.39 P=.033	.49 P=.006	.11 P=.597	1.00

Table 3. The effects of exercise intensity and ovariectomy on bone density, ash %, and breaking strength

	Bone Density (wt./vol.)	Ash% (g)	Breaking Strength (n/m^2)
Main Effect	F = .97 P = .431	F = 11.81 P = .000	F = 1.30 P = .284
Intensity of Exercise	F = .25 P = .856	F = 2.48 P = .072	F = .13 P = .943
Surgery	F = 3.03 P = .088	F = 37.69 P =. 000	F = 4.89 P = .032
Interactions Intensity Surgery	F = .61 P = .613	F = 1.96 P = .131	F = .25 P = .864

F = ratio of the mean square regression to the mean square residual

There was not a significant difference between OVX and S group femoral mass (.9519 g and .9224 g, respectively). As with femur length, body mass variables seemed to relate more to femur mass within the S group than the OVX group. In both S and OVX groups, bone breaking strength was significantly related to femur mass.

Femur volume was significantly higher within the OVX compared to the S group (.6210 ml, and .5773 ml, respectively; P =.014). Intensity of exercise did not significantly influence femoral volume in the S or OVX groups. Within the OVX group, bone breaking strength had a significant positive relationship to femoral volume, which was not the case within the S group (Tables 1 and 2).

Body Mass Measurements.--Body mass appeared to influence bone variables within the S group to a greater extent than the OVX group (Tables 1 and 2). The initial mass of the OVX group was significantly greater than the S group (242.6 g and 233.2 g OVX and S respectively; P = .001). Mass gain between the two groups was significantly different. The OVX group gained an average of 114.63 g compared to the S group that gained only 62.20 g (P< .001).

Discussion and Conclusions

The evaluation of the effects of exercise intensity on bone adaptation is necessary for the development of an exercise protocol that promotes bone growth and lifelong maintenance. The discussion of data centers upon BI, and the individual variables that comprise this construct: bone breaking strength, bone density and bone ash. These variables indirectly reflect bone adaptation.

The reduction of bone mass to the point that minimal stress can produce a fracture (fracture threshold) defines the development of osteoporosis (Aloia, 1989). Bone mass includes both organic (collagen matrix, water, cells, etc.) and inorganic (mineral) components. A major component of bone mass that influences fracture threshold is mineral content and the quality of mineralization. Bone mass and mineralization, however, are not the only factors that influences bone fracture threshold.

Bone architecture plays a significant role in bone integrity. Bone size, shape, cortical thickness as well as distribution of cortical and trabecular bone in the cross-section influence bone strength (Frost, 1997). The loss of cross-bracing trabeculae or the thinning of intact trabeculae compromise the integrity of bone. Mechanical stress and ovarian hormones affect both bone mass and architecture. There are other variables that influence bone integrity, but the scope of this research was limited to the effects of varied mechanical stress (exercise intensity) and ovarian hormone deficiency (ovariectomy) on bone adaptations.

Bone Breaking Strength.--In this study femoral bone breaking strength was significantly higher within the OVX group than the S group. Pohlman et al. (1986) found tensile strength of femoral shaft to be higher within ovariectomized exercising or sedentary groups than their non-ovariectomized counter parts. In contrast, Peng et al. (1994) found that ovariectomized animals experienced a decrease in maximal failure load for the femoral neck. Breaking strength measures within this study were taken as compressive force on the medial shaft of the femur (cortical bone), and Peng et al. (1994) measured breaking strength of the femoral neck (trabecular bone). An explanation for the difference in findings between Peng et al., Pohlman et al., and this study may be due to bone type differences. Trabecular bone constitutes a major portion of the femoral neck while cortical bone is the primary component of the femoral shaft. The mechanical properties of the different bone types impart significant breaking strength differences.

Trabecular and cortical bone respond differently to estrogen deficiency. Most studies indicate that trabecular bone decreases in mineral and matrix and mechanical integrity more rapidly than cortical bone (Iwamoto et al., 1998; Tamaki et al., 1998; Westerlind et al., Gilsanz et al., 1995; Hodgskinson and Currey, 1993; Riggs et al., 1986). More specifically the absence of ovarian hormones can cause a decrease in crossbracing trabeculae, which subsequently will result in decreased breaking strength (Aloia, 1989). The effect of estrogen deficiency on cortical bone is much less severe. Extensive metabolic changes in cortical bone which decrease breaking strength are observed only after long term deficiency, 18 to 26 weeks (Yamazaki and Yamaguchi, 1989; Jee et al., 1991); however, changes occur in trabecular bone between 3 and 4 weeks after ovariectomy (Yamazaki and Yamaguchi, 1989; Jee et al., 1991).

The age of a rat at the time of ovariectomy influences body size and other anthropometric characteristics. Femur length and volume are significantly increased in rats that are ovariectomized at 4 and 10 weeks of age compared to rats ovariectomized at 52 weeks of age (Yamazaki and Yamaguchi, 1989). The rats within this study were ovariectomized at 13 weeks. Similar to findings by Yamazaki (1989) the ovariectomized rats in this study were significantly larger than the sham rats not only in mass but femoral length and volume. This could elucidate the significantly higher femoral breaking strength in the OVX rats when compared to the Sham rats. The continued physiologic bone growth of the younger rats in the absence of ovarian hormones seems to be the stimulus for enhanced femoral growth (Yamazaki and Yamaguchi, 1989; Turner et al., 1987; Jee et al., 1991).

Bone Density.--When bone density was compared between OVX and S groups, the OVX group was numerically less but there was no significant difference. This was contradictory to findings by Iwamoto et al. (1998), Tamaki et al. (1998) and Westerlind et al. (1997). The previously mentioned studies all found significant reduction in trabecular bone area specifically within certain regions of long bone. They found reduction of bone area in both the proximal and distal regions with most loss occuring in the central region of the cancellous metaphysis. The difference found in BMD in this study could possibly be explained by differences in BMD measurements (calculated vs histomorphometric)

Although exercise intensity had no significant effect on BMD within this study, numerical differences were observed. Because the degree to which an increase/decrease in BMD affects structural integrity is not known, a statistically non-significant increase may very well have physiological pertinence. For this reason, the numerical trends will be discussed. Mean bone density within the S groups increased from S0 through S6 with a decrease from S6 to S9. Exercise has been demonstrated by some researchers to augment bone mass (Iwamoto et al., 1998; Tamaki et al., 1998; Westerlind et al., 1997; Dalsky et al. 1988; Grove and Londeree, 1992; Ayalon et al., 1987), while other researchers have observed loss of bone as one of the consequences of over-training (Iwamoto et al., 1998; Drinkwater et al., 1984; Michel et al., 1989). Iwamoto et al. (1998) found that duration of a moderate intensity exercise had a significant effect on BMD. Iwamoto, compared 30 minutes of treadmill running to 60 minutes of running (same intensity 16 m/min) in OVX rats. He found a significant increase in bone area in both trabecular and cortical bone within the exercising 30 minute group but not in the exercising 60 minute group. Such findings substantiate an overtraining effect and indicate that certain ranges of intensity and duration create an osteogenic effect.

The OVX group did not respond to intensity of exercise in the same manner as the Sham group. Between OVX0 and OVX3 there was a decrease in bone density, but an increase occurred from OVX3 through OVX9. The increase in bone density between the OVX3 and OVX9 groups was significant. The animals comprising the OVX3 group were lighter than the animals in the OVX0 group. The OVX0 animals had a larger bone density than OVX3 animals. This may be due to body mass and its direct effect on the level of mechanical strain when the heavier animals exercised. Westerlind et al. (1997) postulated that estrogen deficiency would increase the threshold at which bone cells would respond to mechanical strain. If that hypothesis is correct then bone cells subjected to the lowest mechanical strain are at the greatest risk of being resorbed. Low strain level could explain the differences found between OVX0 and OVX3. The numerically linear increase in bone density observed from 3% to 9% intensity may suggest that without the benefit of estrogen, the greater mechanical strain placed on the bone did promote bone modeling. Bone density did not correlate to breaking strength for either group. Because in this study bone density is a calculated value, it does not reveal the way in which mineral/matrix is specifically distributed throughout the bone. More sensitive measures which depict bone architecture (histological determination of trabecular bone volume and trabeculae arrangement) might have revealed differences due to exercise intensity. Some researchers have reported differences in trabecular bone morphology as a result of OVX in as little as 3 to 4 weeks (Yamazaki and Yamaguchi, 1989), while others have observed differences as a result of exercise at six weeks (Peng et al., 1994).

Percent Ash.--Ovariectomy had a significant effect on ASH% ($P<.001$) with the OVX group having significantly less bone ash than the S group. This is in accordance with findings by Yamazaki and Yamaguchi (1989), who observed that bone ash in 10 week old rats was significantly affected by ovariectomy. Intensity of exercise did not significantly

Journal of the Arkansas Academy of Science, Vol. 53 [1999], Art. 1

affect ASH% but approached significance in both groups. Within the S group, bone ash was significantly correlated to breaking strength, a relationship not observed in the OVX group. Within the OVX group, initial body mass was the only variable that had a relationship to bone ash. Other variables that related to ASH% within the S group were femur mass and length. A deficiency of ovarian hormone apparently results in complex alterations of bone metabolism. This appears to be substantiated by the relationship of such variables as breaking strength, bone ash, femur mass and length observed in S but not OVX rats.

Final body mass plus the final added mass is a variable that reflects intensity of exercise. Within the S group, there was a significant positive correlation between body mass plus mass added and ASH% (P=.015). Because ASH% significantly correlated with breaking strength within the S group, intensity of exercise apparently made a positive contribution to bone adaptation within this group.

Bone integrity was significantly affected by both ovariectomy and exercise intensity, with ovariectomy having the most profound influence. Because of the confounding influence of ovariectomy on bone architecture, it was not possible to determine whether exercise intensity caused any of the differences (numerical or statistical) observed. Further, the construct of BI was also less informative because of this interaction. Therefore, future investigations should focus on minimizing the effects of growth and ovariectomy on data, while pursuing the level of intensity at which bone integrity is optimized.

Although there was no significant effect of intensity of exercise on bone breaking strength, bone density or ASH%, data observed within this study suggest adaptations associated with exercise intensity. For example, ASH% approached significance (P =.072) with respect to exercise intensity in both the S and OVX groups. While bone density in the S group followed a curvilinear path. At the highest level of intensity, decreases in both ASH% and bone density were noted. These findings may indicate a training effect with the drop corresponding to a detrimental over-training effect as indicated previously by others (Iwamoto et al., 1998; Frost, 1997; Michel et al., 1989; Drinkwater et al., 1984).

Literature Cited

Aloia, J. 1989. Osteoporosis a Guide to Prevention and Treatment. Champaign, IL: Leisure Press.

Ayalon, J., A. Simkin, I. Leichter, and **S. Raifmann,** 1987. Dynamic bone loading exercises for postmenopausal women: Effect on the density of the distal radius. Arch. Phys. Med. Rehab. 68:280-283.

Clark, A. 1992. Targeted estrogen/progesterone replacement therapy for osteoporosis: Calculation of health care cost savings. Osteop. Internat. 2:231-234.

Dalsky, G., K. Stocke, A. Ehsani, E. Slatopolsky, W. Lee, and **S. Birge,** 1988. Mass-bearing exercise training and lumbar bone mineral content in postmenopausal women. Ann. Inter. Med. 108:824-828.

Drinkwater, B., K. Nilson, C. Chesnut, W. Bremner, S. Shainholtz, and **M. Southworth,** 1984. Bone mineral content of amenorrheic and eumenorrheic athletes. The New England J. Med. 311:277-281.

Frost, H. M., 1997. Why do marathon runners have less bone than weight lifters? A vital-biomechanical view and explanation. Bone, 20:3:183-189.

Gilsanz, V., M. Loro, R. Thomas, J. Sayre, R. Gilsanz, and **E. Schulz,** 1995. Vertebral size in elderly women with osteoporosis. J. Clin. Invest. 95:2332-2337.

Grove, K., and **B. Londeree,** 1992. Bone density in postmenopausal women: high impact vs low impact exercise. Med. Sci. Sports Exer. 24:1190-1194.

Hodgskinson, R., and **J. Currey, 1993.** Separate effects of osteoporosis and density on the strength and stiffness of human cancellous bone. Clin. Biomech. 8:262-268.

Iwamoto, J., T. Takeda, and **S. Ichimura,** 1998. Effects of moderate intensity exercise on tibial bone mass in mature ovariectomized rats: bone histomorphometry study. Keio J. Med. 47:3:162-167.

Jee, W., X. Li, and **M. Schaffer,** 1991. Adaptation of diaphyseal structure with aging and increased mechanical usage in the adult rat: A histomorphometrical and biomechanical study. Anat. Rec. 230:332-338.

Levin, R. M. 1991. The prevention of osteoporosis, Hosp. Pract. 26:897-905.

Michel, B., D. Bloch, and **J. Fries.** 1989. Weight-bearing exercise, over-exercise and lumbar bone density over age 50 years. Arch. Int. Med. 149:2325-2329.

Myburgh, K., T. Noakes, M. Roodt, and **F. Hough,** 1989. Effect of exercise on the development of osteoporosis in adult rats. J. Appl. Phys. 66:14-19.

Omi, N., N. Morikawa, and **I. Ezawa,** 1993. The effect of voluntary exercise on bone mineral density and skeletal muscles in the rat model at ovariectomized and sham stages. Bone Miner. 24:211-222.

Papazian, R. 1994. Osteoporosis treatment advances (DHHS Publication No. FDA 94-1181). Washington, DC: U.S. Government Printing Office.

Peng, Z., J. Tuukkanen, and **K. Vaananen,** 1994. Exercise can provide protection against bone loss and prevent the decrease in mechanical strength of femoral neck in ovariectomized rats. J. Bone Miner. Res. 9:1559-1564.

Pohlman, R., L. Darby, and **A. Lechner,** 1986. Morphometry and calcium contents in appendicular and axial bones of exercised ovariectomized rats. Amer. J. Phys. 248:R12-R17.

Riggs, B., H. Wahner, L. Melton, L. Richelson, H. Judd,

and **K. Offord,** 1986. Rates of bone loss in the appendicular and axial skeletons of women. Evidence of substantial vertebral bone loss before menopause. J. Clin. Invest. 77:1487-1491.

Skerry, T. M., 1997. Mechanical loading and bone: what sort of exercise is beneficial to the skeleton. Bone, 20:3:179-181.

Tamaki, H., T. Akamine, N. Goshi, H. Kurata, and **T. Sakou,** 1998. Effects of exercise training and etidronate treatment on bone mineral density and trabecular bone in ovariectomized rats. Bone, 23:2:147-153.

Westerlind, K., T. Wronski, E. Ritman, Z. Luo, K. Ann, N. Bell, and **R. Turner,** 1997. Estrogen regulates the rate of bone trunover but bone balance in ovariectomlized rats is modulated by prevailing mechanical strain. Proc. Nat. Acad. Sci. 94:4199-4204.

Yamazaki, I., and **H. Yamaguchi,** 1989. Characteristics of an ovariectomized osteopenic rat model. J. Bone Miner. Res. 4:1:13-22.

Yeh, J., J. Aloia, and **M. Barilla,** 1993. Effects of 17B-estradiol replacement and treadmill exercise on vertebral and femoral bones of the ovariectomized rat. Bone Miner. 24:223-234.

Morphometry and Limnology of Ferguson Lake, Saline County, Arkansas

John D. Rickett
Biology Department
University of Arkansas at Little Rock
Little Rock, AR 72204

E.P. (Perk) Floyd
U.S. Public Health Service (ret.)
2423 E. Woodson Lateral, No. 35
Hensley, AR 72065

Abstract

To more fully understand Ferguson Lake as an ecosystem and eventually relate its water quality and production potential to fisheries management, several limnological variables were sampled monthly from April 1997 through March 1999. Vertical profiles of temperature and dissolved oxygen were recorded, and water samples from 0.5 m. depth were tested for turbidity, pH, total alkalinity, total hardness, ortho-phosphate, nitrate-nitrogen, sulfate, iron and specific conductance. Evaporation rate experiments, spillway discharge and rainfall records were used to estimate lake hydrology. Depth transects on the lake and USGS topographic maps were used to measure and calculate morphometric and watershed features.

The lake is essentially the deep end of a swamp (d_{max}= 4.27 m.; d_{mean} =1.92 m.) which is dominated by a lowland hardwood species-pine mix. Numerous cypress (*Taxodium distichum*) and tupelo gum (*Nyssa aquatica*) trees stand in the uppermost one-third of the lake. The rapid deposition and slow decomposition of organic debris on the lake bottom are the primary contributors to the brown water, relatively low pH, and hypoxia in and near the sediments from May through November. There was no evidence of thermal stratification, and pH ranged between 6 and 7, except for brief periods of rapid photosynthesis during the summers. Alkalinity, hardness and specific conductance were quite low, compared to most natural waters in this region. Phosphate, nitrate and sulfur were also comparatively low, and iron was low except after rainfall events which resulted in fairly heavy runoff.

Introduction

Ferguson Lake is a privately-owned recreation lake located in eastern Saline County, Arkansas. The charter members of the newly-formed country club purchased the land from C.E. Ferguson, who had bought the land earlier from William Farrell. When a narrow-gauge, 25-mile railroad tram crossed the property (it crossed Clear Creek about 50 m. upstream of the current levee), Mr. Farrell built a state-of-the-art sawmill at Wrightsville and employed the railroad to transport logs to the mill. In the early 1900s Clear Creek was dammed to create a small impoundment associated with timber harvest, which was included in an enlargement project in 1920 by the construction of a second taller levee further downstream on Clear Creek (Rice and Rooker, n.d.). The second levee more than doubled the original area of the lake.

Large portions of the watershed are swampy and blanketed with a mix of pine and deciduous lowland tree species. Three smaller lakes (Sandy, Mary and Spring Lakes) are located on Clear Creek upstream from Ferguson Lake; each has limited adjacent housing development. The water in all four lakes is brownish, superficially indicating a significant loading of organic acids, low pH and slow nutrient turnover. Numerous local housing developments and a few small businesses are also located in the watershed.

Forty-three cabins and a lodge are located around the eastern and southern sides of Ferguson Lake. Seven cabins are permanently occupied whereas the others are used only for week-end getaways and short-term vacations. Additionally, numerous other visitors use various recreational resources that the lake and its environs offer. Angling is the foremost activity, and, understandably, concerns regarding angler satisfaction have periodically arisen. This project was begun to more fully understand the lake as an ecosystem and the roles played by its major components in the production of catchable fish.

Beasley and Wigley (1988) described the shallow end of Ferguson Lake as containing a dense stand of tupelo gum (*Nyssa aquatica*) and abundant fanwort (*Cabomba caroliniana*), bladderwort (*Utricularia* sp.), waterlily (*Nymphaea odorata*), watershield (*Brasenia schreberi*), and American lotus (*Nelumbo lutea*). They found no evidence of excessive sedimentation due to watershed runoff, and opined that the dense stand of tupelo gum trees probably rapidly slowed the water which contributed to quick deposition of sediments transported by tributaries. They also noticed a fairly rapid accumulation of leaf litter, primarily from the tupelo gum trees and connected local hypoxia to leaf decomposition.

Methods

Two stations were established on the lake (Fig. 1), and

22 data collecting trips were made between 29 April 1997 and 6 March 1999. Water quality variables (turbidity, pH, ortho-phosphate, nitrate-nitrogen, sulfate and iron) were measured with a HACH DR-EL portable spectrophotometer using reagents provided by Hach Chemical Company. Total alkalinity was determined with the BCG-MR titration method whereas total hardness was determined with the EDTA titration method using Eriochrome Black-T as an endpoint indicator (Standard Methods, 1985). Vertical temperature and dissolved oxygen profiles were measured with a YSI Model 51 Dissolved Oxygen Meter, and specific conductance was measured with a HACH Conductivity/TDS Meter. These data were statistically compared by Student's T-test with a dataset collected between 1979 and 1989 by Arkansas Power & Light (now Entergy Corporation) personnel. Duplicate samples of benthic organic detritus were taken at each station with a 6 X 6-inch Ekman grab. Overflow discharge was recorded by measuring the depth of flow over the spillway crest and its velocity with a General Oceanics Model 2031 impeller-type flowmeter. Evaporation rates were measured and, with overflow data, were related to the lake's volume. Watershed parameters and lake surface area were calculated from USGS topographic maps and aerial photos. Form factor and coefficient of compactness (formulae in Reid and Wood, 1976) were determined to estimate the proportion of any given rainfall event covering the entire watershed. Morphometric characteristics were calculated from a series of north-south depth transects.

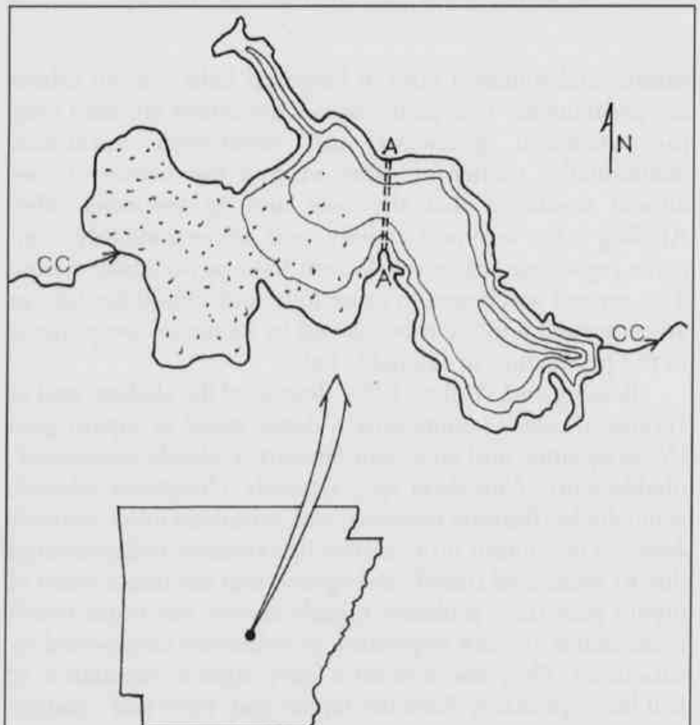


Fig. 1. Location of Ferguson Lake, Saline County, Arkansas. Stippling: swamp dominated by tupelo gum, *Nyssa aquatica* A-A': original dam from "high" point (A) to "low" point (A') CC: Clear Creek Depth contours: 1m intervals

Results and Discussion

Lake Morphometry and Watershed.--Ferguson Lake does not precisely fit the usual characterization of a "blackwater" habitat. Harper and Bolen (1995) describe a blackwater lake as one with waters stained dark brown with pH usually less than 5.5. In such a lake the pH doesn't appreciably affect the decomposition rate of organic materials. The water in Ferguson Lake was medium brown in color, and the pH readings usually ranged between 6 and 7. Brinson (1977) described an alluvial wetland/swamp habitat in North Carolina that appeared to be very similar with respect to pH, water color, and dominant watershed species to Ferguson Lake. He observed a "moderate" rate of leaf decomposition (faster than in a blackwater habitat).

Morphometric characteristics of Ferguson Lake and its watershed are given in Table 1. Much of the upper (shallower) half of the lake contains standing bald cypress (*Taxodium distichum)* and tupelo gum (*Nyssa aquatica*) at high density. These trees deposit a large amount of organic

Table 1. Morphometric characteristics of Ferguson Lake and watershed, Saline County, Arkansas

1. Area of lake proper	115.04 ha
2. Area of lake and adjacent swampy area	171.22 ha
3. Depth-maximum	4.27 m
4. Depth-mean	1.92 m
5. Volume	3.3×10^6 m^3
6. Shoreline length	10.235 km
7. Shoreline development	2.692
8. Normal pool elevation	74.4 m
9. Watershed area	58.56 km^2
10. Watershed axial length	11.27 km^2
11. Watershed mean width	5.39 km^2
12. Watershed form factor (ff)	0.479
13. Watershed coefficient of compactness (cc)	1.44
14. Watershed to lake area ratio	34.2:1
15. Watershed elevation range	74.4-115.8 m
16. Total area of other impoundments above Ferguson Lake	60.94 ha
17. Total creek channel length (incl. lakes) above Ferguson Lake	10.82 km
18. Total unimpounded channel length above Ferguson Lake	6.96 km
19. Mean channel sinuosity	1.308

material into the lake in addition to what is washed in from the watershed. The buildup of semi-decomposed matter on the bottom (heavier at station 2) indicates the deposition rate exceeds the decomposition rate. A cypress/gum-dominated swamp that is permanently inundated is usually considered oligotrophic (Horne and Goldman, 1994), that is, relatively few basic nutrients are available to be fed into the primary productivity process. In part, this slow release of nutrients is due to a mild hypoxia near and in the sediments during much of the summer. Lower pH levels may also inhibit decomposition. It has also been noted by Comer and Day (1991) that tupelo gum leaves decompose much slower than many other species of leaves (65% [by mass] of their experimental tupelo gum leaf packets remained in a Louisiana forested wetland after five months).

The shoreline is heavily vegetated with almost no bare soil at the water's edge, so erosion is slight, and the silt load in the water is low. The water is brown indicating high concentrations of tannic and humic acids. The intensity of the brown water color varies according to the discharge of Clear Creek - heavy runoff carries some silt which lightens the brown color.

Many types of activities occur in the watershed, but none are done on a large enough scale to alter the dominant impact of the lowland forest community on the lake. The watershed to lake area ratio of 34.2:1 would also lead us to expect the lake to be mostly controlled by the adjacent swamp and swamp-like character of the watershed. The relative lack of elevation change indicates rainfall runoff would proceed slowly, easily picking up a load of organic acids before it reaches any impoundment. The three smaller lakes upstream from Ferguson Lake probably trap some of the organics, but sufficient other watershed areas draining into Ferguson Lake directly still contribute much to its native water characteristics.

Of all geometric figures, a circle contains the maximum area for a given perimeter length. The form factor (FF) relates the axial watershed length to its mean width and was calculated as 0.479 (a circle would be 1). The coefficient of compactness (CC) relates the watershed perimeter to the circumference of a circle of the same area and was calculated as 1.44. Both values indicate the watershed shape is considerably different from a circle, thus for a given rainfall event, the total precipitation descending on the watershed area would be considerably less than if the watershed was a circle. If we relate the watershed area to the area of a circle whose circumference equals the watershed perimeter, the result is 0.482. This value could be used as the probability of any given rainfall event covering the entire watershed.

Hydrology.--Most of the soils in the watershed contain large amounts of semi-permeable clays, so infiltration of rainfall is slow. If the rain falls rapidly, much of it runs off but not rapidly because of the forested nature of the watershed, the heavy ground litter and the lack of significant slope. Evaporation rate trials were conducted near the shore of the lake through the months of May 1998 and February 1999. The mean rate for the entire lake was calculated to be 0.574 $ml/cm^2/day$ (6.6×10^3 m^3 per day for the lake) in May and 0.258 $ml/cm^2/day$ (3×10^3 m^3 per day for the lake) in February. The estimates represent 5.6 and 2.5 percent, respectively, of the lake volume.

Spillway discharge was zero or unmeasurably small from June through November 1998 and ranged between 0.07 and 2.54 m^3/s from December 1998 through March 1999, except a heavy rain in mid-September caused 0.044 m^3/s to overflow (Table 2).

Table 2. Spillway discharge (Q) at Ferguson Lake.

Date	$Q(m^3/s)$	$Q(m^3/day)$
27 Feb 98	1.19	102,816
30 Apr 98	0.07	6408
1 May 98	0.0064	553
2 Jul 98	0.0	0
31 Jul 98	0.0	0
20 Aug 98	0.0	0
17 Sep 98	0.044	3787
29 Oct 98	0.0	0
3 Dec 98	0.018	1555
4 Feb 99	2.54	219,594
6 Mar 99	0.052	4530

Physiochemical Characteristics.--Temperature (Fig. 2) exhibited the expected seasonal variations of a summer high of 36°C and winter low of 8°C. During the summer of 1997, the surface to bottom range was 35.5°C to 22.4°C (13.1°C difference) on 24 June and 33.2°C to 27.2°C (6.O°C difference) on 26 August. In 1998 the same temperature range was 34.9°C to 29.8°C (5.1°C difference top to bottom) on 2 July and 33.2°C to 30.5°C (2.7°C difference) on 31 July. For both years, the maximum surface temperature was recorded in June, whereas the maximum bottom temperature was recorded about a month later. The lake did not develop thermal stratification, although the mean top to bottom

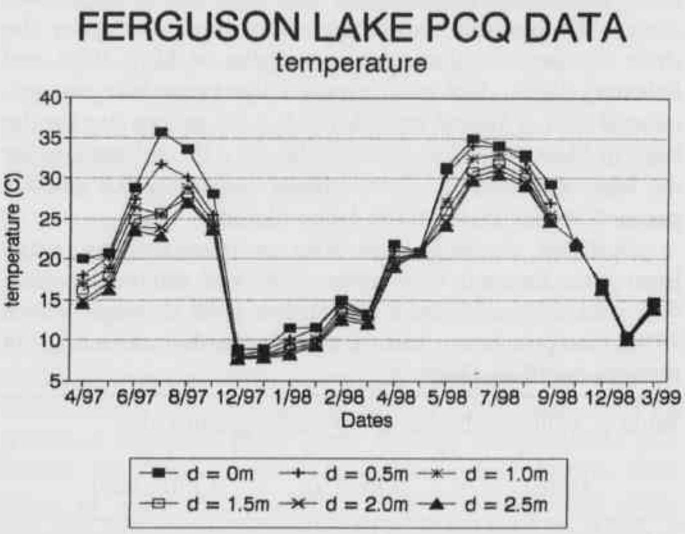


Fig. 2. Temperature profiles in Ferguson Lake, April 1997-March 1999.

range for the summer (May through September) was 7.2°C in 1997 and 4.6°C in 1998. The vertical profile of temperatures at all other times was more tightly clustered.

Dissolved oxygen (Fig. 3) also exhibited greater top to bottom spread in the summer than during other months. Water just above the bottom during both years became hypoxic. On 24 June 1997, the top to bottom range was 9.0 to 0.4 mg/l (8.6 mg/l difference), whereas on 19 May 1998, the range was 14.5 to 0.8 mg/l (13.7 mg/l difference). The most rapid decline usually occurred between 1.5 and 2.0

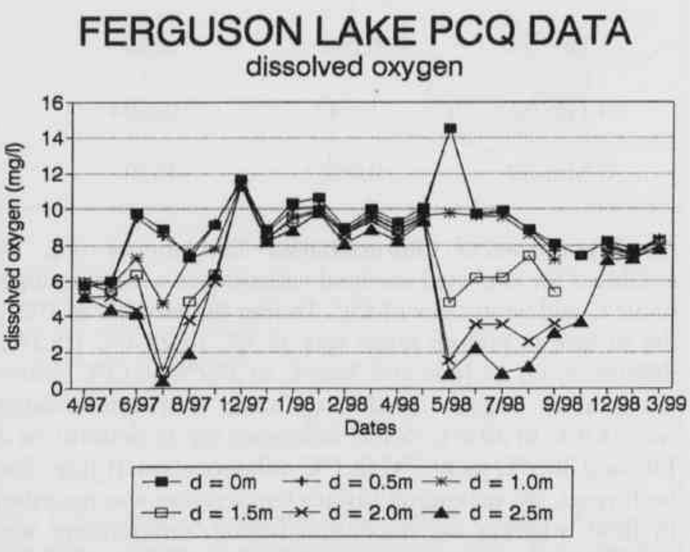


Fig. 3. Dissolved oxygen profiles in Ferguson Lake, April 1997-March 1999.

meters depth. The oxygen content within one-meter of the bottom was less than 4.0 mg/l from June through August in 1997 and from mid-May through mid-October in 1998. The heavy layer of semi-decomposed organic matter on the bottom was probably the primary contributor to this hypoxia.

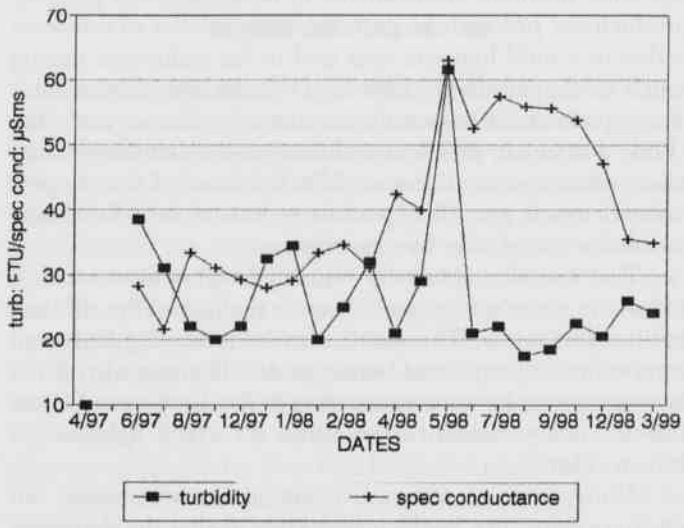


Fig. 4. Turbidity and specific conductance in Ferguson Lake, April 1997-March 1999.

Although the water was organically brown, the silt load, as indicated by turbidity, was relatively low (18-39 FTU) except for one sampling period (19 May 98: 62 FTU) which followed a heavy rain (Fig. 4). Specific conductance (Fig. 4) was also quite low (20-35 µSms), except for a high of 63 on the same date. Specific conductance exhibited a general but not consistent increase from mid-1997 to early fall 1998 then declined sharply from October 1998 to February 1999. Compared to other similar bodies of water, Ferguson Lake was quite low in electrolyte content.

Figure 5 shows pH and sulfate measurements. Excepting the period mid-May through mid-September 1998, pH ranged between 6.0 and 7.0. On 19 May 1998 pH spiked at 9.8 then steadily declined back to 6.1 on 4 February 1999. Sulfate readings varied erratically between zero and 2.5 mg/l for all but two sampling times (31 July and 20 August 1998) when the measurements were 4.5 and 3.5 mg/l, respectively. High sulfur content is certainly not a problem in the lake.

Alkalinity and hardness fluctuated randomly but in concert (Fig. 6). Most of the alkalinity measurements were between 10 and 27 mg/l (as $CaC0_3$), and hardness mostly ranged from 13 to 24 mg/l (as $CaC0_3$). Both variables exhibited a general decline from August 1997 to January 1998, a general rise from February to August 1998 and another

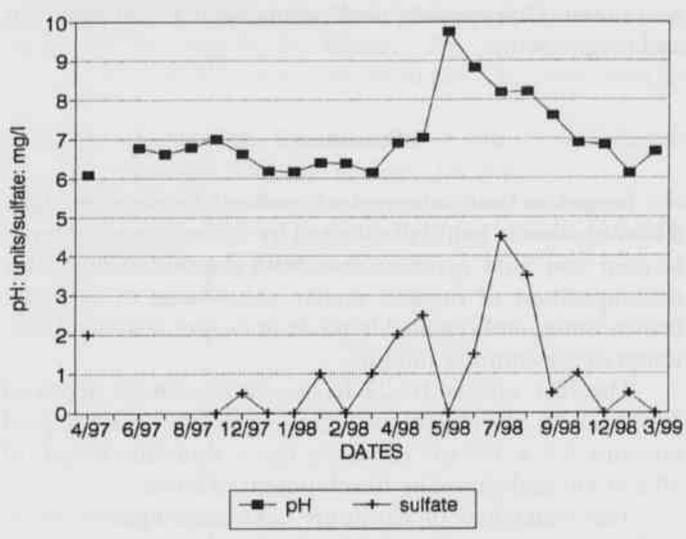


Fig. 5. pH and sulfate measurements in Ferguson Lake, April 1997-March 1999.

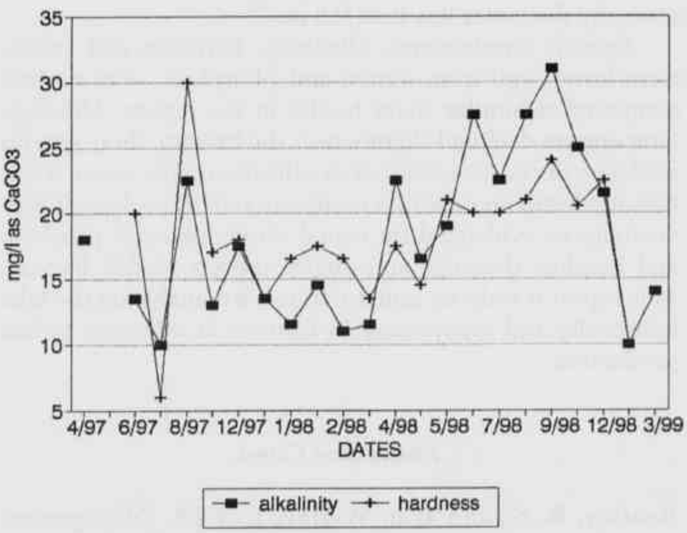


Fig. 6. Total alkalinity and total hardness measurements in Ferguson Lake, April 1997-March 1999.

decline until February 1999. The relatively low concentration of the anions OH^-, $HC0_3^-$ and $CO_3^=$ (alkalinity) indicates a very low buffering capacity of the water. The lake would not be able to absorb a surge (spillage) of cations (for example, H^+, Na^+ or K^+). The low concentration of divalent cations Mg^{++}, Mn^{++}, Fe^{++} and Ca^{++} (hardness) indicates the water is "soft" (soap will lather easily), a characteristic that is of concern for snails (Mollusca:Gastropoda) and clams (Mollusca:Bivalvia) but has little effect on other organisms.

Nitrate-nitrogen (Fig. 7) fluctuated between a low of 0.08 mg/l (late winter) to prominent summer peaks of 1.2 mg/l (August 1997) and 1.05 mg/l (July 1998). Otherwise, sample-to-sample fluctuations were rather erratic. On 21 April 1998 fertilizer was applied aerially to the lake to enhance primary productivity, and the nitrate concentration increased from 0.15 mg/l to 0.25 mg/l within about two weeks, then declined back to 0.1 mg/l. Measurements further removed from the date of the application fluctuated (increased or decreased) much more. Except for the period 23 April to 19 May 1998, ortho-phosphate measurements varied randomly between 0.05 and 0.23 mg/l. Immediately following the fertilizer application, phosphate spiked to 1.21 mg/l but fell to its previous level (0.18-0.23 mg/1) almost as quickly (Fig. 7).

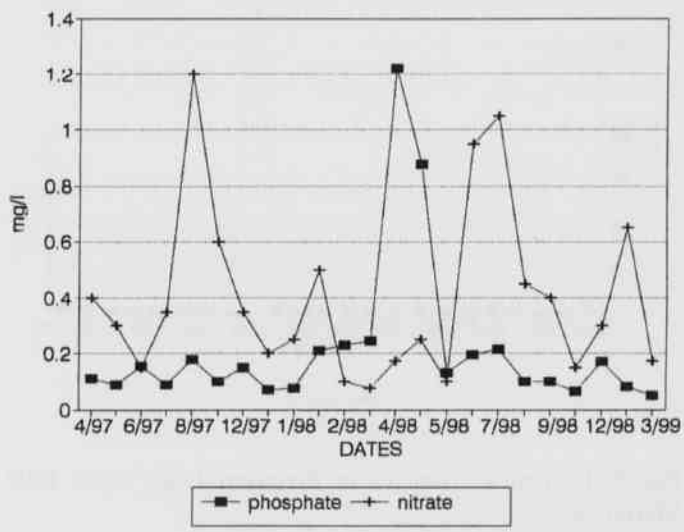


Fig. 7. Ortho-phosphate and nitrate-oxygen readings in Ferguson Lake, April 1997-March 1999.

Iron concentrations (Fig. 8) fluctuated lightly between 0.3 and 0.5 mg/l for the duration of the study period, except on 19 May 1998 when 39 mg/l was measured. Heavy rain had recently fallen in the watershed which would account for the unusually high peak and also for the quick decline of the phosphate after the fertilizer application.

From 1979 to 1989 Arkansas Power & Light Company (now Entergy Corporation) personnel conducted tests similar to ours on single samples taken every three months from Ferguson Lake. Our data varied from theirs in the following respects: (1) the older (AP&L) pH readings (mean = 6.298) were significantly ($P = 0.05$) lower than ours (mean = 6.996); (2) their phosphate (mean = 0.084 mg/l) and nitrate (mean = 0.148 mg/1) measurements were significantly (P = 0.05) lower than ours (means = 0.217 mg/l and 0.401 mg/l, respectively); (3) the older sulfate measurements (mean = 4.46 mg/l) were significantly (P = 0.05) higher than ours (mean 1.08 mg/l) ; (4) their iron readings (mean = 0.906 mg/l) were significantly (P= 0.05) higher than ours (mean = 0.504 mg/l); and (5) the older specific conductance measurements (mean = 35.1 uSms) were significantly (P= 0.05) lower than ours (mean = 40.4 uSms). Specific conductance readings in the older data exhibited cyclic variations, but they appeared to have a 15- or 16-month periodicity. Our data exhibited a strong "summer" peak in 1998 but not in 1997. Further data collection is necessary to verify this unusual cyclic periodicity.

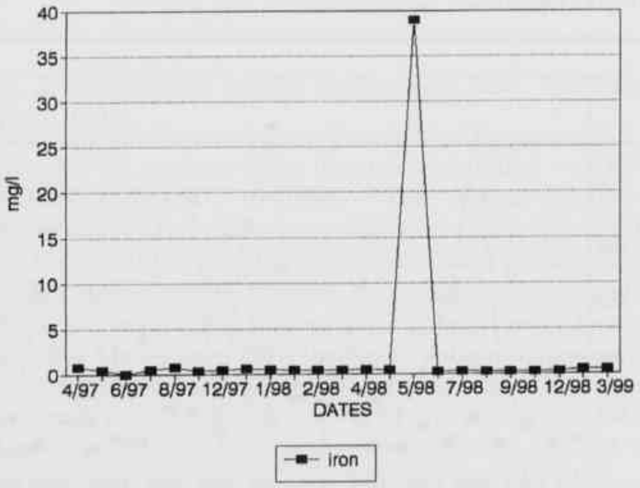


Fig. 8. Iron measurements in Ferguson Lake, April 1997-March 1999.

The observation that the concentrations of phosphate and nitrate seem to be increasing from the earlier study to ours suggests ongoing eutrophication of the water column. Such an increase would most likely stimulate higher rates of primary productivity, which, in turn, would gradually elevate the daytime pH as observed. The increase in conductance indicates an increase in electrolytes; predominantly cations such as Na^+, K^+, CA^{++}, Fe^{++}, and perhaps Mg^{++} and Mn^{++}. Our tests indicated iron decreased, but data for the other cations for both time periods are not available. AP&L personnel recorded 10 alkalinity measurements during the last three years of the earlier period which exhibited a mean of 7.13 mg/l (our mean was 18.4 mg/l). Usually alkalinity and hardness are related, and in natural waters both variables are likely to be high or both low. If hardness has increased similarly with alkalinity, then some of the increase in conductance would be identified, because hardness measures several divalent cations such as calcium, iron and magnesium.

Summary

Ferguson Lake is a typical lowland brownwater lake whose shallower half is dominated by a dense stand of tupelo gum and bald cypress. The rapid deposition and slow decomposition of organic matter contributes to low pH, brown water, and regional hypoxia in deeper water and sediment in the summer months.

The lake covers 171.22 ha, has a maximum depth of 4.27 m and a mean depth of 1.92 m. The lake's normal pool contains 3.3 x 10^6 m^3 of water, has a shoreline length of 10.235 km and shoreline development of 2.692.

The watershed of Ferguson Lake encompasses 58.56 km^2 and is mostly a forested lowland with an elevation gradient of 74.4 to 115.8 m(msl). The watershed to lake area ratio is 34.2 to 1. Heavy precipitation may cause rapid rises in the lake level, but spillway overflow is usually restricted to the period from November through June. Evaporation from the lake's surface is relatively rapid, but the water level normally fluctuates less than 0.5 m.

Specific conductance, alkalinity, hardness and sulfate were lower, and iron, nitrate and phosphate were normal compared to similar water bodies in the region. Although temperature declined slightly near the bottom, there was no evidence of classical thermal stratification. The water is sufficiently fertile to exhibit a moderate rate of ecological productivity as evidenced by casual observations of plankton and benthos densities and angler reports of fish harvest. This report is only an initial step toward analyzing the lake holistically and interpreting its features in reference to fish production.

Literature Cited

Beasley, R. S., and **T. B. Wigley, Jr.** 1988. Management alternatives for Ferguson Lake. Unpubl. Report to Lakeside Country Club Lake Preservation Committee, 24 Oct 1988, pp. 1-7 with appdx.

Brinson, M. M. 1977. Decomposition and nutrient exchange of litter in an alluvial swamp forest. Ecology 58:601-609.

Comer, W. H., and **J. W. Day.** 1991. Leaf litter decomposition in three Louisiana freshwater forested wetland areas with different flooding regimes. Wetlands 11: 303-312.

Harper, C. A., and **E. G. Bolen.** 1995. Leaf-litter decomposition in blackwater impoundments. J. Freshw. Ecol. 10(2):193-195.

Horne, A. J., and C. R. Goldman. 1994. Limnology, 2nd ed. McGraw-Hill, Inc., New York, pp. 420,1.

Reid, G. K., and R. D. Wood. 1976. Ecology of inland waters and estuaries. Van Nostrand Co., New York, p. 90.

Rice, K. D., and M. Rooker. n.d. A history of Lakeside Country Club. Unpubl. mimeo., pp. 3-8.

Standard Methods for the Examination of Water and Wastewater, 16th ed., 1985. Publ. by APHA, AWWA, and WPCA, pp. 210ff and 269ff.

Statistical Analysis of Climatic Variables in the Arkansas-Red River Basin

Felix Tendeku
Department of Mathematical Sciences and Technology
University of Arkansas at Pine Bluff
Pine Bluff, AR 71611

Abstract

Surface meteorological data for the Arkansas-Red River basin are analyzed in order to provide statistical data for modeling and simulation of climatic trends within the basin. The variables studied are the ambient temperature, temperature range, and precipitation. Daily and monthly mean values, spatial and seasonal variations, and frequency distributions are determined.

Introduction

This study is restricted to three surface meteorological variables, namely, ambient temperature, temperature range, and precipitation. These variables play an important role in climate change modeling, climatic impact studies and solar energy simulation studies. In agronomy, the study of climatic impact on crop growth and productivity requires data on daily global solar irradiation (H) for simulation models (Amir and Sinclair, 1991). Although historical global solar irradiation data are sparse, statistical relationships between H and other climatic variables provide a practical way to estimate H at locations where it was not measured (Barr et al., 1996; De Jong and Stewart, 1993). In solar heating and cooling studies, data on long wave atmospheric radiation are required. Often, as measured data are scarce or unavailable for the location under study, long wave radiation data may be estimated from meteorological data. Indeed, a large number of empirical formulae have been used for this purpose (Skartveit et al., 1996). Of the empirical formulae expressing irradiance in terms of surface-based variables, temperature and humidity dependent formulae have been applied with considerable success.

Historical data on precipitation amounts and spatial coverage are used in the design and operation of river-basin water-resource systems such as stream flow and reservoir regulation, real time operation of water works and hydrologic forecasting (Bras and Rodriguez-Iturbe, 1993).

The data used in this work was obtained from the University Consortium for Atmospheric Research (UCAR) Joint Office for Science Support (JOSS) Data Management System. It is archived as the National Climatic Data Center (NCDC) Summary of the Day Cooperative Data Set, one of several data sets provided for the Global Energy and Water-cycle Experiment (GEWEX) Continental-scale International Project (GCIP). The data contain surface meteorological observations from some 1450 stations within the Arkansas-Red River basin located approximately from

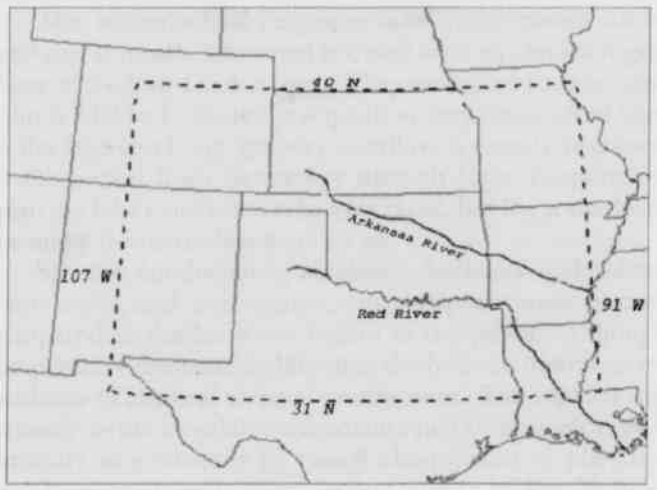


Fig. 1: A map showing Arkansas-Red River basin, the area under study, extending from 31N to 40N and 91W to 107W.

91W to 107W longitude and 31N to 40N latitude (Fig. 1). GEWEX has been initiated to study, on a global scale, the fast climate system mechanisms controlling radiation, cloud and rain, evaporation and fresh water storage. The Mississippi River basin provides a geographic area where significant atmospheric and hydrologic variations as well as land surface changes occur. The Arkansas-Red River basin, one of several intensively observed areas within the Mississippi River basin, represents different climatic and soil hydrology regimes to be studied during the GCIP project. Figure 2 shows the topography of the Arkansas-Red River basin. The time scales of the individual data sets used in this study are February 1 through April 30, 1992 (GIDS-1, 1992), April 1 through August 31, 1994 (GIST, 1994), April 1 through September 30, 1995 (GCIP/ESOP-95, 1995), and April 1 through September 30, 1996 (GCIP/ESOP-96, 1996). These data sets are compiled for the period of the year considered to have hydrological importance, that is, early spring through summer snowmelt and runoff.

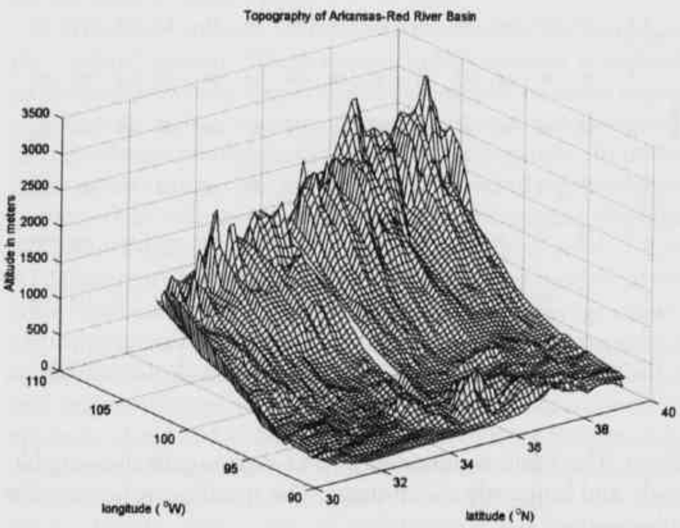


Fig. 2. Topography of Arkansas-Red River basin showing a westward rise in elevation from the Mississippi River (at approximately 91W longitude).

Data Analysis and Results

Time series data are formed for each variable by averaging daily readings over a spatial grid and a four-year period according to the following formula:

$$V_d = (1/NY)\sum_{y=1}^{Y}\sum_{n=1}^{N} V_{n,y} \qquad (1)$$

where $V_{n,y}$ is the value of the variable of the day for the nth station, y = 1,2,...,Y is the number of years of observation, n = 1, 2, ..., N is the number of stations with valid data points for a given day of the year, and V_d is the area-averaged daily value of the variable under consideration. Table 1 shows the number of data points per year used to determine V_d. The ambient temperature, T_a, and temperature range, T_r, are calculated from the daily minimum temperature, T_{min}, and maximum temperature, T_{max} as follows: $T_r = T_{max} - T_{min}$ and $T_a = T_{min} + T_r/2$. By merging the data sets using the above equation we obtain a time series for 243 days, from February 1 through September 30.

Figure 3 shows the time series of the area daily mean values of the climatic variables along with their daily spatial standard deviations, obtained by averaging data for the entire basin. These time series are analyzed to determine the monthly area statistics. A test of normality shows that all

Year	Number of stations with data for: Minimum Temperature	Maximum Temperature	Precipitation
1992	850	850	1435
1994	822	822	1334
1995	852	852	1470
1996	850	850	1382

Table 1. The number of stations providing data for the determination of basic statistics.

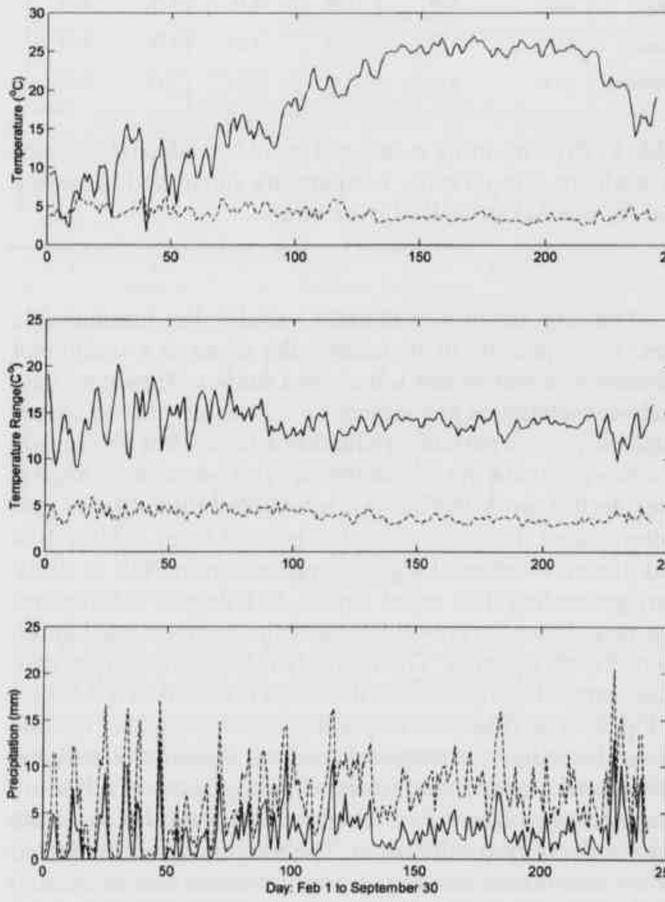


Fig. 3. A four-year averaged daily area mean (solid line) of climatic variables: air temperature, temperature range and precipitation with their spatial standard deviations (dashed line). Abscissa values refer to the day, from February 1 to September 30.

three variables deviate significantly from normal distribution. Since the underlying distribution is not precisely known, we employ a non-parametric method, the bootstrap method (Efron and Tibshirani, 1993), to estimate the monthly mean and standard deviation. These statistics are reported in Table 2.

Month	Ambient Temperature °C		Temperature Range C°		Precipitation (mm)	
	Mean	Stdev	Mean	Stdev	Mean	Stdev
February	7.26	4.57	13.67	4.30	2.03	4.91
March	10.49	4.58	14.94	4.37	2.21	4.70
April	13.82	4.57	15.50	4.45	2.74	5.90
May	18.99	4.47	13.22	4.23	3.82	8.21
June	33.99	3.55	13.95	3.64	2.96	7.66
July	25.65	3.58	13.94	3.51	3.17	8.36
August	25.43	3.24	13.64	3.29	2.84	7.66
September	20.12	3.64	13.41	3.66	3.41	7.86

Table 2. Area monthly mean and spatial standard deviations for ambient temperature, temperature range and precipitation for the Arkansas-Red river basin.

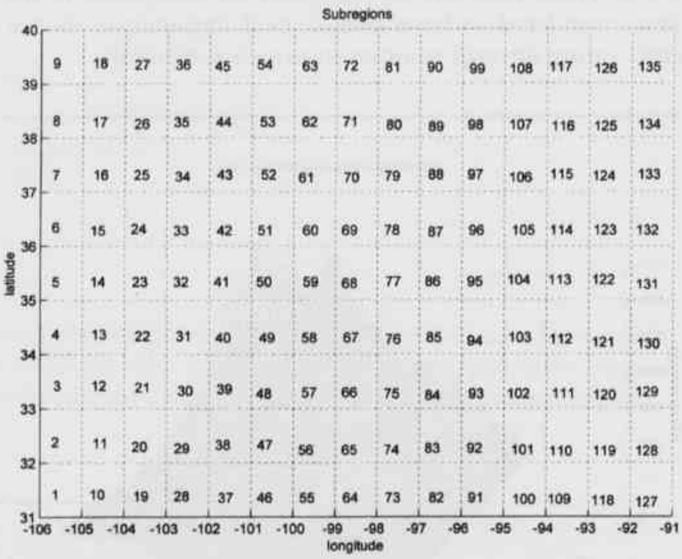


Fig. 4. The basin subdivided by 1x1 degree grid showing latitude and longitude coordinates. The numbers reference the sub-regions.

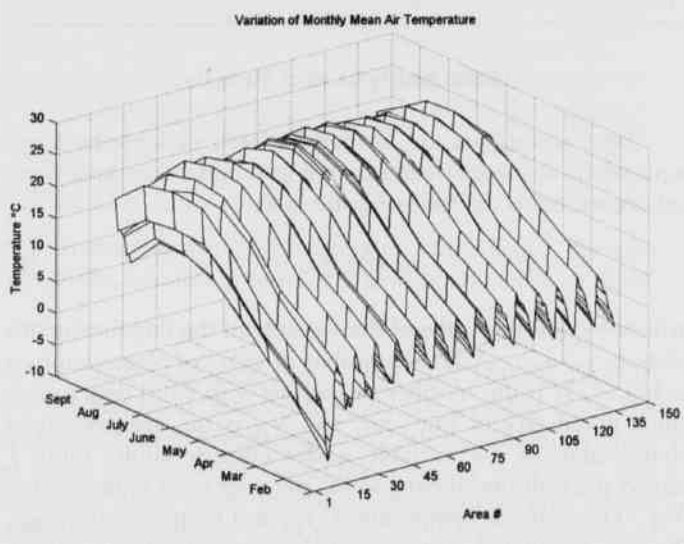


Fig. 5. Surface plot of air temperature versus location and month.

The area mean of a climatic variable has innumerable uses. For example, in hydrology the mean is a traditional parameter in runoff and water-yield studies. However, data analysis techniques are subject to uncertainty due to spatial variability. In a variance reduction scheme, it is a common practice to divide the region into several sub-areas of similar sizes. In this work the basin is subdivided into a 9 x 15 grid pattern, nine divisions along the latitude from 31N to 40N and fifteen divisions along the longitude from 91W to 106W thus generating 135 equal square 1x1 degree sub-regions. Figure 4 shows the coordinates and the numbers used to reference each sub-area. The monthly mean temperature variation versus location within the basin is shown in a 3-D plot in Fig. 5. The ridges correspond to areas along 31N latitude while the valleys correspond to areas along 40N latitude. The spatial trend is characterized by a positive north-south temperature gradient due to higher mean values in the south than in the north of the basin. The temporal trend is depicted by a nonlinear rise in the mean ambient temperature. It reaches a peak in July for areas in the south but in August for areas in the north.

After determining the basic statistics, attention is focused on the study of the time series data. Each time series may be considered to consist of two components:- (1) a steady periodic component composed of all seasonal cycles and (2) fluctuations which may be interpreted as the daily weather variations. The two components are studied separately and their characteristics are determined.

The Periodic Component.--To obtain the different seasonal cycles and their relative importance, the power spectrum is obtained for each area time series. It consists of finding the discrete-time Fourier transform of samples of the time series, taking the magnitude squared of the result, and scaling by the square of the norm of the data window applied to the time series (Welch, 1967). For ambient temperature, the most significant component is 1 day/cycle. Other important harmonics occur at 2, 3, 4, 5, 8, and 11 days/cycle. For the temperature range, significant cyclical components occur at 1, 3, 4, 5, 12, and 13 days/cycle. Precipitation has significant seasonal components at 1, 4, 5, 22, 24, and 27 days/cycle.

Of special interest is the determination of the length of the "warm" season. Warm season in this context is defined as the period whose beginning in late winter or early spring and ending in late summer or early autumn are characterized by abrupt change in the ambient temperature. To determine when abrupt changes occur, a method of segmentation is used that is based on the Adaptive Forgetting through Multiple Model (AFMM) method (Ljung, 1994). The AFMM algorithm consists of building parallel models of the auto-regressive and auto-regressive moving-average types, assuming that the model parameters are piece-wise constant over time. It results in a model that splits the data record into segments over which the model remains constant. On applying the AFMM algorithm to the ambient temperature time series, abrupt changes in the ambient temperature were found to occur approximately on February 20 and September 23. The warm season is thus defined as the period from February 20 to September 23.

Residual Analysis.--After the significant cyclical components have been determined, they are subtracted from the original data, and the residuals thus formed are examined for statistical characteristics. If all cyclical components have been subtracted out, the residuals should have a zero mean. Thus we subject the residual signals to the test of hypothesis that the mean is zero. Using the sample mean, $\bar{y}$, the sample variance, S, the hypothesized population mean, μ, and the number of data points, N, then the statistic $t = (\bar{y} - \mu)\sqrt{N}/S$ will follow a Student's t-distribution with N- 1 degrees of freedom. For $N = 243$ if the test statistic is between ± 2.596 for $\alpha = 0.01$ level of significance, then the sample mean may be regarded as coming from a population with zero mean. Results of this test on the residual signals show the mean in each case is not significantly different from zero.

The residual signal for each climatic variable is separated into two temporal groups referred to as the spring and summer groups, respectively. A comparison is made to determine whether the frequency distribution is the same during the two periods. The Mann-Whitney statistic was used to test the null hypothesis that spring and summer samples follow the same frequency distribution. For both samples to be considered to have come from the same population, the Mann-Whitney statistic, M, must be between ± 1.96 at $\alpha = 0.05$ level of significance. Figure 6 shows the results of the Mann-Whitney statistic plotted for each of the three variables for all sub-regions within the basin. The test indicates that the frequency distribution of variables during spring may be considered to be the same as the summer distribution for all locations throughout the basin. In other words, the variables may be considered to have the same

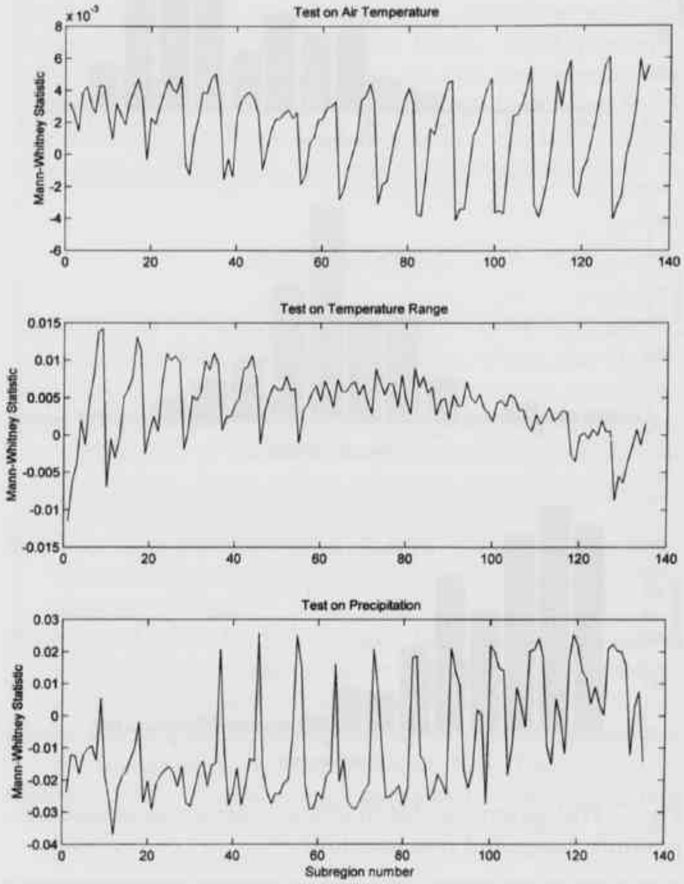


Fig. 6. Mann-Whitney test statistic for climatic variables versus locations within the Arkansas-Red River basin.

distribution throughout the warm season.

After examining the temporal distribution of variables, attention is focused on the examination of the spatial distribution of climatic variables. To test the uniformity of frequency distribution of variables between locations within the basin, the Kruskal-Wallis test was applied to see if samples from different locations could be considered to have come from the same population. If the size of samples from each population is at least 5 then the Kruskal-Wallis statistic, K, will closely follow a chi-square distribution (pchisq) with degrees of freedom, df = N-1, where N is the number of spatial samples. At a level of significance, α, the acceptance of the hypothesis that N samples follow the same distribution is given by pchisq(K,df) < $1 - \alpha$. Results show that K is 0.82 for ambient temperature residuals, 1.96 for temperature

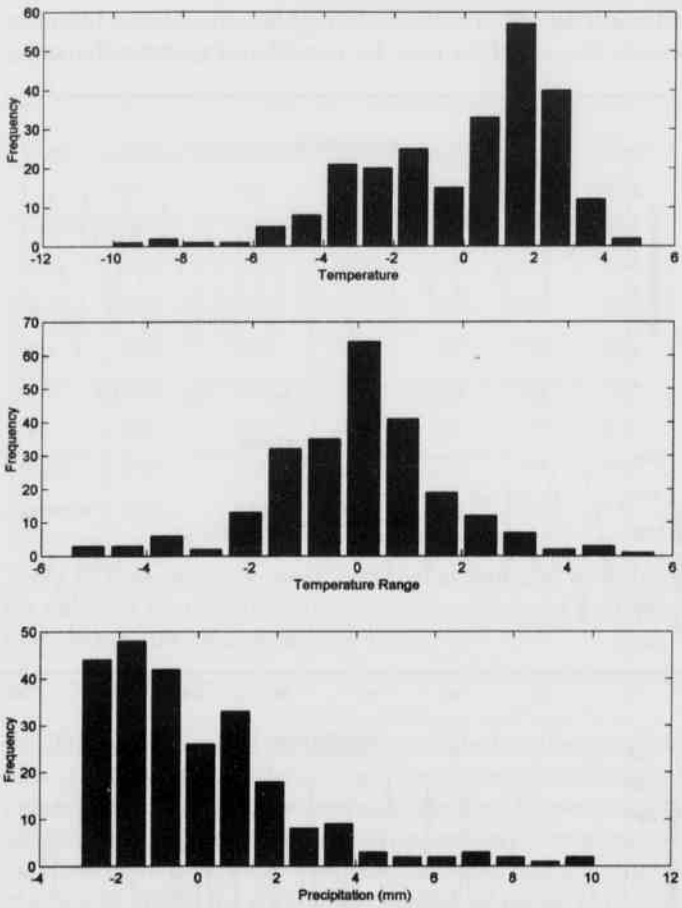


Fig. 7. Histograms of distributions of air temperature, temperature range and precipitation.

range residuals and 105.7 for precipitation residuals. Applying the Kruskal-Wallis test to the spatial samples gives values of pchisq(K,df) which are significantly less than 0.99 for each climatic variable. These results lead to the acceptance of the hypothesis that all variables follow the same distribution irrespective of location in the basin.

Frequency Distribution Functions.--The histograms of the residual signals (Fig. 7) are curve-fitted to a set of well known probability density functions, notably, the Gaussian, Lorentzian, Pearson VII, Log Normal, Symmetric and Asymmetric Double Sigmoid, Symmetric and Asymmetric Double Cumulative, Gamma, Weibull, Beta, Logistic, Pulse and Error functions. The choice of the best-fit function is based on the examination of three fit statistics, namely, the coefficient of determination, r^2, the fit standard error, S_e, and the F-statistic.

In the following, the mathematical relations of the fit statistics are given. The Sum of the Squares due to Error (SSE) is

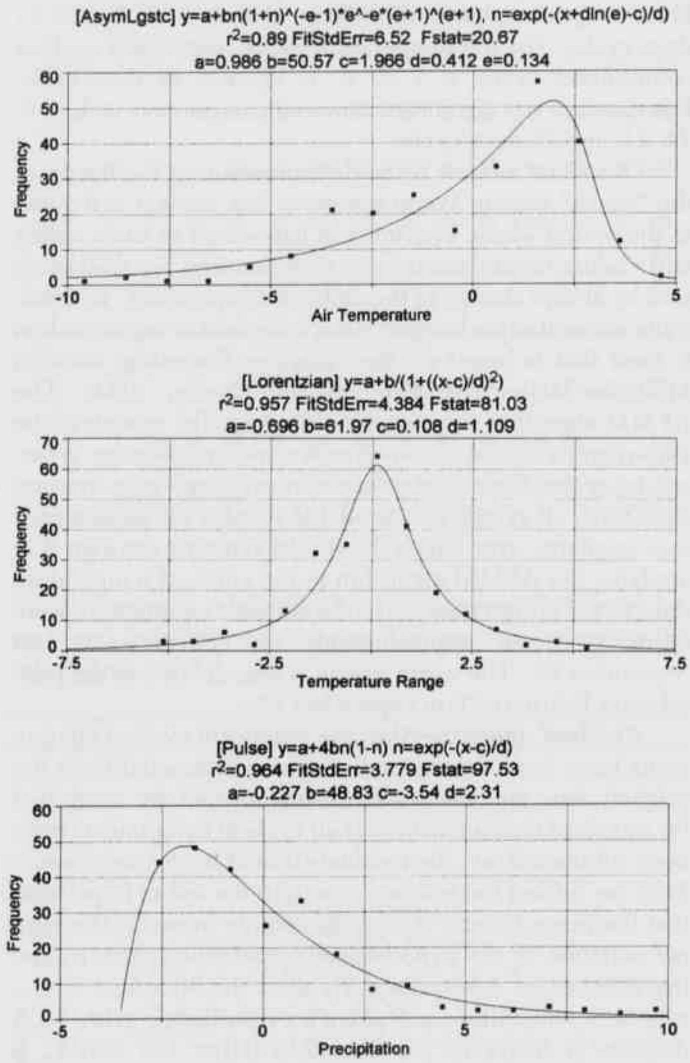


Fig. 8. Best-fit frequency distribution functions for air temperature, temperature range and precipitation.

$$SSE = \sum_{i=1}^{n} w_i(\hat{y}_i - y_i)^2 \tag{2}$$

where SSE is the weighted (w) sum of the squared residuals, the data values are $\hat{y}_i$, the estimated values are $\hat{y}_i$, and the total number of data points is n. The Sum of the Squares about the Mean (SSM) is

$$SSM = \sum_{i=1}^{n} w_i(y_i - \bar{y})^2 \tag{3}$$

where $\bar{y}$ is the arithmetic mean of the data values. The coefficient of determination is r^2=1-SSE/SSM. The degree of freedom, df, is defined as df = n-m, where m is the number of coefficients in the fit equation. The Mean Square Error, MSE, is defined as MSE = SSE/df. The Fit Standard Error

Journal of the Arkansas Academy of Science, Vol. 53 [1999], Art. 1

is $S_e = \sqrt{MSE}$. The Mean Square Regression, MSR = (SSM-SSE)/(m-1) and the F-statistic is defined as F = MSR/MSE.

The closer r^2 is to 1.0, the better the goodness of fit. However, this statistic is known to increase with increasing number of terms in an equation even though there may have been no real improvement in the fit. The Fit Standard Error, S_e, is the least-squares error of a fit. The closer this value is to zero the better the fit. It is directly related to the number of data points and is sensitive to outlying data points. The F-statistic is a measure of the extent to which a given equation represents the data. If an additional parameter makes a statistically significant contribution to a model, the F-statistic increases, otherwise it decreases. The higher the F-statistic the more efficiently a given equation fits the data. Figure 8 shows the best-fit frequency distribution functions for the residuals of the climatic variables. The Asymmetric Logistic function is the choice for the ambient temperature distribution, the Lorentzian function for temperature range and Pulse function for precipitation. The choice of the best-fit function is based on seeking the best compromise between r^2, S_e, and F-statistic.

Summary and Conclusions

Temperatures within the basin are time and location dependent. For all locations the temporal trend is characterized by a rise from February through September, reaching the peak in July for areas along 31N latitude while reaching the peak in August for areas along 40N latitude (Figs. 4 and 5). The peak values decrease northward, resulting in a north-south temperature gradient. The daily spatial variances are higher during spring than during summer. The frequency distribution during the warm season is found to follow approximately the Asymmetric Logistic function. Statistical tests show that the distribution is the same for all locations.

The daily temperature range, that is, the difference between daily maximum and minimum temperatures, exhibits the largest fluctuations during March and April. Peak values may attain 20C° while minimum values may drop to about 9C°. The warm season diurnal temperature range fluctuates between 12C° and 16C°. The temporal distribution, which is statistically the same for all locations, follows the Lorentzian function (Fig. 8).

Precipitation exhibits a very high degree of randomness with high spatial variances throughout the warm season. The highest four-year averaged monthly mean occurs in May. The frequency distribution follows the Pulse function (Fig. 8).

The work done so far has focused on the determination of the basic climatic statistics and general area trends within the basin. Our future work will include the determination of statistical models of both temporal and spatial variations, estimation of scales of spatial and temporal correlation, and the interdependence between the three surface meteorological variables considered in the present study.

ACKNOWLEDGMENTS.—The data sets used in this work were obtained from the University Corporation for Atmospheric Research (UCAR) Joint Office for Science Support (JOSS). I thank Dr. Tom DeFelice with the Atmospheric Science Group at the University of Wisconsin at Milwaukee for his collaboration on a related project using the GCIP data. The support received from Dr. Robert Jones, Associate Dean for Sponsored Programs at the University of Wisconsin at Milwaukee, is gratefully appreciated.

Literature Cited

Amir, J., and **T. R. Sinclair.** 1991. A model for temperature and solar radiation effects on spring wheat growth and yield. Field Crops Res. 28:47-58.

Barr, A. G., S. M. McGinn and **Si Beng Cheng.** 1996. A comparison of methods to estimate daily global solar irradiation from other climatic variables on the Canadian prairies. Solar Energy 56:213-224.

Bras, R. L., and **I. Rodriguez-Iturbe.** 1993. Random functions and hydrology. Dover Publications, Mineola, New York. xv+559pp.

De Jong, R., and **D. W. Stewart.** 1993. Estimating global solar radiation from common meteorological variables in western Canada. Can. J. Plant Sci. 73:509-518.

Efron, B., and **R. J. Tibshirani.** 1993. An Introduction to the bootstrap. Chapman and Hall, New York.

GIDS-1. 1992. Global energy and water-cycle experiment (GEWEX) Continental-scale international project (GCIP) Initial data set.

GIST. 1994. Global energy and water-cycle experiment (GEWEX) Continental-scale international project (GCIP) Integrated systems test.

GCIP/ESOP-95. 1995. Global energy and water-cycle experiment (GEWEX) Continental-scale international project (GCIP) 1995 Enhanced seasonal observing period.

GCIP/ESOP-96. 1996. Global energy and water-cycle experiment (GEWEX) Continental-scale international project (GCIP) 1996 Enhanced seasonal observing period.

Ljung, L. 1994. System identification - theory for the user. Prentice Hall, Englewood Cliffs, NJ.

Skartveit, A., J. A. Olseth, G. Czeplak and **M. Rommel**. 1996. On the estimation of atmospheric radiation from surface meteorological data. Solar Energy 56:349-359.

Welch, P. D. 1967. The use of Fast Fourier Transform for the estimation of power spectra: A method based on time averaging over short, modified periodograms. IEEE. Trans. Audio Electroacoust. AU-15: 70-73.

Survey of Diseases in Wild Turkeys in Arkansas

Wayne E. Thogmartin*, James E. Johnson,
Bradley A. Schaeffer, and Camille C. Ciriano
Arkansas Cooperative Fish and Wildlife Research Unit,
U.S. Geological Survey, Biological Resources Division,
Department of Biological Sciences, University of Arkansas,
Fayetteville, AR 72701

*Corresponding Author: Coopertive Wildlife Research Laboratory, Southern Illinois Univ., Carbondale, IL 62901-6504

Abstract

Nineteen dead wild turkeys were necropsied and 573 live wild turkeys were physically examined for pathological agents in Arkansas between 1992 and 1997 to determine the proximate role disease may play in declining wild populations in Arkansas. Necropsy of the dead wild turkeys identified avian pox and histomoniasis as the most common diseases (16% and 11% of necropsies, respectively). Avian pox was recorded from three major physiographic regions in the state (Ozark Highlands, Ouachita Mountains, Gulf Coastal Plain). One hen died of non-accidental crop impaction, the fifth occurrence observed in the southeastern United States. Another hen died after developing severe, focal necrotic dermatitis caused by a *Penicillium* sp. fungus, the first occurrence observed in wild turkeys. All live wild turkeys appeared free of gross signs of disease. We found diseases in wild turkeys in Arkansas are not uncommon and are more diverse than previously reported. Continued monitoring of disease in wild turkeys is therefore encouraged.

Introduction

Annual harvest of eastern wild turkeys (*Meleagris gallolpavo silvestris*) in the Ouachita Mountains of west-central Arkansas suggested a decline in abundance from 1987 to 1996 (Thogmartin, 1998). Nest predation, reproductive effort, and clutch size have been identified as factors influencing this decline (Thogmartin and Johnson, 1999). Furthermore, body mass of adult male and subadult female turkeys in the Ouachita Mountains declined significantly from 1993 to 1996 (9% and 22%, respectively; Johnson et al., 1996). Conversely, populations in the Ozark Highlands of Arkansas were stationary despite poor reproductive success (Badyaev, 1995).

Our objectives in this study were to report on the presence and prevalence of disease in dead wild turkeys in Arkansas. Furthermore, we wished to reexamine the notion provided by Hopkins et al. (1990) that wild turkey populations in Arkansas were "in good health". Our purpose with this study was not so much to detail occurrence of mortality sources in wild turkeys in Arkansas, the epidemiological details of which will be published elsewhere, as much as it was to discuss their potential influence on wild turkey population ecology and management in Arkansas.

Hopkins et al. (1990) examined only live turkeys captured at bait sites in a study of infectious diseases in wild turkeys. This procedure likely excluded infirmed turkeys unable to travel to bait sites. The study by Hopkins et al. (1990) also suffered from an autocorrelation of results; diseases and parasites carried by one individual in a flock are also likely to have infected other individuals in the captured flock, thus potentially confounding true levels of disease prevalence. Our study controlled for potential autocorrelation of disease results by examining independently gathered specimens. However, our survey was also biased because we sampled only dead wild turkeys recovered in a radiotelemetry project and birds submitted to the Arkansas Game and Fish Commission (AGFC) because they appeared in poor condition. Despite this bias, our study complements the efforts of Hopkins et al. (1990) by sampling turkeys more likely to carry disease, thus providing a more complete perspective of disease in wild turkeys in Arkansas.

Methods

Wild turkeys were captured with rocket nets (Bailey et al., 1980) at White Rock (35°37' to 35°46' N, 93°50' to 94°07' W) and Piney Creek (35°37' to 35°49' N, 93°07' to 93°30' W) Wildlife Management Areas in the Ozark Highlands, Arkansas, from January to March 1992 to 1995 and at Muddy Creek Wildlife management Area (34°39' to 34°52' N, 93°30' to 94°00' W) in the Ouachita Mountains from January to March 1993 to 1997. We ascertained sex by breast and tail feather coloration, age (adult or subadult) from shape and barring patterns on the ninth and tenth primary feathers (Larson and Taber, 1980), and body mass to the nearest 0.1-kg. All birds were inspected for clinical signs of disease and other abnormalities including unusually low weight, exudations around the eyes and nares, and presence of gross external lesions indicative of avian pox and other diseases (Couvillion et al., 1991). A topical antiseptic spray was applied to abrasions incurred during capture. Turkeys were outfitted with 110-g motion-sensitive radio transmitters (Telonics, Mesa, AZ) and located two or more times weekly for up to 30 months. Transmitters signaling prolonged inactivity were located and carcasses retrieved. Because of scavenging, predation, and our reluctance to approach inactive hens during the nesting season, only 10 carcasses were retrieved in the three study areas. Wild turkeys collected by hunters ($n = 3$) and AGFC personnel ($n = 6$) from throughout the state were also included in this survey.

Southeastern Cooperative Wildlife Disease Study (SCWDS) personnel in Athens, Georgia, conducted necropsies. All carcasses were sent to them frozen. Condition of the animal at time of recovery influenced the type of necropsy performed (Davidson et al., 1985). All specimens were examined for gross external and internal lesions. Relative physical condition was determined by a visual estimation of fat bodies; for instance, lack of subcutaneous or internal fat reserves resulted in a "fair" rating. Swabs of gross lesions were taken for bacterial cultures and tissues were examined for microscopic lesions when warranted. Radiographs were taken when trauma was suspected.

Results And Discussion

No obvious signs of disease were observed in any of 573 wild turkeys (Ozark Mountains, $n = 298$; Ouachita Mountains, $n = 275$) captured at bait sites. Because this was a post-hoc study conducted ancillary to an investigation into wild turkey population dynamics, we did not investigate subacute diseases in live-caught birds. Sub-clinical diseases may manifest into epidemics after long periods of low level infection, as Davidson et al. (1980) suggested for avian pox in northern bobwhite (*Colinus virginianus*). This also may have been observed by Lutz and Crawford (1987) when

Table 1. Wild turkeys ($n = 19$) submitted to the Southeastern Cooperative Wildlife Disease Study from Arkansas, 1992 - 1996, by source of mortality, sex, age, and county area. A = adult, S = subadult, P = poult. Radio indicates whether wild turkey was radio collared.

	Source of Mortality	Sex	Age	Radio	County Location	Season of Mortality	Parasite Infection	Physical Condition	Comments
Disease									
1	Avian Pox	F	A	N	Montgomery	Autumn	*Heterakis* spp.	Poor	Legally harvested by hunter; emaciated; prominent lesions
2	Avian Pox	F	S	N	Desha	Spring	None	Fair	
3	Avian Pox*	M	A	N	Johnson	Spring	None	N/A	
4	Crop Stasis	F	A	Y	Pope	Winter	*H. gallinarum*, lice	Fair	≥26% mass loss (1.4 kg) in 26 days since capture
5	Histomoniasis	M	S	N	Yell	Summer	Histomonads	Fair	
6	Histomoniasis	M	P	N	Johnson	Spring	Numerous	Fair	4 gastro-intestinal parasite spp.; sustained trauma
7	Necrotic Dermatitis[b]	F	A	Y	Montgomery	Winter	None	Poor	*Heterakis* and *Ascaridia* spp.
8	Fibrinous Perotinitis and Salpingitis	F	A	N	Johnson	Spring	None	Excellent	*E. coli, S. aureus,* and *Enterococcus* infection of oviduct
9	Unknown[c]	M	A	Y	Montgomery	Summer	Numerous	Fair	Enteric disease possible mortality source
10	Unknown Chronic Disease	M	A	Y	Franklin	Summer	None	Poor	Emaciated; secondary condition: gout tophi in kidney sections

[a]Secondary infection of septicemia, contributing to emaciated condition. [b]Severe focal necrotic dermatitis caused by *Penicillium* sp. fungus, at site of trauma.

Table 1. Continued.

	Source of Mortality	Sex	Age	Radio	County Location	Season of Mortality	Parasite Infection	Physical Condition	Comments
Accident									
11	Trauma	M	A	Y	Montgomery	Spring	None	Good	Mortality due to lightning striking roost tree
12	Trauma (Crop Impaction)	F	A	Y	Montgomery	Winter	None	Good	≥28% mass loss (1.2 kg) in 337 days since capture
13	Trauma	M	A	N	Unknown	N/A	N/A	N/A	
Anthropogenic									
14	Gunshot (Legal Harvest)	F	A	N	Chicot	Fall	None	Poor	Evidence of healed gunshot wounds
15	Gunshot (Legal Harvest)	M	A	N	Yell	Spring	Tapeworm (1)	Good	Unrecovered by hunter
16	Gunshot (Legal Harvest)	M	A	Y	Yell	N/A	N/A	N/A	Lesions from previous gunshots
17	Gunshot (Poach)	M	A	N	Yell	Summer	Nematodes (4)	Good	Unrecovered by poacher
18	Capture-related Myopathy	F	A	Y	Yell	Winter	None	Good	Stress-related biochemical changes
19	Capture-related Injury	F	A	Y	Scott	Winter	None	Good	Traumatic injuries resulting from capture

[c]Approximately 100 cecal worms (*Heterakis* spp.), 15 roundworms (*Ascaridia disimilis*), and 25-30 tapeworms (*Raillietina* and *Metroliasthes* spp.) observed in gastrointestinal tract. Emaciated state possibly related to loss of nutrients due to intestinal disease rather than reduced food intake.

they reported avian pox lesions in a small number of captured Merriam's wild turkeys (*M. g. merriami*) in Oregon. Regardless, gross signs of disease were not apparent in live-caught turkeys in Arkansas, similar to turkeys studied by Hopkins et al. (1990).

Infectious disease did, however, cause death for ten recovered wild turkeys (Table 1). Not surprisingly, diseased birds were in worse physical condition than those dying by trauma or by anthropogenic means ($\chi^2 = 9.01$, $P < 0.005$). Infectious disease is common in wild turkeys (Davidson and Wentworth, 1992), and incidence of disease in wild turkeys as well as their associated vectors has been widely reported for the Southeastern and Midwestern U.S. (e.g., Davidson et al., 1985; Castle and Christensen, 1990; Luttrell et al., 1991; Fedynich and Rhodes, 1995).

Three carcasses exhibiting evidence of gross lesions of avian pox were recovered; none of the wild turkeys captured and examined by Hopkins et al. (1990) were infected with avian pox. Avian pox is the most commonly reported disease in wild turkeys in the southeastern U.S. (Davidson et al., 1985) and in Arkansas, pox was identified in three physiographic regions, the Ozark Highlands, Ouachita

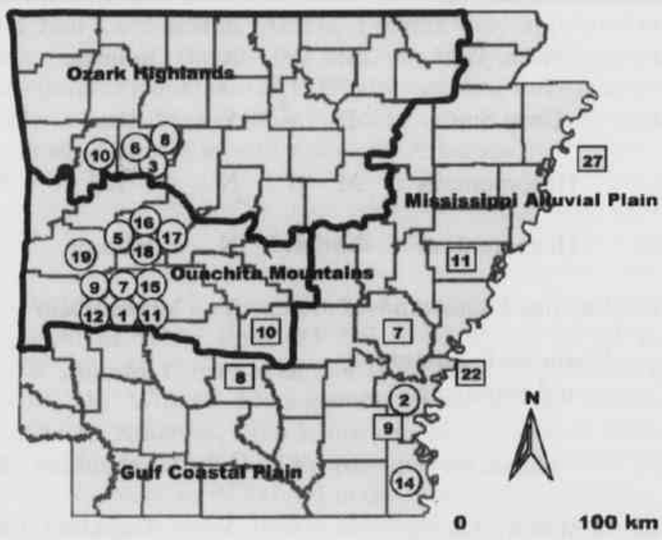


Fig. 1. County map of Arkansas depicting numbered locations (in circles) of recovered dead wild turkeys listed in Table 1, 1992 to 1997. Boxed numbers are specimens described in Maxfield et al. (1963).

Mountains, and Gulf Coastal Plain (Fig. 1). Its negative consequences to fecundity may be important in limiting population growth (Thompson et al., 1997).

This study is the first to report necrotic dermatitis associated with a *Penicillium* sp. The *Penicillium* sp. fungus cooccurred with *Stalphylococcus hyicus, S. aureus, Klebsiella oxytoca*, and *Bacillus* sp. bacteria in an infection of the wing. While it is not clear whether this infection was a direct source of mortality (there were additional infections of the spleen, kidney, and duodenum), it likely was severely debilitating and thus the main contributor to mortality. Mycoses (fungal infections) in general are rare in wild turkeys (Hopkins et al., 1990). Davidson et al. (1985) reported one respiratory case of fungal infection in turkeys and believed it to be unique (Davidson and Wentworth, 1992). Hopkins et al. (1990) reported several infections of turkeys by *Aspergillus fumigatus*, a common soil fungus.

Bacterial infection may be a more frequent source of natural mortality in wild turkeys than previously demonstrated (Davidson and Wentworth, 1992). A single case of salpingitis and fibrinous peritonitis (inflammation of the oviduct and body cavity) resulted from infection by *Staphylococcus aureus, Eschericia coli,* and *Enterococcus* spp. This syndrome is uncommon in wild turkeys; Davidson et al. (1985) reported one case of salpingitis. *Eschericia coli* is normally found in the intestinal tract and operates opportunistically following stress, internal trauma, or other infection (Woodard et al., 1993).

In our study, two of 19 (11%) turkeys exhibited histomoniasis (blackhead disease), a disease caused by *Histomonas meleagridis.* Blackhead is the second most commonly reported disease in wild turkeys and represents about 12% of turkey accessions to SCWDS (Davidson and Wentworth, 1992). Blackhead has been reported in numerous studies of wild turkeys (Kozicky, 1948; Amundson, 1985; Davidson et al., 1985) including turkeys in Arkansas (Hopkins et al., 1990). Emaciation and reduced activity are common clinical signs associated with advanced cases of blackhead disease. Blackhead can reduce growth in young birds (Woodard et al., 1993) and cause early cessation of laying in adult hens (Davis et al., 1971), suggesting this pathogen may affect wild populations by increasing risk of predation and reducing fecundity.

Data regarding diversity, geographic distribution, and prevalence of parasites in wild turkeys of Arkansas is incomplete. Maxfield et al. (1963) reported gastrointestinal helminths in 76 wild turkeys from southeastern Arkansas (Fig. 1). In our survey, at least seven of 17 examined birds were infected with endoparasites; partial scavenging precluded examination for parasite infection in two birds. In our survey, one adult male turkey from Montgomery County was parasitized by *Brachylaema* sp., extending observed incidence of this trematode parasite northwest into the Ouachita Mountains. Maxfield et al. (1963) reported *Brachylaema* sp. infection in one of 45 turkeys in Desha county in southeastern Arkansas. *Ascaridia disimilis* (nematode), *Heterakis gallinarum* (nematode), *Metroliasthes lucida* (cestode), and *Raillientina* spp. (cestodes), four helminths observed in our study, were also common in the viscera of birds examined by Maxfield et al. (1963). Parasite burden may alter reproductive performance, intraspecific competition for food resources, and opportunities for mating (Hudson and Dobson, 1991), but the helminth species observed in our study are not generally associated with severe consequences to otherwise healthy animals.

Trauma is another leading source of mortality in wild turkeys (Davidson and Wentworth, 1992) and in this study three carcasses exhibited injuries suggesting mortality related to trauma. Fatal injuries included fractured bones in wings, keel, beak, and neck, and crop impaction. Crop impaction often occurs when ingested vegetation is blocked in the esophagus due to trauma in the neck area. However, rare cases of crop impaction are not accident-related, but instead may have their origins in lead poisoning or genetic malfunction (Davidson et al., 1985). Our single case of crop impaction (or crop stasis) was believed to be a non-accident related case (SCWDS necropsy report 52-94). SCWDS reported only four other incidences of crop stasis not attributed to accidental trauma in over 250 wild turkeys necropsied between 1975 and early 1994 (Davidson et al., 1985; SCWDS necropsy report 52-94).

Several authors have suggested turkeys that die from gunshots and are unrecovered during the hunting season may vary between 7 and 30% of all hunting season mortalities (Mosby and Handley, 1943; Bailey and Rinell, 1967; Everett et al., 1978). Three of 19 birds (15.8%) in this study exhibited evidence of healed gunshot wounds. Two of three were eventually harvested, likely within the same season they received the initial wound. The full impact of this disturbance to population dynamics has not been evaluated in Arkansas, but it may be high. One of three birds radiographed in New York, for instance, was positive for shot (S. D. Roberts, pers. comm.), whereas in Washington, 15% of examined pheasants (Phasianus sp.) were carrying shot (9% of females, 32% of males; D. S. Galbreath and E. S. Dziedzic, unpub. rept.).

Conclusions

Results from our survey suggest disease is not uncommon and more diverse in wild turkeys of Arkansas than previously reported. The prevalence of disease, however, has yet to be fully ascertained due to biased collection methods in this and past studies. Without more comprehensive collections from captured wild turkeys for bacterial and viral isolation, we cannot know if sub-clinical infection by avian pox, histomoniasis, or other diseases may be limiting reproduction in the Interior Highlands of Arkansas. Mortality from infectious diseases (avian pox and histomoniasis) comprised half of all diseased birds and approximately one-quarter of all necropsies in this study. Continued research on the extent of these diseases in Arkansas is therefore warranted. We recommend a more systematic inspection of wild turkey pathologies in Arkansas. We urge the testing of blood, feces, and throat swabs of all captured wild turkeys.

Wild turkeys captured for translocation should be tested for disease prior to introduction to new areas to prevent dissemination of pathogens into unaffected flocks (Maxfield et al., 1963; Hopkins et al., 1990). Greater knowledge of disease occurrence within source and recipient populations in Arkansas should also aid in managing disease outbreaks. Lastly, dead birds should continue to be necropsied periodically to aid in monitoring disease outbreaks in Arkansas.

ACKNOWLEDGMENTS.—This study was funded by the Arkansas Game and Fish Commission (AGFC) and the National Wild Turkey Federation. We acknowledge assistance of AGFC, especially K. Gardner, D. Goad, L. A. Moore, M. Rodrigues, and M. Staton. We thank G. Horton, R. Knoernschild, and W. Smith for submitting specimens for necropsy. Our appreciation is extended to K. G. Smith for general guidance on this manuscript. This manuscript was substantially improved by F. Clark, L. Newberry, A. Radomsky, and five anonymous reviewers. This paper is a cooperative contribution of the Arkansas Cooperative Fish and Wildlife Research Unit - U. S. Geological Survey, Biological Resources Division; Arkansas Game and Fish Commission; University of Arkansas; and Wildlife Management Institute.

Literature Cited

Amundson, T. E. 1985. Health management in wild turkey restoration programs. Proc. Natl. Wild Turkey Symp. 5:285-294.

Badyaev, A. V. 1995. Nesting habitat and nesting success of eastern wild turkeys in the Arkansas Ozark Highlands. Condor 97:221-232.

Bailey, W., D. Bennett, Jr., H. Gore, J. Pack, R. Simpson and **G. Wright.** 1980. Basic considerations and general recommendations for trapping the wild turkey. Proc. Natl. Wild Turkey Symp. 4:10-23.

Bailey, R. W,. and **K. T. Rinell.** 1967. Events in the turkey year. Pp. 73-91 *In* The wild turkey and its management (0. Hewitt, ed.) The Wildlife Society, Washington, D. C.

Castle, M. D., and **B. M. Christensen.** 1990. Hematozoa of Wild Turkeys from the midwestern United States: translocation of Wild Turkeys and its potential role in the introduction of *Plasmodium kempi.* J. Wildl. Dis. 26:180-185.

Couvillion, C. E., L. M. Stacey and **G. A. Hurst.** 1991. Absence of avian pox in wild turkeys in central Mississippi. J. Wildl. Dis. 27:467-469.

Davidson, W. R., F. E. Kellogg and **G. L. Doster.** 1980. An epornitic of avian pox in wild bobwhite quail. J. Wildl. Dis. 16:293-298.

Davidson, W. R., V. F. Nettles, C. E. Couvillion and **E. W. Howerth.** 1985. Diseases diagnosed in wild turkeys (*Meleagris gallopavo*) of the southeastern United States. J. Wildl. Dis. 21:386-390.

Davidson, W. R., and **E. J. Wentworth.** 1992. Population influences: diseases and parasites. Pp. 101-143 *In* The wild turkey: biology and management (J. G. Dickson, ed.) Stackpole Books, Harrisburg, Pennsylvania.

Davis, J. W., R. C. Anderson, L. Karstad and **D. O. Trainer.** 1971. Infection and parasitic diseases of wild birds. Iowa State Univ. Press, Ames, Iowa, 283 pp.

Everett, D. D., D. W. Speake, W. K. Maddox, D. R. Hillestad and **D. N. Nelson.** 1978. Impact of managed public hunting on wild turkeys in Alabama. Proc. Annu. Conf. Southeast. Assoc. Fish and Wildl. Agencies 32:116-125.

Fedynich, A. M., and **O. E. Rhodes Jr.** 1995. Hemosporid (Apicomplexa, Hematozoea, Hemosporida) community structure and pattern in wintering Wild Turkeys. J. Wildl. Dis. 31:404-409.

Hopkins, B. A., J. K. Skeeles, G. E. Houghten, D. Slagle, and **K. Gardner.** 1990. A survey of infectious diseases in wild turkeys (*Meleagris gallopavo silvestris*) from Arkansas. J. Wildl. Dis. 26:468-472.

Hudson, P., and **A. P. Dobson**. 1991. The direct and indirect effects of the caecal nematode, *Trichostrongylus tenuis,* on red grouse. Pp. 49-68 *In* Bird-parasite interactions: ecology, evolution, and behaviour (J. E. Loye and M. Zuk, eds.) Oxford Univ. Press, New York, New York.

Johnson, J. E., W. E. Thogmartin and **W. J. Etges.** 1996. Population dynamics of wild turkeys of the Ouachita Mountain region: a final report of the Ouachita Wild Turkey Project (to Arkansas Game and Fish Commission). Arkansas Cooperative Fish and Wildlife Research Unit, Fayetteville, Arkansas, 96 pp.

Kozicky, E. L. 1948. Some protozoan parasites of the eastern wild turkey in Pennsylvania. J. Wildl. Manage. 12:263-266.

Larson, J. S., and **R. D. Taber**. 1980. Criteria of sex and age. Pp. 190-197 *In* Wildlife management techniques manual (S. D. Schemnitz, ed.) The Wildlife Society, Washington, D. C.

Luttrell, M. P., S. H. Kleven, and **W. R. Davidson.** 1991. An investigation of the persistence of *Mycoplasma gallisepticum* in an eastern population of wild turkeys. J.

Wildl. Dis. 27:74-80.

Lutz, R. S., and **J. A. Crawford.** 1987. Prevalence of poxvirus in a population of Merriam's wild turkeys in Oregon. J. Wildl. Dis. 23:306-307.

Maxfield, B. G., W. M. Reid and **F. A. Hayes.** 1963. Gastrointestinal helminths from turkeys in southeastern United States. J. Wildl. Manage. 27:261-271.

Mosby, H. E,. and **C. O. Handley.** 1943. The wild turkey in Virginia: its status, life history, and management. Virginia Commission of Game and Inland Fisheries, Richmond, 281 pp.

Thogmartin, W. E. 1998. Factors influencing the decline of an eastern wild turkey (*Meleagris gallopavo silvestris*) population in the Ouachita Mountains, Arkansas. Unpublished M.S. Thesis. Univ. Arkansas, Fayetteville, 275 pp.

Thogmartin, W. E., and **J. E. Johnson.** 1999. Reproduction in a declining population of wild turkeys from Arkansas. J. Wildl. Manage. 63:1281-1290.

Thompson, C. W., N. Hillgrath, M. Leu and **H. E. McClure.** 1997. High parasite load in house finches (*Carpodacus mexicanus*) is correlated with reduced expression of a sexually selected trait. Am. Nat. 149:270-294.

Woodard, A., P. Vohra and **V. Denton.** 1993. Commercial and ornamental game bird breeders handbook. Hancock House, Blaine, Washington, 493 pp.

Post-metamorphic Growth and Reproduction in the Eastern Narrowmouth Toad (*Gastrophryne carolinensis*) from Northeastern Arkansas

Stanley E. Trauth*, Walter E. Meshaka, Jr., and Robert L. Cox
Department of Biological Sciences, Arkansas State University
P.O. Box 599, State University, AR
Museum, Everglades National Park,
40001 SR-9336, Homestead, FL 33034-6733; RLC (deceased)

*Corresponding Author

Abstract

Post-metamorphic growth and the reproductive cycle of the eastern narrowmouth toad (*Gastrophryne carolinensis*) were studied from 204 individuals collected during the April August 1989 activity season in a two-county area of northeastern Arkansas near the northwestern edge of the species' geographic range. Late summer metamorphs require a full growing season before they can reproduce as they approach their second year of life. The oldest individuals may be at least five years old. By late April, gonadal cycles of adults had commenced; the males were producing sperm, and some of the females were gravid. Fertility of both sexes increased during the season and peaked in June. Males remained fertile through August, but only two gravid females were found after June indicating that adults were physiologically capable of breeding for a period longer than weather conditions were acceptable for oviposition. Neither clutch size nor ovum diameter increased with female body size. Disparity of body size and clutch characteristics throughout the brief breeding season could be explained by deposition of partial clutches. The growth, maturity, and gonadal cycle of this species at the northern edge of its range are similar to findings in southern populations, and climate, not changes in breeding physiology, constrain breeding at this northern site.

Introduction

The eastern narrowmouth toad, *Gastrophryne carolinensis*, is a small, semi-fossorial, microhylid species that attains a maximum body length of 38 mm (Conant and Collins, 1998). This species ranges throughout the southeastern and southcentral United States (from Maryland westward to central Missouri and southward to central Texas). Anderson (1954) provided the most thorough study of the ecology of *G. carolinensis* from populations in Louisiana. Recently, Meshaka and Woolfenden (1999) explained geographic variation in calling and reproductive seasons of *G. carolinensis* to fit within a framework of climatic constraints. Nelson (1972) summarized the literature on this species; however, quantitative life history information on this species is still rare. In the present study, we report on population structure and reproduction from samples collected during one season from sites near the northwestern edge of its geographic range and relate our finding with those of more southerly locations.

Materials and Methods

Post-metamorphic individuals of *G. carolinensis* were collected on 31 separate dates by one of us (RLC) during April-August 1989 from a two-county area (Craighead and Greene) in northeast Arkansas. Individuals were killed in a 20% solution of chloretone and fixed in 10% formalin within 24 hr of capture. Specimens were eventually transferred to 70% ethanol and are currently deposited in the herpetology collection at Arkansas State University (ASUMZ).

Body size of preserved specimens was measured in snout-vent length (SVL) with calipers to the nearest 0.1 mm. Routine histological techniques were used to prepare the testes of 87 males for light microscopy following standard methods (Humason, 1979). Testes were dehydrated in a graded series of ethanol, cleared with xylene, infiltrated and embedded in paraffin, sectioned into serial ribbons (8 µm in thickness), affixed to microscope slides using Haupt's adhesive, stained with Harris hematoxylin followed by eosin counterstaining (H & E), and mounted with coverslips. Maturation of sperm was categorized using the two phase system for *G. carolinensis* of Anderson (1954). Phase I (Ph-1) = recrudescence (i.e., increased mitotic activity) within the primary spermatogonial cysts following the breeding season. Ph-2 = a proliferation of clusters of secondary spermatocytes and spermatids which dominate the germinal epithelium.

After being blotted dry, the ovaries were massed (to the nearest 0.001g) using an analytical balance; this was followed by the removal of a small subsample of ovarian follicles in specimens containing pigmented ova. The subsamples were also massed using the same method as above. The largest diameters of 10 pigmented ova were measured with an ocular micrometer. Mean values, when given, are accompanied by 1 standard deviation.

Results

Growth and Maturity.--Post-metamorphic individuals were found during late summer of a short active season (Fig. 1). Sexual maturity was reached as individuals entered their second spring of life (Fig. 1) at body sizes smaller in males (21.5 mm SVL) than in females (26.7 mm SVL). Maximum body size of females (36.5 mm SVL also exceeded that of males (33.6 mm SVL), and mean adult body size of females (29.6 $\pm$2.6 mm; range, 24.0 - 36.5; n = 60) was significantly larger (t = -4.44; $P < 0.001$) than that of males (27.6 $\pm$ 2.6; range, 24.0 - 36.5); n = 91). Groups of size-classes in males were unclear; however, three groups of size-classes were apparent in sexually mature females (Fig. 1). This being the case, female *G. carolinensis* in northeastern Arkansas could live at least five years. The sex ratio (1:1.52) in favor of males reflected a collecting bias within breeding aggregations ($\chi^2 = 6.36$; df = 1; $P < 0.01$).

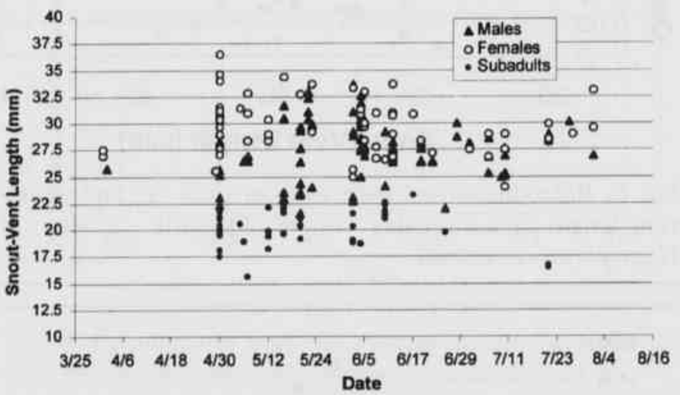


Fig. 1. Seasonal distribution of snout-vent lengths of *Gastrophryne carolinensis* collected in northeastern Arkansas during 1989.

Male Reproductive Cycle.--The testicular structure of *G. carolinensis* consisted of convoluted seminiferous tubule masses surrounded by interstitial cells; the germinal epithelium in each tubule undergoes cystic maturation of sperm (termed cystic spermatogenesis; see Lofts, 1987). Spermatogenic Ph-I and II were observed in the testes of Arkansas specimens of *G. carolinensis* (Figs. 2 and 3). Nearly all males > 21.5 mm SVL exhibited sperm; the smallest male not producing sperm was 22.7 mm SVL collected on 2 June. The percentages of Ph-I males decreased over time: 100% (12 of 12) in April, 74% (17 of 23) in May, and 3% (1 of 33) in June. Testes in smaller males generally remained in Ph-I longer into the breeding season compared to larger males; the latest Ph-I individual was observed on 2 June. Ph-II males were first observed in early May. The greatest concentrations of sperm were observed in Ph-II testes of June individuals. Because the testes of most adult males possessed sperm, males were capable of participating in breeding activities during April - August.

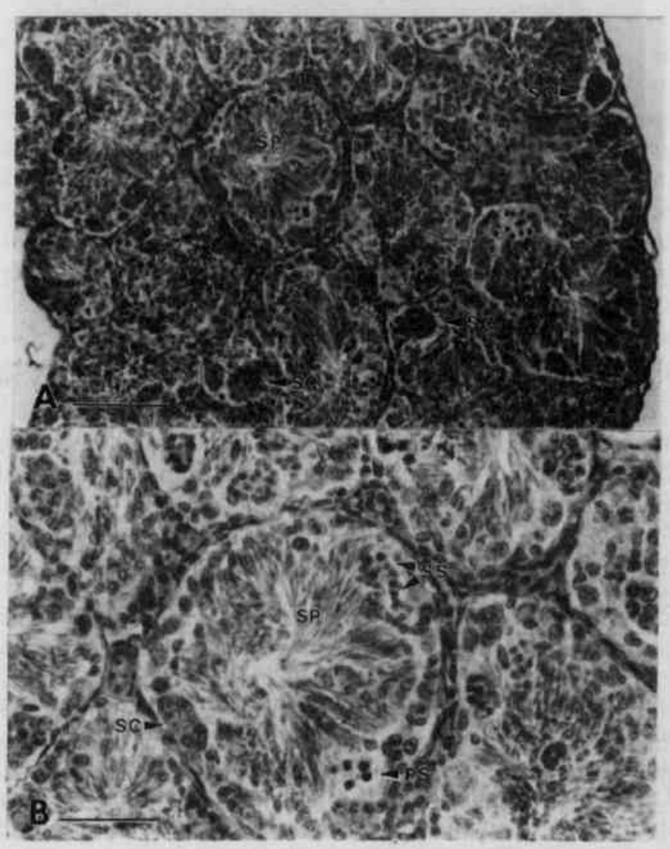


Fig. 2. Light photomicrographs of the testicular histology of *Gastrophryne carolinensis* illustrating Phase I. A. Testis of specimen ASUMZ 13006 (SVL = 30.5 mm) collected on 30 April 1989. Clusters of spermatogonial cells form spermatogonial cysts (SC) in seminiferous tubules; sperm (SP) are numerous within lumina of tubules. Line = 100 µm. B. Magnification of A revealing additional spermatogenic stages (i.e., primary spermatocytes [PS] and secondary spermatocytes [SS]). Line = 50 µm; abbreviations same as in A.

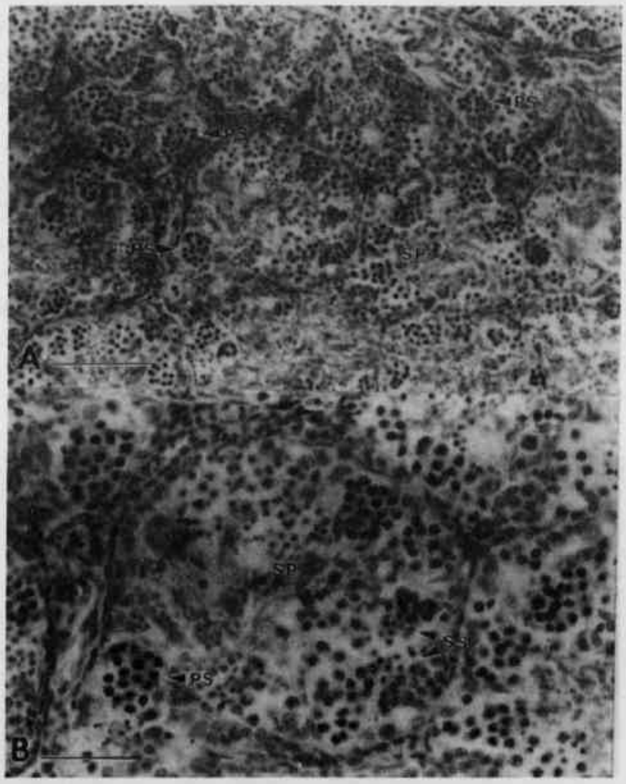


Fig. 3. Light photomicrographs of the testicular histology of *Gastrophryne carolinensis* illustrating Phase II. A. Testis of specimen ASUMZ 13274 (SVL = 30.2 mm) collected on 5 June 1989. Clusters of primary spermatocytes dominate the basal epithelium within seminiferous tubules. Line = 100 m. B. Magnification of A revealing additional spermatogenic stages (i.e., primary spermatocytes [PS] and secondary spermatocytes [SS]). Line = 50 µm; abbreviations same as in Fig. 2.

Female Reproductive Cycle.--Gravid females were present throughout the activity season; however, fertility, as measured by ovarian mass and follicular diameter, increased through the season and peaked in June (Fig. 4). Large females were gravid throughout the season, whereas the ovaries of small females generally did not mature until June (Fig. 5). The range of individual variation among adult females may help explain the seasonal variation observed in clutch size (Fig. 6).

Ovarian mass of all females possessing enlarged, pigmented eggs varied greatly ($\bar{x}$ = 0.4002 ± 0.259 g; range = 0.1021-1.0078; n = 24), and although smaller adult females generally contained fewer pigmented eggs than older, larger females, the largest clutches were not found in the largest females (Fig. 7). Consequently, clutch size ($\bar{x}$ = 673.2 ± 321.0; range = 186 -1459; n = 24) was not significantly correlated (r = 0.262; $P > 0.05$) with body size of the female (Fig. 7).

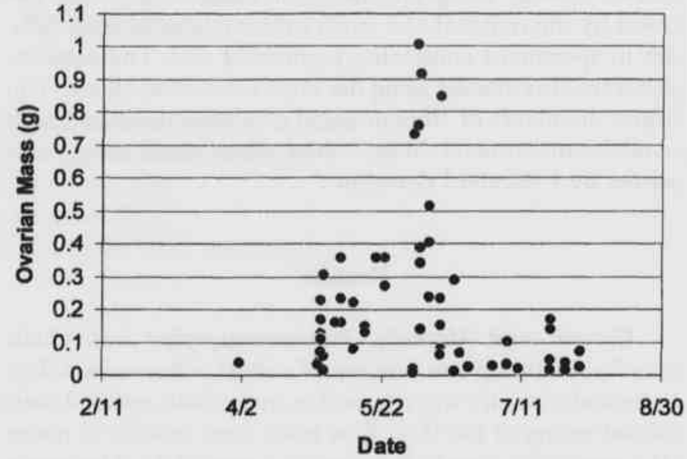


Fig. 4. Relationship between ovarian mass (g) and date of collection in *Gastrophryne carolinensis* in northeastern Arkansas during the 1989 activity season.

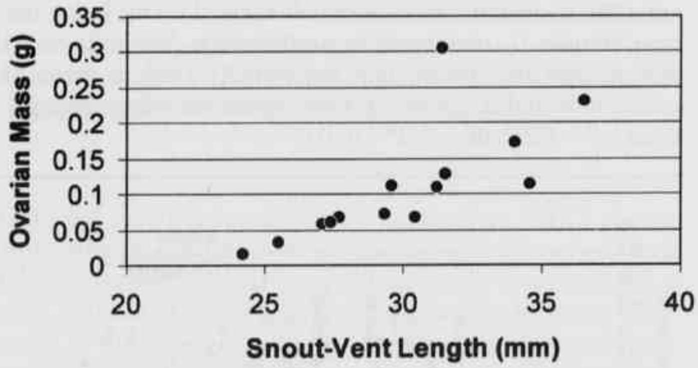


Fig. 5. Relationship between ovarian mass (g) and snout-vent length in a three-day sample (30 April – 2 May) of *Gastrophryne carolinensis*.

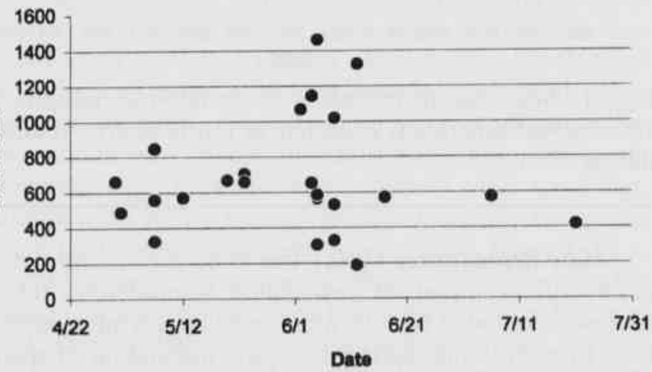


Fig. 6. Relationship between clutch size and date of collection in *Gastrophryne carolinensis*.

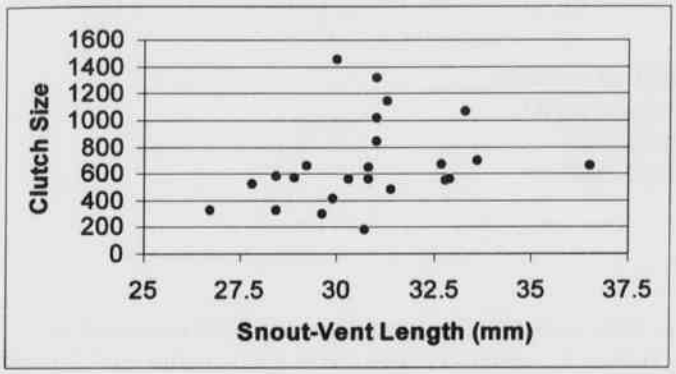


Fig. 7. Clutch size as a function of snout-vent length in *Gastrophryne carolinensis*.

Ovum diameter, likewise, varied greatly ($\bar{x}$ = 1.0448 ± 0.144 mm; range = 0.7312 -1.2870) among females. Like the seasonal shifts in frequency of gravid females, average ovum diameter gradually increased as the season progressed (Fig. 8); the largest diameters (> 1.10 mm) were recorded in June. No significant correlation ($r = -0.2195$; $P > 0.05$) was found between ovum diameter and body size of the female.

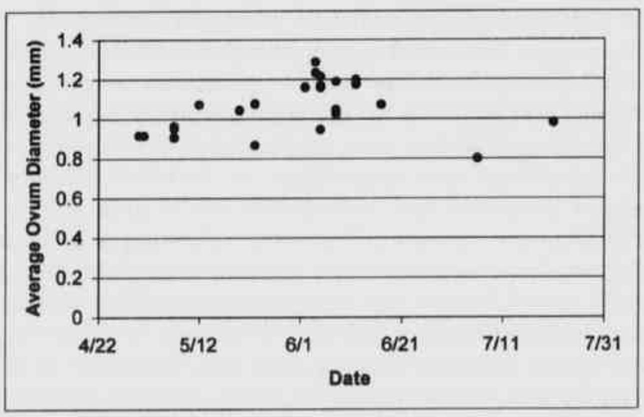


Fig. 8. Relationship between average ovum diameter and date of collection in gravid *Gastrophryne carolinensis*.

Discussion

Despite a shorter active season in northeastern Arkansas, post-metamorphic growth and reproduction of *G. carolinensis* from northeastern Arkansas were similar in many respects to findings from southern populations. Sexual maturity appeared to occur at similar ages as in a Louisiana population (Anderson, 1954). Although body size at maturity was slightly larger in Arkansas populations, body size/age cohorts among Arkansas females were similar to those in Louisiana (Anderson, 1954). For example, in Louisiana body size of individuals ranged 13.0 - 19.0 mm SVL in the first spring of life, 21.0 - 24.0 mm SVL in the second year, 24.5 - 26.9 mm SVL in the third year, and 27.0 - 35.0 mm SVL in succeeding year samples. Using our late April sample, there appeared to be size gaps in the frequency in adult females between 25.5 -27.1 mm, 31.5 -34.0 mm, and 34.6 -36.5 mm in body size. This suggests the possibility of at least five different age classes using female size as noted by Anderson (1954). Like south-central Florida (Meshaka and Woolfenden, 1999) and Louisiana (Anderson, 1954) populations, mean adult body sizes were similar between the sexes, and the sex ratio did not differ from unity.

The gonadal cycle of Arkansas males and females were in synchrony. Although both sexes mere capable of reproduction from emergence in the spring until the end of their active season, frequency of fertile individuals peaked strongly in June. For males, this was evidenced by few Ph-I and maximal number of Ph-II testes in June. High midsummer fertility in females was disclosed by the high frequency of gravid individuals and large ova at the same time. Louisiana *G. carolinensis* captured over a longer period than those from our study revealed a similar pattern and synchrony to the gonadal cycle during April - August (Anderson, 1954). In this connection, throughout its geographic range, mid summer is the peak in calling and presumably oviposition in *G. carolinensis* (Meshaka and Woolfenden, 1999).

Anderson (1954) observed that some females oviposited early in the season, while others oviposited later in the season, but was unsure why this occurred. In Arkansas, smaller females were generally ready to oviposit later in the season than larger-bodied females, perhaps because of recent attainment of sexual maturity. We also observed that among size-classes of females, clutches ranged from small to very large. Although energetics could be responsible for this phenomenon, partial deposition of clutches, suspected in other Arkansan anurans (Trauth et al., 1990), might better explain the wide range in clutch characteristics within size-classes in light of the shortend available months for oviposition.

Meshaka and Woolfenden (1999) identified temperature and rainfall thresholds that constrain calling and reproductive-related movements in this species. Our findings indicate that although climate severely constrains the breeding season in northeastern Arkansas, physiologically, *G. carolinensis* at the northwestern edge of its geographic range is no less capable of breeding over a longer season than southerly populations, and adheres to the mid-summer peak in breeding found throughout its range.

ACKNOWLEDGMENTS.—We thank the Department of

Biological Sciences, Arkansas State University, for providing facilities to complete this study. Specimens were collected under the authority of a scientific collecting permit (No. 37) issued to SET by the Arkansas Game and Fish Commission.

Literature Cited

Anderson, P. K. 1954. Studies in the ecology of the narrow-mouthed toad, *Microhyla carolinensis.* Tulane Stud. Zool. 2:15-45.

Conant, R., and **J. T. Collins.** 1998. A field guide to reptiles and amphibians of eastern and central North America. 31rd ed. Expanded. Houghton Mifflin Co., Boston. 450 pp.

Humason, G. L. 1979. Animal tissue techniques. 4th ed. W. H. Freeman, Co., San Francisco, xvi + 661 pp.

Lofts, B. 1987. Testicular function. Pp. 283-325, *In* Hormones and reproduction in fishes, amphibians, and reptiles (D. O. Norris and R. E. Jones, eds.) Plenum Press, New York. xxv + 613 pp.

Meshaka, W. E., Jr., and **G. E. Woolfenden.** 1999. Relation of temperature and rainfall to movements and reproduction of the eastern narrowmouth toad (*Gastrophryne carolinensis*) in south-central Florida. Florida Scient. 62:213-221.

Nelson, C. E. 1972. *Gastrophryne carolinensis.* Cat. Amer. Amph. Rept. 120.1-120.4.

Trauth, S. E., R. L. Cox, B. P. Butterfield, D. A. Saugey, and **W. E. Meshaka.** 1990. Reproductive phenophases and clutch characteristics of selected Arkansas amphibians. Proc. Arkansas Acad. Sci. 44:107-113.

Status of Three Plethodontid Salamanders (Genus *Plethodon*) from the Ouachita National Forest of Southwestern Arkansas

Stanley E. Trauth and J. D. Wilhide
Department of Biological Sciences
Arkansas State University
State University, AR 72467

Abstract

A three-year field investigation was initiated in 1996 to update previous information on the local abundance and distribution of three salamanders of the genus *Plethodon* (*P. caddoensis*, *P. fourchensis*, and *P. ouachitae*); these salamanders are found within a five-county area of the Ouachita National Forest in southwestern Arkansas. *Plethodon fourchensis* was most numerous at three sites in Polk County; a total of 18 specimens was found. Searching for *Plethodon fourchensis* was successful following moderate-to-heavy precipitation but only in selected habitats on Fourche and Irons Forks mountains. The preferred habitats of *P. caddoensis* were talus-covered slopes and wet ravines consisting of mostly small loose rocks within the Caddo Mountains. This species was found at 17 of 25 collection sites (n = 108); the largest single collection (n = 52) occurred on 19 April 1998. Rocky habitats with an abundance of leaf litter on Rich Mountain yielded *Plethodon ouachitae* in modest numbers (n = 45); three new locality sites were found during this study. Although new localities were discovered for each species during this study, none occurred outside its currently recognized range. Current forest management/landscape practices should strive to prevent any precipitous declines in populations of these salamanders.

Introduction

Historical Perspective and Review.--Traditionally, herpetological field survey data gained from local, regional, and state inventories have yielded a wealth of specific locality information about the presence (or absence) of a herpetofaunal species in a geographic area and have provided an important resource to supplement our knowledge and understanding of the distribution and ecological requirements of a particular species. Fortunately, a considerable amount of historic locality information is available from museum collections throughout the United States. These repositories of specimens and data contain priceless holdings of organisms and, thus, provide scientists with a database from which to assess the current trends and effects of habitat perturbations on a species' distribution and/or its local abundance. Yet, only by analyzing marked habitat change across the intervals of both time and space, can researchers reveal any significant changes in population size and structure in a species. This is especially true for North American terrestrial salamanders. Today, man's alterations to forest quality (by means of deforestation, habitat fragmentation, timber harvesting, etc.) have caused a rapid decline in total environmental quality; for instance, terrestrial salamanders within the Appalachian Mountains are known to have been dramatically impacted by forestry practices which have resulted in a loss of microhabitat diversity and have caused a reduced abundance within localized populations (Dodd, 1997). Plethodontid salamanders, in particular, are vulnerable to clearcutting and are less abundant in young timber stands where clearcutting has occurred (e.g., Petranka, 1994; Petranka et al., 1993, 1994). Consequently, the declines in salamander numbers observed within populations in the eastern United States (due to habitat degradation) may well represent a harbinger of what can happen to similar plethodontid species elsewhere.

Three species of plethodontid salamanders (Fourche Mountain salamander, *P. fourchensis*; Rich Mountain salamander, *P. ouachitae*; Caddo Mountain salamander, *P. caddoensis*) are found within the Ouachita National Forest of southwestern Arkansas. They have shared a long history of scientific scrutiny ever since the description and naming of the first of these recognized species, *P. ouachitae* (Dunn and Heinze, 1933), over 65 years ago. In recent years, their habitat requirements have become a topic of special concern to forest managers (see Sievert, 1986). Because these three *Plethodon* species have limited distributions and appear to have unique habitat preferences, they have been given special collection protection by the U. S. Forest Service and are generally considered as "species at risk." Current silvicultural practices in the Ouachita National Forest no longer utilize clearcutting as a permissible timber management practice, and streamside protection zones have been established for these *Plethodon* as well as for other plethodontid salamanders in the Ouachitas. Furthermore, mining activities have been prohibited or largely curtailed within most of the known ranges of these three salamanders.

Literature reviews dealing with the biology of *P. caddoensis*, *P. ouachitae*, and *P. fourchensis* were published by Pope (1964), Blair (1967), and Highton (1986), respectively.

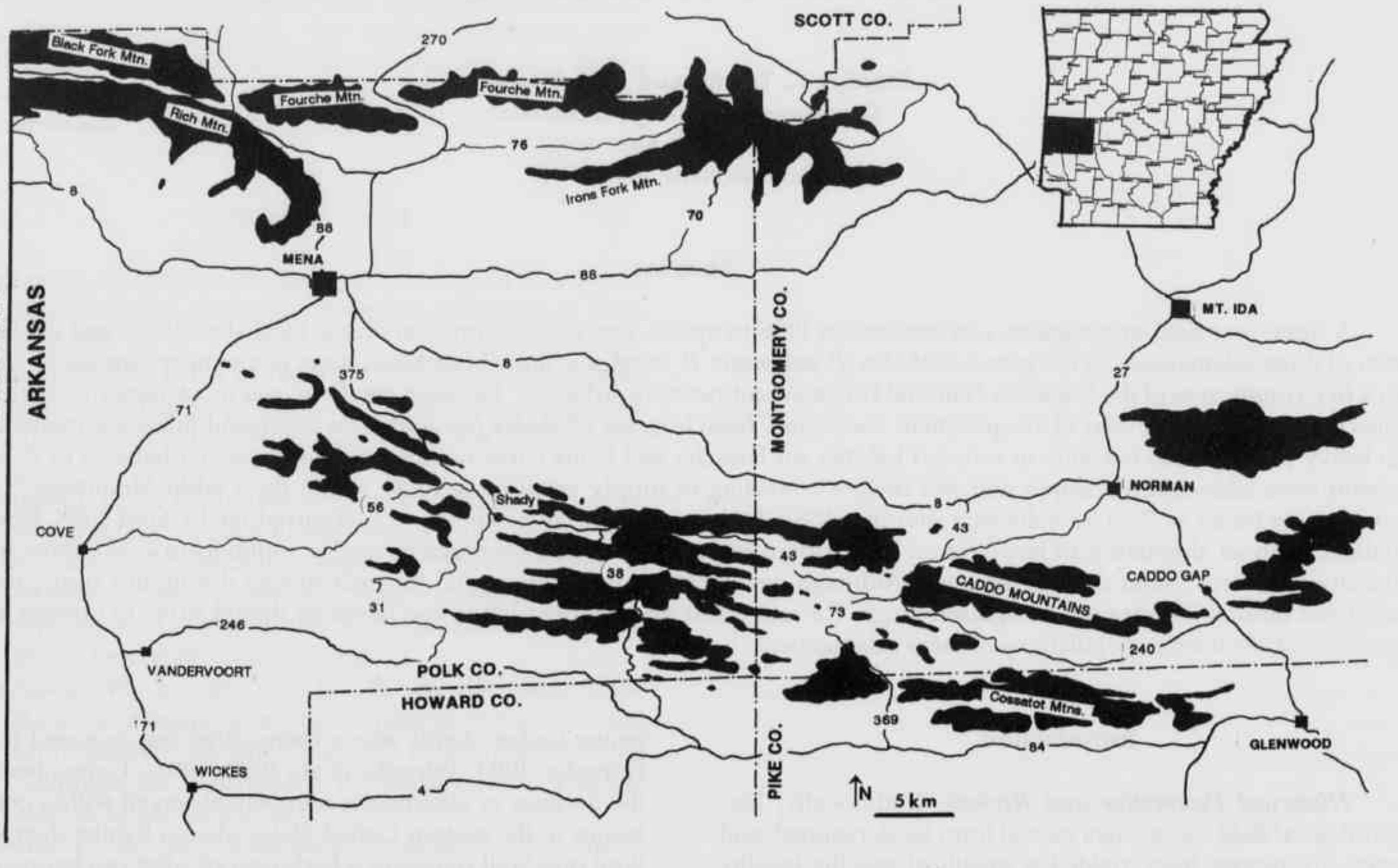


Fig. 1. Map illustrating the study area within a five-county region of southwestern Arkansas. The elevated mountainous habitats of the Ouachita National Forest are shown in black (> 440 m = Fourche Mountain, Rich Mountain, and western Caddo Mountains of Polk County; 300 - 440 m = eastern Caddo Mountains region of Montgomery and Pike counties). Numerals indicate selected highways and National Forest roads.

Additional information on these species can be found in works by Kuss (1986) and Sievert (1986). Winter et al. (1986) reported on parasitism in these species, whereas Atwill and Trauth (1988) published on mandibular dentition. Taylor et al. (1990) investigated the reproductive biology. Anthony et al. (1997) reviewed recent studies on social behavior and aggression in *Plethodon* (includes works on *P. caddoensis* and *P. ouachitae*).

The current field investigation began in 1995 to supply new information on local distribution and abundance of two of the three *Plethodon* salamanders (*P. fourchensis* and *P. caddoensis*); survey on the third species, *P. ouachitae*, was initiated in 1997. The above field work was authorized through two Challenge Cost-Share Agreements between the U. S. Forest Service and Arkansas State University. These projects were designed to gain new knowledge on the current distribution, range, ecological associates, habitat requirements and preferences, and life history of these species. New locality data would specifically augment information generated by several previous studies and surveys. This project was also undertaken to seek information on any trends in salamander numbers as revealed through the examination of historic collection records currently deposited in the Arkansas State University herpetological collection. Therefore, this study includes a combination of many historic locality records along with the recent locality data (1996-1998) generated by the current investigation. We have attempted to provide these combined records to show some continuity between the various field surveys on these salamanders.

Methods

Sampling Activity and Techniques.--Over an 18 yr span (1980-1998), one of us (SET) has conducted numerous herpetofaunal field trips to a five-county area of the Ouachita Mountains of southwestern Arkansas (Fig. 1); during each visit, a considerable amount of time and effort was devoted to searching for all species of plethodontid salamanders within this area. On many occasions, the senior author was

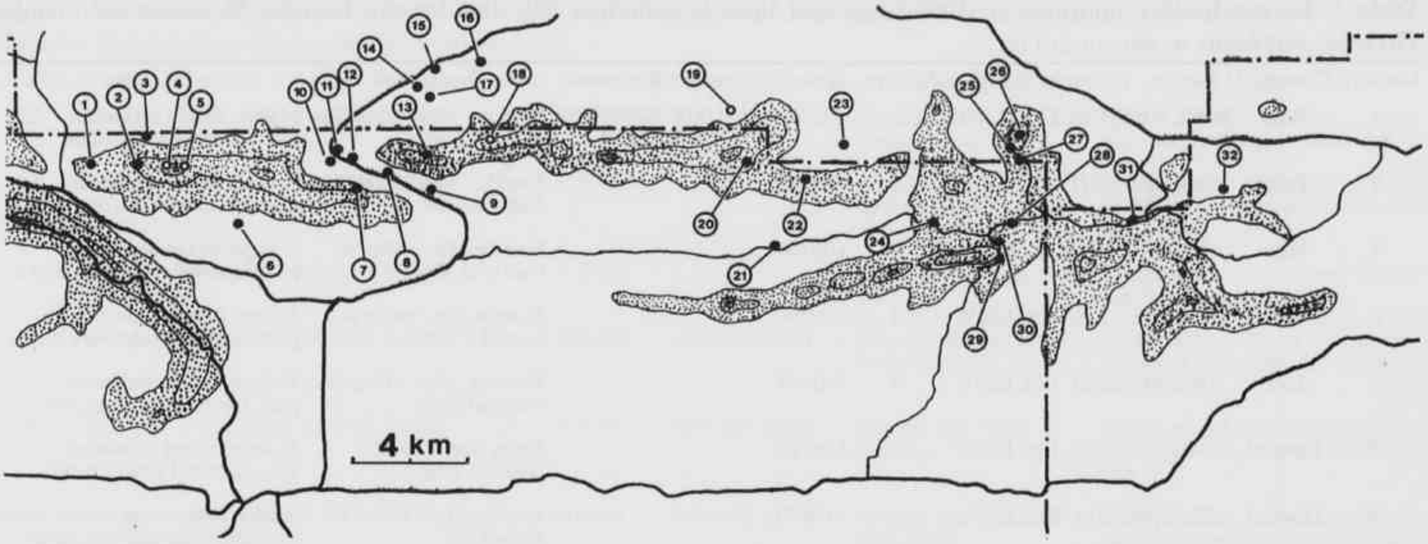


Fig. 2. Map illustrating historic collection sites and/or localities visited during the recent study of *Plethodon fourchensis* in the Fourche Mountain area. Outermost contour lines approximate 440 m in elevation; inner contour lines show increases in elevation at increments of ca. 150 m. See Table 1 for explanation of numbered sites.

assisted by student help in collecting salamanders; normally 5-10 students attended annual field trips conducted during the month of April. In addition, both of us have periodically but routinely visited specific sites to obtain seasonal samples of salamanders.

Selected habitats were searched for salamanders by turning surface rocks and logs or excavating loose talus by hand or potato rakes. In particularly wet areas, such as along or within creekbeds, mountain seeps and ravines, an intensive turning of accumulated leaf litter was often performed. During especially dry conditions and/or during hot weather, more effort was expended on breaking up logs to search for salamanders. Voucher specimens were taken from most sampling sites and are currently catalogued and housed in the Arkansas State University herpetological collection. All collections were conducted during daylight hours.

Although the recent survey work (1996-1998) focused primarily on visiting some of the numerous historic collection sites for the three species, we also attempted to discover additional localities. Information pertaining to the historic localities was gleaned from the scientific literature on the species (e.g., Pope and Pope, 1951; Blair and Lindsay, 1965; Duncan and Highton, 1979; Heath et al., 1986), from an unpublished survey conducted for the Arkansas Natural Heritage Commission (on *P. fourchensis* and *P. caddoensis* reported by Plummer, 1982), and from unpublished field data of the U. S. Fish and Wildlife Service (previously used to prepare status reviews on *P. fourchensis* and *P. caddoensis* as written by Linda LaClaire-USFWS office, Jackson, MS). We utilized locality information on abandoned mines as well as considerable field assistance from David Saugey (U. S. Forest Service, Ouachita National Forest-Jessieville office).

Results and Discussion

***Plethodon fourchensis*.**--The Fourche Mountain salamander is one of the two endemic Arkansas plethodontid salamanders examined in this report; it is known only from parts of Fourche and Irons Fork mountains in Polk and Scott counties (Highton, 1986). All but three of the 32 designated survey sites illustrated for *P. fourchensis* in Fig. 2 were surveyed during the recent field work; the locality information on these sites is found in Table 1. The most productive sites for collecting the Fourche Mountain salamander were site 10, 11, and 12 within a 2 km area W of Foran Gap and along either side of U. S. Hwy 71. Riparian habitat along the headwater region of Cedar Creek is found to the N of the highway, whereas a series of mountain ravines which drain into Cedar Creek are found to the south. We have repeatedly secured *P. fourchensis* in the vicinity of these designated sites on numerous visits with sampling following moderate-to-heavy precipitation being notably productive. Wet conditions are especially crucial to the successful collection of *P. fourchensis*. The largest single collection (n = 17) was on 7 May 1994 during a visit to site 12 with the Nature Conservancy (ca. 25 persons). All salamanders were released following capture. Two U. S. Forest Service biologists (Lohoefener and Jones, 1991) reported finding six specimens (out of a total of nine) along the Ouachita National Recreation Trail (vic. sites 7 and 8) during survey work (which included 21 total sites) in November 1990. Site 1 yielded five specimens in April, 1980; at that time, a National Forest Road (NFR) permitted access by vehicle to this area. The NFR access no longer exists, and much of the western slope between sites 1 and 2 has undergone exten-

Table 1. Recent locality information (1996-1998) and historic collection site data for the Fourche Mountain salamander, *Plethodon fourchensis*, as shown in Fig. 2.

Locality	County	Section, Township, Range	*Source	Date	Voucher Specimens	Description	Habitat
1	Polk	NW¼, NW¼, S10, T1S, R31W	3	4/15/80	ASUMZ 7589, 7597 15113, 15232	Fourche Mtn. (Ouachita National Trail)	N slope, mixed deciduous-pine, scattered rocks, moist
2	Polk	SW¼, NW¼, S11, T1S, R31S	3	4/18/98	–	Fourche Mtn. (Ouachita National Trail)	N slope, mixed deciduous-pine, scattered rocks, dry
3	Polk	SW¼, SW¼, S2, T1S, R31W	3	4/18/98	–	Fourche Mtn. (valley at base of N Slope)	N slope, mixed deciduous-pine, scattered rocks, very dry
6	Polk	NW¼, NE¼, S18, T1S, R30W	3	5/13/97	–	Fourche Mtn. (valley at base of S Slope)	S slope, mixed deciduous-pine, scattered rocks, very dry
7	Polk	NW¼, SW¼, S10, T1S, R30W	3	5/15/98	–	Fourche Mtn. (Ouachita National Trail)	N slope, mixed deciduous-pine, few rocks and logs, dry
8	Howard	SW¼, NE¼, S10, T1S, R30W	2	4/10/82	–	Foran Gap (Ouachita National Trail)	N slope, mixed deciduous-pine, scattered surface rocks
9	Howard	SE¼, NW¼, S10, T1S, R30W	3	10/9/98	–	Fourche Mtn. (1.6 km E Foran Gap)	S slope near stream, mixed deciduous-pine, rocks and logs, moist
10	Polk	SW¼, SE¼, S4, T1S, R30W	3	4/20/97	1	Fourche Mtn. (1.6 km W Ouachita National Trail)	N slope, near stream, mixed deciduous, numerous rocks
				4/13/87 5/15/89 10/7/89 4/15/90	ASUMZ 7276-79 ASUMZ 12696-12700 ASUMZ 14187 ASUMZ 15866		
11	Polk	SW¼, SE¼, S4, T1S, R30W	3	5/3/96	ASUMZ 20982-88	Fourche Mtn. (1.8 km W Ouachita National Trail)	S slope near stream, mixed deciduous, numerous rocks, moist
				4/27/91 4/24/93	ASUMZ 17664-68 ASUMZ 18979		
12	Polk	NW¼, NE¼, S10, T1S, R30W	3	5/17/94	17	Fourche Mtn. (0.8 km W Ouachita National Trail)	S slope near stream, mixed deciduous, numerous rocks, logs, moist
				5/3/96 4/19/98	ASUMZ 21261 ASUMZ 22674-75		
13	Polk	NW¼, NE¼, S11, T1S, R30W	2,3	5/27/97	–	Fourche Mtn. (4.0 km W Wolf Pinnacle)	S slope, mixed deciduous-pine, rocks and logs, dry
14	Scott	SW¼, NE¼, S26, T1N, R30W	3	4/13/96	–	Ca. 3 km N Fourche Mtn.	SW slope, mixed deciduous-pine, rocks and logs, dry
15	Scott	NE¼, NW¼, S25, T1N, R30W	3	4/3/96	–	Ca 3.5 km N Fourche Mtn.	Creek bottom, SW slope, mixed deciduous-pine, scattered rocks, moist
16	Scott	SW¼, NW¼, S30, T1N, R29W	3	5/27/97	–	Ca 2.5 km N Fourche Mtn.	N slope, mixed deciduous-pine, scattered rocks, dry
17	Scott	NW¼, NW¼, S35, T1N, R30W	3	5/27/97	–	Fourche Mtn. (valley at base of N slope off NFR 807)	N slope, mixed deciduous-pine, scattered rocks, very dry
18	Polk	NW¼, NW¼, S5, T1S, R29W	1	–	–	Fourche Mtn. (Wolf Pinnacle)	
19	Scott	NE¼, NE¼, S35, T1N, R29W	3	5/3/96	–	Ca. 0.5 km N Fourche Mtn.	N slope, mixed deciduous-pine, numerous rocks and boulders, moist
20	Montg.	NW¼, NE¼, S12, T1S, R29W	3	5/15/96	–	Fourche Mtn. (0.5 km SE Blue Mtn.)	S slope, mixed deciduous-pine, rocks and logs, very dry
21	Montg.	SE¼, SE¼, S18, T1S, R28W	3	5/15/96	–	Irons Fork Creek (along NFR 76)	N slope along creek, mixed deciduous-pine, rocks and logs, moist

Table 1. Recent locality information (1996-1998) and historic collection site data for the Fourche Mountain salamander, *Plethodon fourchensis*, as shown in Fig. 2 (continued).

Locality	County	Section, Township, Range	*Source	Date	Voucher Specimens	Description	Habitat
22	Montg.	NE¼, SW¼, S8, T1S, R28W	3	5/13/97	–	Fourche Mtn. (Ouachita National Trail)	S slope, mixed deciduous-pine, scattered surface rocks, dry
23	Montg.	SW¼, SE¼, S32, T1N, R28W	3	5/28/97	–	Fourche Mtn. (along Turner's creek)	N slope near creek, mixed deciduous-pine, scattered rocks and logs, moist
24	Montg.	SW¼, SW¼, S15, T1S, R28W	3	5/3/96	1	Irons Fork Creek (along NFR 76)	S slope near stream, mixed deciduous, numerous rocks, moist
25	Montg.	NW¼, SW¼, S1, T1S, R28W	3	5/15/98	ASUMZ 22741	Fourche Mtn. (0.7 km S Buck Knob)	Rocky ridge, mixed deciduous, numerous rocks, logs, dry (salamander in log)
26	Montg.	NW¼, NW¼, S1, T1S, R28W	2,3	5/3/96	ASUMZ 20983	Fourche Mtn. (Buck Knob)	S slope, mixed deciduous-pine, scattered rocks, logs, moist following rain
27	Montg.	SE¼, SW¼, S1, T1S, R28W	3	5/15/98	ASUMZ 22740	Fourche Mtn. (1.0 km S Buck Knob)	N slope/ridge, mixed deciduous-pine, numerous large surface rocks, logs, dry (salamander in log)
28	Montg.	SE¼, NW¼, S13, T1S, R28W	3	10/9/98	–	Fourche Mtn. (along NFR 76, 1.3 km W NFR 76A)	S slope, mixed deciduous, scattered rocks and logs, mostly dry
29	Montg.	SW¼, NWE¼, S23, T1S, R28W	3	10/9/98	–	Fourche Mtn. (0.7 km SE Brushy Knob along NFR 216)	S slope near seapage area, mixed deciduous, numerous rocks, moist
30	Montg.	SW¼, NE¼, S23, T1S, R28W	3	10/9/98	ASUMZ 22843	Fourche Mtn. (0.7 km NE Brushy Knob along NFR 216)	N slope in roadcut, mixed deciduous, numerous rocks, moist
31	Montg.	SW¼, NE¼, S17, T1S, R27W	3	5/26/98	–	Fourche Mtn. (NFR 76, 2.0 km N Mast Mtn.)	N slope/rocky ridge, mixed deciduous-pine, scattered rocks and logs
32	Montg.	NW¼, SE¼, S10, T1S, R27W	3	5/26/98	–	Fourche Mtn. (2.0 km S US Hwy 270; NFR 813)	NE slope, mixed deciduous-pine, scattered rocks and logs, moist

*1 - Duncan and Highton (1989)
2 - Plummer (1982)
3 - This report

sive timber harvesting. Plummer (1982) found a large number (n = 20) of *P. fourchensis* on Buck Knob (site 26) during April and May, 1982. Only two specimens were found there on 3 May 1996 during the present study. We were able to collect two specimens from within logs at sites 25 and 27 not far from Buck Knob. The largest reported collection of *P. fourchensis* (n = 23) was by Lohoefener and Jones (1991) in May 1991 ca. 2 km NW of Buck Knob (Scott Co.) at the end of NFR 218. Plummer (1982) failed to find *P. fourchensis* at three sites along the eastern and middle portions of Irons Fork Mountain. This area was not searched during the present study.

Plethodon ouachitae.--The Rich Mountain salamander is known to occur on Rich Mountain and Black Fork Mountain, two mountains that dominate extreme northwestern Polk County (Figs. 1 and 3). Locality information on *P. ouachitae* is found in Table 2. Three of the nine collection sites (2, 3, and 4) represent historic collection sites utilized in the past by many collectors of this species (e.g., site 4 = site 3 in Pope and Pope, 1951). Pope and Pope (1951) reported the largest single collection of *P. ouachitae* (n = 131; their site 4) in May 1950 near the base of the Rich Mountain fire tower in the area of an old homestead. Lohoefener and Jones (1991)visited this site in November 1990 without success. We also visited the fire tower area in recent years, but never attempted to collect there primarily because the surface habitat was heavily overgrown with dense vegetation and was not ideally suited for collecting activities. Three new sites (7, 8, and 9) yielded specimens during the present survey. Typically, the Rich Mountain salamander can be collected in large numbers in late April and early May on the north-to-northwest slope and the ridge top of Rich Mountain; a wet substrate (moist leaf litter around the rocks) and precipitation immediately prior to collection greatly

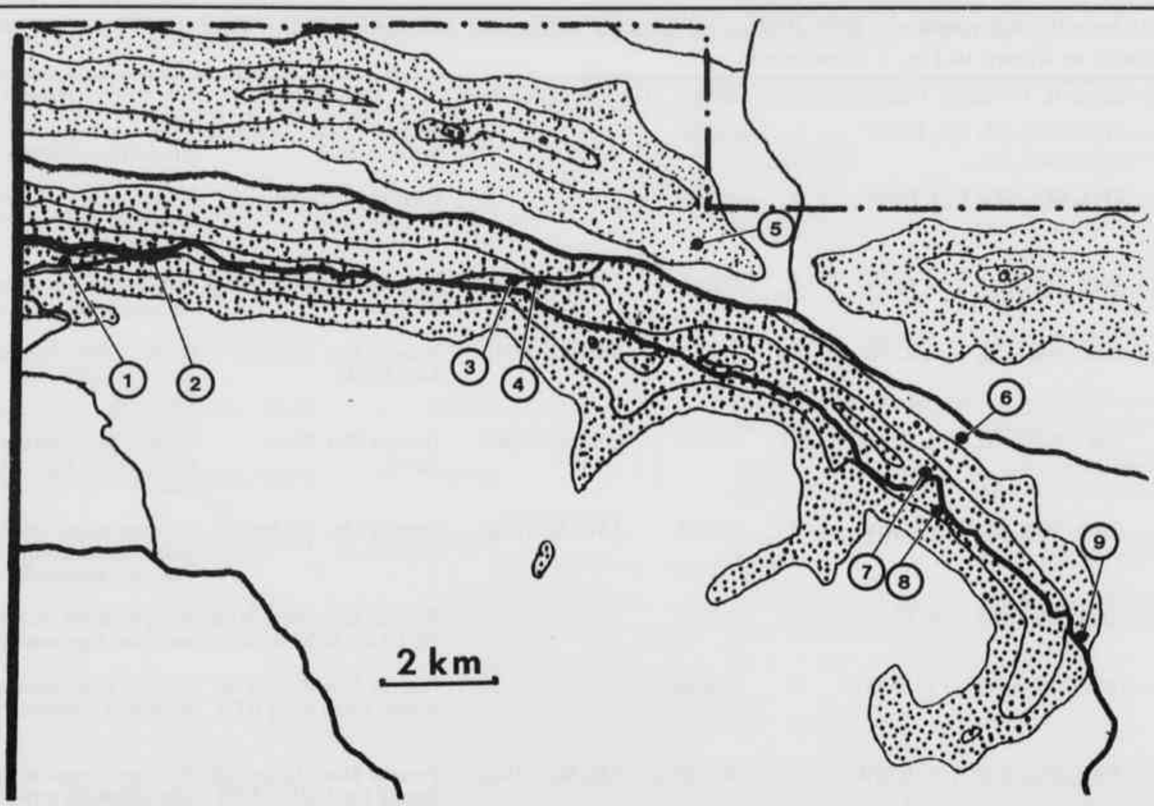


Fig. 3. Map illustrating historic collection sites and/or localities visited during the recent study of *Plethodon ouachitae* in the Rich Mountain area. Outermost contour lines approximate 440 m in elevation; inner contour lines show increases in elevation at increments of ca. 150 m. See Table 2 for explanation of numbered sites.

increase the chances of encountering salamanders beneath rocks. At drier times of the year (when the salamanders seek deeper shelters), breaking into rotting logs often proves to be the best collection method. Pope and Pope (1951) collected 59 specimens in the vicinity of site 4 in late April and early May; over the years, sites 3 and 4 (along St. Hwy 272 as it winds steeply to meet St. Hwy 88 on the top of the mountain) have consistently yielded large numbers of *P. ouachitae*. For instance, during the initial visit to this area in April 1980, the senior author and his students collected 23 specimens and released many others in a short period of time (ca. 45 min.). Most visits to this locality (along the highway) have been conducted in April and last ca. 45 min. A recent visit to site 4 (8 October 1998) yielded four specimens; Lohoefener and Jones (1991) reported only one *P. ouachitae* in this area in November 1990. There are several small seeps and ravines along St. Hwy 272; the wet conditions are ideally suited for the Ouachita dusky salamander, *Desmognathus brimleyorum*. On occasion, *P. ouachitae* can be found along the fringe of this moist, mostly-rocky microhabitat. The same can be said about the microhabitat conditions and the occurrence of these two salamanders along NFR 514 (sites 1 and 2). In contrast, Site 7 below Eagleton Vista is more open, exhibits fewer rocks, and is much less mesic than sites 1-4; however, this area was very productive for salamanders on 18 April 1998. We found three *P. ouachitae* (two vouchers) at site 8 (between 6:16-6:55 pm) on 8 October 1998 in a mostly rocky habitat just off St. Hwy 88. This site was more or less randomly selected to see whether a southwest facing slope would yield salamanders. We uncovered one salamander at site 9 in May 1998. Habitat disruption at this site (east-facing slope) indicated that it had been searched by collectors in the recent past. No *P. ouachitae* were observed at sites 5 or 6 during the present study, although some *P. albagula* were collected. Lohoefener and Jones (1991) visited five sites on the east end (north slope) of Black Fork Mountain (to the north and west of site 5) and successfully collected 19 *P. ouachitae* in May 1991.

Plethodon caddoensis.--The distribution of *P. caddoensis* is mostly limited to the Novaculite Uplift area in the Caddo and Cossatot Mountains of southeastern Polk, southwestern Montgomery, and northwestern Pike counties (Blair and Lindsay, 1965). Additional localities are found along the Cossatot River and its tributaries in Howard County (see Figs. 1 and 4). Of the 44 localities shown in Fig. 4, 25 were visited during the recent study period. Of these sites, 17 yielded *P. caddoensis*. The other sites represent historic localities visited between 1980 and 1996. Several records were

Table 2. Recent locality information (1996-1998) and historic collection site data for the Rich Mountain salamander, *Plethodon ouachitae*, as shown in Fig. 3.

Locality	County	Section, Township, Range	*Source	Date	Voucher Specimens	Description	Habitat
1	Polk	SW¼, NW¼, S8, T1S, R32W	4	5/14/96	–	Rich Mtn. (NFR 514)	S slope, mixed deciduous, scattered rocks, moist
2	Polk	SW¼, NE¼, S8, T1S, R32W	4	4/27/91	ASUMZ 17676-86	Rich Mtn. (5.4 km W Queen Wilhelmina State Park, along NFR 514)	S slope, mixed deciduous, scattered rocks, moist
				5/14/98	–		
				5/7/94	5		
3	Polk	NW¼, SW¼, S7, T1S, R31W	4	4/12/87	ASUMZ 7346-48	Rich Mtn. (Along St. Hwy 272, vic. edge of Queen Wilhelmina State Park)	N slope, mixed deciduous, wet ravine, rocks, wet
				4/15/90	ASUMZ 15859/63		
				5/27/98	ASUMZ 22761-64		
4	Polk	NE¼, SW¼, S7, T1S, R31W	4	6/5/80	ASUMZ 15111	Rich Mtn. (Along St. Hwy 272)	N slope, mixed deciduous, scattered large rocks, moist
				9/30/83	ASUMZ 7435		
				3/15/84	ASUMZ 7592		
				4/27/85	ASUMZ 5333-37		
				4/11/87	ASUMZ 7173-75		
				4/11/87	ASUMZ 7393-7408		
				4/15/89	ASUMZ 12791-12808		
				8/7/89	ASUMZ 15274		
				10/7/89	ASUMZ 14192-93		
				4/24/93	ASUMZ 18863-18927; 18967-74		
				3/18/94	ASUMZ 19615-36		
				4/19/97	ASUMZ 21756-73		
			2	May 1991	(See text)		
			2	11/19/90	(See text)		
			4	4/28/90	23 (See text)		
5	Polk	NW¼, NW¼, S9, T1S, R31W	4	5/27/98	–	Black Fork Mtn. (Along Ouachita National Trail)	S slope, mixed deciduous-pine, scattered rocks, dry
			1	-	(See text)		
			2	May 1991	(See text)		
6	Polk	NW¼, SW¼, S14, T1S, R31W	4	5/27/98	–	Rich Mtn. (valley at base of mountain near creek)	S slope, mixed deciduous-pine, scattered rocks, moist
7	Polk	NE¼, SW¼, S23, T1S, R31W	4	4/18/98	ASUMZ 22430-40	Rich Mtn. (Eagleton Vista)	NW slope, mixed deciduous, numerous rocks and logs, dry
8	Polk	SW¼, SE¼, S10, T1S, R31W	4	10/8/98	ASUMZ 22816-17	Rich Mtn. (0.6 km E Eagleton Vista, St. Hwy 88)	S slope, mixed deciduous, scattered rocks, moist
9	Polk	NE¼, SW¼, S31, T1S, R30W	4	5/28/98	ASUMZ 22764	Rich Mtn. (0.5 km SE Blue Haze Vista, St. Hwy 88)	E slope near ridge crest, mixed deciduous-pine, scattered rocks and logs, moist

*1 - Blair and Lindsay (1965)
2 - Ren Lohoefener and Robert L. Jones, 17-21 Nov., 1990; 8-16 May, 1991 (unpublished locality data)
3 - Pope and Pope (1951)
4 - This report

drawn from the scientific literature, whereas others represent localities unpublished by other investigators.

Talus-covered slopes within the Caddo Mountains are the preferred habitat of *P. caddoensis*. Typically, the talus is comprised of drifts of loose gravel to small-to-medium sized rocks. The occurrence of *P. caddoensis* in abandoned mines has been reported by several authors (e.g., Saugey et al., 1985; Heath et al., 1986; Saugey et al., 1988). Two mine sites (5 and 6) were visited during the present study. Wet conditions were not suitable within the Twin Mines site for habitation by *P. caddoensis* on 19 April 1997. This site typically contains large numbers of this species, especially during the egg-laying season of mid-to-late summer. Rocks and loose talus along Brushy Creek near the mouth of Pipistrelle Mine

Table 3. Recent locality information (1996-1998) and historic collection site data for the Caddo Mountain salamander, *Plethodon caddoensis*, as shown in Fig. 4.

Locality	County	Section, Township, Range	*Source	Date	Voucher Specimens	Description	Habitat
1	Polk	NW¼, SW¼, S11, T3S, R31W	3	4/19/97	ASUMZ 21631-33	Low water bridge on Clear Fork/Twomile Creek	NE slope, mixed deciduous-pine, scattered rocks along stream, moist
2	Polk	SE¼, NE¼, S9, T3S, R30W	3	4/19/97 5/4/96	– –	Along Carter Creek (St. Hwy 375)	N slope, mixed deciduous-pine, along stream, moist
3	Polk	NW¼, SE¼, S13, T3S, R31W	2	-	–	Bee Mtn. Tower off NFR	N slope, deciduous, talus
4	Polk	NW¼, NE¼, S33, T3S, R30W	3	4/19/97	–	Along NFR 56	W slope, deciduous, talus, moist
5	Polk	SE¼, NW¼, S27, T3S, R30W	3	4/19/97 8/24/90 8/7/89	– ASUMZ 16789-16802 ASUMZ 15239-61	Vicinity Twin Mines (along NFR 56)	S slope, mixed deciduous-pine, along creek and in mines, moist
6	Polk	SE¼, NW¼, S27, T3S, R30W	3	4/19/98	ASUMZ 21679-85	Pipistrelle Mine (along stream at base of N slope)	N slope, mixed deciduous-pine, scattered rocks, wet
7	Polk	S27, T3S, R30W	-	4/29/88	ASUMZ 11176-84	Sugarstick Mine	-
8	Howard	NE¼, NW¼, S26, T5S, R30W	2	-	–	St. Hwy 4 at Cossatot River	N slope, deciduous, talus, very wet
9	Howard	SE¼, SWE¼, S24, T5S, R30W	3	4/15/89 4/27/91	ASUMZ 12758 ASUMZ 17643-44	St. Hwy 4 at Baker Creek (south side of bridge)	N slope, mixed deciduous-pine, scattered surface rocks
10	Polk	NW¼, NSW¼, S24, T4S, R30W	3	5/11/97	ASUMZ 21824-29	Along NFR 402 (0.8 km W jct. 402 & 605)	N slope, mixed deciduous-pine, rocks and logs, dry
11	Polk	NW¼, SW¼, S32, T3S, R28W	3	5/12/97	ASUMZ 21821-22	Along NFR 38-1 (1.9 km E jct. 38-1 & 95)	N slope near seep, mixed deciduous, numerous rocks, moist
12	Polk	NE¼, SW¼, S34, T3S, R29W	3	5/4/96	ASUMZ 21227	Along Mine Creek	N slope, mixed deciduous-pine, along creek, scattered rocks, moist
13	Polk	SW¼, SW¼, S33, T3S, R29W	3	5/4/96	ASUMZ 21254-66	Along Little Missouri River	N slope, mixed deciduous-pine, rocks and large, dry
14	Polk	SE¼, NW¼, S7, T4S, R28W	3	5/12/97	ASUMZ 21820	Along NFR 38 (edge of Caney Creek Wilderness Area)	NW slope near creek, mixed deciduous-pine, numerous rocks, logs, moist
15	Polk	NE¼, SE¼, S18, T4S, R28W	3	5/12/97	ASUMZ 21842	Caney Creek Trail at NFR 64	SW slope near stream, mixed deciduous, numerous rocks, logs, moist
16	Polk	NW¼, NE¼, S30, T4S, R30W	3	5/11/97	ASUMZ 21831	Along NFR 64 (4 km S jct 106 & 38)	Creek bottom, SW slope, mixed deciduous pine, scattered rocks, moist
17	Polk	NW¼, NE¼, S30, T4S, R30W	2	–	–	Shady Lake Rec. Area	Gentle slopes, mixed deciduous-pine, scattered surface rocks
18	Polk	SW¼, NW¼, S21, T4S, R28W	3	5/21/97	ASUMZ 21841	Along NFR 106 (1.4 km E jct. 106 & 38)	S slope, mixed deciduous-pine, along creek, moist
19	Polk	NE¼, NE¼, S26, T4S, R27W	3	5/11/97	ASUMZ 21832-33	Along NFR 106	S slope, mixed deciduous-pine, scattered rocks, moist
20	Montg.	NE¼, NE¼, S35, T1N, R29W	3	5/12/97	ASUMZ 21804	St. Hwy 8 at Pittman Creek (upstream from bridge)	W slope, mixed deciduous-pine, numerous rocks and boulders, creek dry
21	Montg.	SW¼, SE¼, S5, T4S, R27W	3	5/4/96	ASUMZ 21253	Along Crooked Creek	S slope, mixed deciduous-pine, rocks and logs, very wet
22	Montg.	NW¼, NW¼, S4, T4S, R27W	2	–	–	Slatington Tower (off NFR 43A)	N slope, deciduous, talus, scattered small seeps
23	Montg.	S26, T3S, R27W	3	7/8/92	ASUMZ 18519-20	Cox Spring	-

Table 3. Recent locality information (1996-1998) and historic collection site data for the Caddo Mountain salamander, *Plethodon caddoensis*, as shown in Fig. 4 (continued).

Locality	County	Section, Township, Range	*Source	Date	Voucher Specimens	Description	Habitat
24	Montg.	NW¼, NW¼, S4, T4S, R27W	3	5/4/96	ASUMZ 21228-30	Caddo River at St. Hwy 8 (upstream from bridge)	NW slope, streamed, leaf litter, moist
25	Montg.	NE¼, NE¼, S31, T3S, R26W	3	4/24/93	ASUMZ 18862-64; 18886-96	Along St. Hwy 8 (old homesite)	N slope near dump site, mixed deciduous, numerous rocks, moist
26	Montg.	SE¼, NW¼, S33, T3S, R26W	3	4/19/98 5/11/97 5/28/97 10/8/98	ASUMZ 22562-22614 ASUMZ 21861-62 ASUMZ 21887-94 ASUMZ 22805-09	0.8 km S St. Hwy 8, off NFR 73	E slope, mixed deciduous-pine, embankment along stream
27	Montg.	SE¼, SW¼, S5, T4S, R26W	3	5/11/97	ASUMZ 21842	Bank along creekbed	S slope, mixed deciduous-pine, scattered rocks, logs, moist
28	Montg.	NE¼, SE¼, S12, T4S, R27W	2	–	–	Pass between Statehouse Mtn. and Polk Creek Mtn.	N slope, mostly deciduous-pine, talus scattered surface rocks, TYPE locality
29	Montg.	SW¼, NW¼, S22, T4S, R27W	3	5/11/97	1	Along NFR 73 (step talus slide)	W slope, mixed deciduous, numerous rocks, mostly moist
30	Montg.	NE S30, T4S, R27W	1	11/17-21/90	5	Vicinity Albert Pike Rec. Area	–
31	Montg.	NW¼, SE¼, S12, T1S, R29W	3	5/3/93	ASUMZ 18984-86	Indian Quarry (ca. 3 km W Albert Pike Rec. Area)	–
32	Montg.	NW¼, NW¼, S27, T4S, R27W	2	–	–	Albert Pike Rec. Area	N slope along Little Missouri River, deciduous, talus
33	Montg.	NE¼, SW¼, S8, T1S, R28W	4	5/25/31/95	4	0.96 km E Albert Pike Rec. Area (north side of road)	–
34	Montg.	SW¼, NE¼, S19, T4S, R26W	2	–	9	9.6 km NE Albert Pike Rec. Area (County rd. 4)	N slope, deciduous, talus
35	Montg.	SW¼, SW¼, S14, T3S, R25W	3	10/8/98	–	3.5 km E St. Hwy 8 along Montgomery Creek (NFR 177)	N slope, deciduous, along creek
36	Montg.	SW¼, SE¼, S13, T3S, R25W	3	10/8/98	–	1.3 km E Crystal Rec. Area along Montgomery Creek (NFR 177)	N slope near creek mixed deciduous, numerous rocks, moist
37	Montg.	NW¼, NE¼, S17, T3S, R24W	3	10/8/98	–	0.6 km N Collier Spring Rec. Area along Collier Creek (NFR 177)	N slope, mixed deciduous-pine, scattered rocks and logs, wet
38	Montg.	S13, T4S, R25W	5	–	1	Caddo Gap (western face of gap)	E slope of gap, mixed deciduous-pine, steep slope, under log
39	Montg.	S13, T4S, R25W	2	5/10/82	2	Caddo Gap (E side of St. Hwy 8)	N slope, mixed deciduous, scattered rocks
40	Montg.	NW¼, SE¼, S17, T4S, R24W	3	5/10/97	–	Along Gap Creek (1.6 km E St. Hwy 8)	NW slope along creek, mixed deciduous-pine, talus
41	Montg.	NE¼, SE¼, S17, T4S, R24W	3	5/10/97	ASUMZ 21861-62	Along Gap Creek (2.4 km E St. Hwy 8)	W slope, wet ravine, mixed deciduous-pine, scattered rocsk
42	Montg.	SW¼, NE¼, S17, T1S, R27W	3	4/27/80	ASUMZ 5650	Along Gap Creek (4 km E St. Hwy 8)	S slope, mixed deciduous-pine, talus, mostly dry
43	Pike	SE¼, NE¼, S10, T5S, R24W	3	3/13/87	ASUMZ 6851-53	Caddo River (just downstream US Hwy 70 bridge)	N slope, talus

Table 3. Recent locality information (1996-1998) and historic collection site data for the Caddo Mountain salamander, *Plethodon caddoensis*, as shown in Fig. 4 (continued).

Locality	County	Section, Township, Range	*Source	Date	Voucher Specimens	Description	Habitat
44	Pike	SE¼, NE¼, S6, T5S, R27W	3	3/13/87	ASUMZ 6851-53	Along Little Missouri River	–

*1 - Ren Lohoefener and Robert L. Jones, 17-21 Nov., 1990; 8-16 May, 1991 (unpubl. locality data)
2 - Plummer (1982)
3 - This report
4 - Carl Anthony, 25-31 May 1995 (unpubl. locality data)
5 - Pope and Pope (1951)

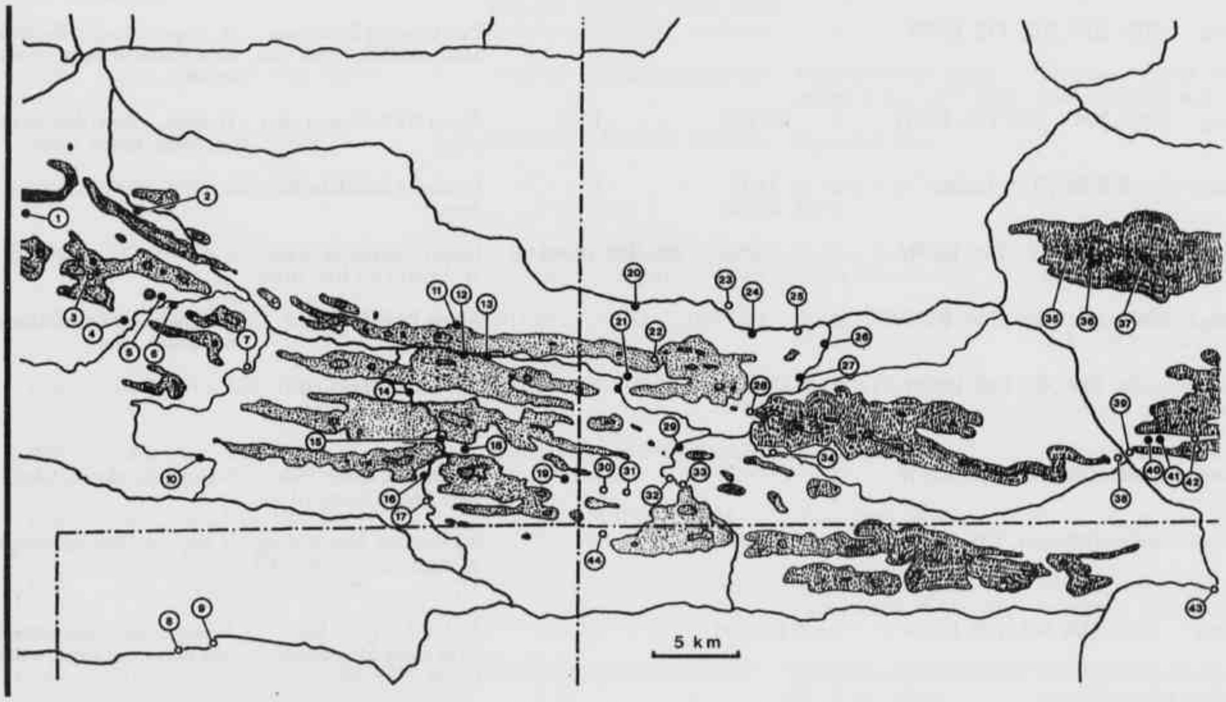


Fig. 4. Map illustrating historic collection sites and/or localities visited during the recent study of *Plethodon caddoensis* in the Caddo Mountains area. Outermost contour lines approximate 440 m in elevation (western mountainous region) and 300 m in elevation (eastern mountainous region); inner contour lines show increases in elevation at increments of ca. 150 m. See Table 3 for explanation of numbered sites.

yielded seven specimens on 19 April 1998. The salamander was also easily found in the vicinity of an old homestead and associated dump area along St. Hwy 8 (site 25) on 24 April 1993. (This site no longer exists following the construction of a new home.) Leaf litter along the dry creekbed of the upper reaches of the Caddo River (site 24) contained a number of *P. caddoensis* and several many-ribbed salamanders (*Eurycea m. multiplicata*) on 4 May 1966. The largest number of *P. caddoensis* collected by Plummer (1982) from a single site was 19 individuals at Albert Pike Recreation Area (site 32) on 4 April 1982. By comparison, five sites yielded 10-12 specimens in a survey by Lohoefener and Jones (1991) in May 1991. Our largest single collection of this species occurred during a third visit to site 26 on 19 April 1998; a total of 52 *P. caddoensis* was collected in a very limited stretch of habitat along a small creek. Four visits to this site during 1997-1998 yielded a total of 69 specimens.

Plummer (1982) searched for *P. caddoensis* at three sites in the Crystal Mountains region just northeast of Norman (Montgomery Co.) without success. We were unable to find this species in three habitat situations within this eastern mountainous area. The Gap Creek populations (sites 41 and 42) indicate that the range of this species probably extends well into the White/Strawn Mountain region and possibly

Table 4. Salamander diversity observed at localities visited during recent survey work (1996-1998) in the Ouachita Mountains of Arkansas. (PF = *P. fourchensis*; Pa = *P. albagula*; Ps = *P. serratus*; Em = *Eurycea multiplicata*; Db = *Desmognathus rimleyorum*).

Locality	Salamander Species (*P. fourchensis* study)					Salamander Species (*P. ouachitae* study)					Salamander Species (*P. caddoensis* study)				
	Pf	Pa	Ps	Em	Db	Po	Pa	Ps	Em	Db	Pc	Pa	Ps	Em	Db
1	0	5	0	0	0	0	0	0	2	2	3	0	3	0	2
2	0	7	8	1	0	0	0	0	4	4	0	1	0	0	2
3	0	0	0	0	0	5	10	0	0	0	0	0	0	0	0
4	0	0	0	0	0	25	15	6	29	29	0	1	1	0	1
5	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0
6	0	4	0	0	0	0	4	0	1	1	7	0	3	1	3
7	0	0	0	0	0	11	3	6	0	0	0	0	0	0	0
8	5	4	0	0	0	3	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
10	8	13	21	3	1						6	0	0	0	0
11	2	3	6	4	0						2	0	0	0	0
12	0	0	0	0	0						1	0	1	0	0
13	0	0	0	0	0						4	0	1	0	0
14	0	2	1	0	0						1	1	0	0	0
15	0	0	0	0	1						2	0	0	0	0
16	0	1	0	0	0						1	0	0	0	0
17	0	1	0	0	0						0	0	0	0	0
18	0	0	0	0	0						1	0	0	0	2
19	0	1	0	0	0						2	0	4	1	0
20	0	0	1	0	0						1	2	0	0	0
21	0	2	1	0	0						1	0	1	0	0
22	0	1	2	0	0						0	0	0	0	0
23	0	0	0	0	0						0	0	0	0	0
24	0	3	1	0	0						2	0	2	7	0
25	1	0	2	0	0						0	0	0	0	0
26	0	1	1	0	0						69	5	39	10	0
27	1	0	0	0	0						1	0	0	0	0
28	0	0	1	0	0						0	0	0	0	0
29	0	0	3	0	0						1	0	0	1	0
30	1	0	1	0	0						0	0	0	0	0
31	0	2	0	0	0						0	0	6	1	0
32	0	1	0	0	0						0	0	0	0	0
33											0	0	0	0	0
34											0	0	0	0	0
35											0	2	0	0	0
36											0	3	0	0	0
37											0	6	1	0	0
38											0	0	0	0	0
39											0	0	0	0	0
40											3	1	0	0	0
41											0	5	3	0	1
42															
43															
44															
Totals	18	43	41	4	2	45	34	12	1	36	108	27	65	21	11

into the Sharp Top Mountain area. The collection site at Glenwood (site 43), however, represents the southeasternmost locality known for this species. Site 1 represents the northwesternmost locality known for this species.

Ecological Associates and Habitat Preferences.--During the course of this study, several additional plethodontid salamanders were collected (Table 4) and included the following species: the southern redback salamander (*P. serratus*) and three species previously mentioned [the western slimy salamander (*P. albagula*), the many-ribbed salamander (*E. m. multiplicata*), and the Ouachita dusky salamander (*D. brimleyorum*)]. Kuss (1986) reported that *P. fourchensis* and *P. ouachitae* seemed to prefer higher slopes compared to *P. albagula*, a salamander of comparable size. He also suggested that no clear difference in habitat preference existed between *P. caddoensis* and *P. albagula*. Although we have searched in a number of disturbed areas along U.S. Hwy 270 in the past (along railroad tracks at Eagleton and the community of Rich Mountain as well as old homesteads and dump sites in the vicinity of the two communities), we have never collected *P. ouachitae* in habitats other than within the well-forested, rocky areas specifically on the higher slopes or at the top of Rich Mountain. Indeed, we have found *P. albagula*, *P. caddoensis*, and *P. fourchensis* at all elevations and in several different microhabitats (beneath rocks, in or beneath logs, and in leaf litter); various authors have indicated that the degree of surface moisture strongly influences the catchability rates in all of these *Plethodon* (Spotila, 1972). *Plethodon fourchensis* seems to be the least tolerant to low substrate moisture levels (i.e., microclimate directly beneath surface rocks), whereas *P. albagula* appears to be the most tolerant. Although a considerable amount of excavation during dry weather is required to collect *P. caddoensis*, this kind of effort is normally successful simply because the surface rocks are usually small and, therefore, can be moved to a greater degree than large rocks. On occasion, we have had to resort to this mode of collection to obtain *P. caddoensis.* This kind of effort is rarely successful for *P. fourchensis* or *P. ouachitae*, primarily because removal of surface rocks does not penetrate into the subterranean niches of these salamanders. *Plethodon serratus*, the smallest plethodontid encountered in this study, is commonly found under rocks, within leaf litter beneath logs, and within logs themselves. This species is often observed in small aggregates, especially within logs. In sympatric rocky habitats, *P. serratus* often shares a common subterranean niche with *P. caddoensis.*

The occasional collection of *Desmognathus brimleyorum* in drier niches several m away from their normal semi-aquatic or aquatic (stream) habitats indicated a marginal habitat overlap between this species and the various *Plethodon* species. As stated previously, the relatively large number of *D. brimleyorum* collected on Rich Mountain resulted from a deliberate attempt to thoroughly search small ravines on this mountain. During dry weather, this type of collecting produced an occasional *P. ouachitae.*

The surprising collection of *P. caddoensis* within moist leaf litter within the drying creekbed of the upper Caddo River at site 20 indicated a small degree of habitat sympatry between this species and the normally semi-aquatic/aquatic *E. m. multiplicata.* The presence of *P. caddoensis* away from normal talus conditions can possibly be explained by the occasional flooding of optimal riparian habitats upstream from this site. Salamander eggs, hatchlings, juveniles, and even adults could easily be wafted downstream. This could also help explain why this species has been found at sites 8 and 9 (along Cossatot River) and on the cliff banks above the Caddo River at Glenwood (site 43). These are areas a considerable distance outside of the Novaculite Uplift area.

Summary.--The present study surveyed populations of three species of plethodontid salamanders in the genus *Plethodon* that occur in the Ouachita National Forest of southwestern Arkansas. Although new localities were discovered for each species, none occurred outside its currently recognized range. In general, all three species were easy to collected during the spring months, especially following several days of moderate-to-heavy precipitation. These salamanders were very difficult to obtain in rocky habitats during dry weather of late summer and fall. *Plethodon fourchensis* was the least abundant of the three species and was observed in both low and high elevation rocky habitats on Fourche Mountain and on parts of Irons Fork Mountain. *Plethodon ouachitae* was common at the higher elevations on Rich Mountain, but probably occurs in rocky habitats at lower elevations. *Plethodon caddoensis* was the most common of the three species and was the easiest to collect at lower elevations throughout the Caddo and Cossatot Mountains.

Recommendations.--Insuring the survival of a salamander species through time in a managed forest ecosystem requires the protection of the most basic of all natural resources, a suitable environment in which to live. Success in managing plethodontid salamander populations will depend upon the willingness of ecosystem managers to preserve the integrity of selected physical habitats. The following statements and/or guidelines represent a summary of desirable conservation biology for the three salamanders in question:

1) Understand that the most critical requirement for the overall future survival of each of the three species is maintaining large tracts of healthy, unaltered forest and streamside habitat within each species' range in Ouachita National Forest.

2) Establish and abide by a highest conservation priority; i.e., limiting large-scale forest habitat and stream degradation during timber harvesting.

3) Determine the appropriate level and method for timber removal that will allow current populations of these salamanders to remain healthy.

4) Continue studies using forested experimental plots designed to examine new or improved silvicultural practices and their effects on salamander populations, especially those within mountainous slopes.

5) Monitor populations on a routine basis as an integral part of the management plan for each species.

Because these salamanders are currently locally abundant and have already been given some degree of protection, they should not be regarded as endangered or even highly vulnerable to immediate threats. And, if landscape protection remains at its current priority level, there appears to be no imminent fear of any of these species precipitously declining in number in the near future.

ACKNOWLEDGMENTS.—We wish to express our sincere appreciation to Ms. Betty G. (Cochran) Crump and Mr. Tim Mersmann, aquatic ecologist and wildlife biologist for the U. S. Forest Service in the Caddo and Mena Ranger Districts, respectively, for arranging the Challenge-Cost Share Agreements. A special thanks goes to David Saugey, USFS wildlife biologist at the Jessieville Ranger District, for numerous favors related to the collection of *P. caddoensis.* Numerous students and several colleagues assisted us during field trips over the years. We especially thank Carl Anthony, Roger Buchanan, Chris T. McAllister, Hilary Worley, Brad Howerton, the late Robert L. Cox, Jr., Walter E. Meshaka, and Anthony Holt. Linda LaClaire, of the U. S. Fish and Wildlife Office at Jackson, MS, provided us with status reviews for *P. caddoensis* and *P. fourchensis* and also authorized use of unpublished field data of Ren Lohoefener and Robert L. Jones. The Arkansas Game and Fish Commission authorized the collection of salamanders by providing the senior author with scientific collection permits.

Literature Cited

Anthony, C. D., J. A. Wicknick, and **R. G. Jaeger.** 1997. Social interactions in two sympatric salamanders: effectiveness of a highly aggressive strategy. Behaviour 134:71-88.

Atwill, R. A., and **S. E. Trauth.** 1988. Mandibular dentition in six species of salamanders, genus *Plethodon* (Caudata: Plethodontidae), from Arkansas using scanning electron microscopy. Proc. Arkansas Acad. Sci. 42:24-25.

Blair, A. P. 1967. *Plethodon ouachitae.* Cat. Amer. Amph. Rept. 40.

Blair, A. P., and **H. L. Lindsay, Jr.** 1965. Color pattern variation and distribution of two large *Plethodon* salamanders endemic to the Ouachita Mountains of Oklahoma and Arkansas. Copeia 1965:331-335.

Dodd, C. K., Jr. 1997. Imperiled amphibians: a historical perspective. Pp. 165-200, *In* Aquatic fauna in peril: the southeastern perspective, (G. W. Benz and D. E. Collins eds.), Spec. Publ. 1, Southeast Aquatic Res. Inst., Lenz Design & Communications, Decatur, GA, 554 pp.

Duncan, R., and **R. Highton.** 1979. Genetic relationships of the eastern large *Plethodon* of the Ouachita Mountains. Copeia 1979:95-110.

Dunn, E. R., and **A. E. Heinze.** 1933. A new salamander from the Ouachita Mountains. Copeia 1933:121-122.

Heath, D. R., D. A. Saugey, and **G. A. Heidt.** 1986. Abandoned mine fauna of the Ouachita Mountains, Arkansas: vertebrate taxa. Proc. Arkansas Acad. Sci. 40:33-36.

Highton, R. 1986. *Plethodon fourchensis.* Cat. Amer. Amph. Rept. 391.1.

Kuss, B. D. 1986. A comparison of habitat utilization in the salamanders of the *Plethodon ouachitae* complex and Plethodon glutinosus. Unpublished Ph. D. Dissertation. University of Arkansas-Fayetteville. 39 pp.

Lohoefener, R., and **R. L. Jones.** 1991. Field survey report of Ouachita endemic salamanders. Unpublished report, U. S. Fish and Wildlife Service, Endangered Species Office, Jackson, Mississippi. 23 pp.

Petranka, J. W. 1994. Response to impact of timber harvesting on salamanders. Conserv. Biol. 8:302-304.

Petranka, J. W., M. E. Eldridge, and **K. E. Haley.** 1993, Effects of timber harvesting on southern Appalachian salamanders. Conserv. Biol. 7:363-370.

Petranka, J. W., M. P. Brannon, M. E. Hopey, and **C. K. Smith.** 1994. Effects of timber harvesting on low elevation population of southern Appalachian salamanders. Forest Ecol. Manag. 67:135-147.

Plummer, M. V. 1982. The status of the Caddo Mountain and Fourche Mountain salamanders (*Plethodon caddoensis, P. fourchensis*) in Arkansas. Unpublished report submitted to the Arkansas Natural Heritage Commission.

Pope, C. H. 1964. *Plethodon caddoensis.* Cat. Amer. Amph. Rept. 14.

Pope, C. H., and **S. H. Pope.** 1951. A study of the salamander *Plethodon ouachitae* and the description of an allied form. Bull. Chicago Acad. Sci. 9:129-152.

Saugey, D. A., G. A. Heidt, and **D. R. Heath.** 1985. Summer use of abandoned mines by the Caddo Mountain salamander, *Plethodon caddoensis* (Plethodontidae), in Arkansas. Southwest. Nat. 30:318-319.

Saugey, D. A., G. A. Heidt, and **D. R. Heath.** 1988. Utilization of abandoned mine drifts and fracture caves by bats and salamanders: Unique subterranean habitat in the Ouachita Mountains. Pp. 64-71 *In* (R. C. Szaro, K. E. Severson, and D. R. Patton, eds.) (Management of amphibians, reptiles, and small mammals in North America) General Technical Report RM-166, USDA Forest Service, Rocky Mountain Station, Ft. Collins, Colorado.

Sievert, G. 1986. An investigation of the distribution and population status of the Rich Mountain salamander (*Plethodon ouachitae*) in Oklahoma. Final report. Oklahoma Department of Wildlife Conservation. 39 pp.

Spotila, J. R. 1972. Role of temperature and water in the ecology of lungless salamanders. Ecol. Monog. 42:95-125.

Taylor, C. L., R. F. Wilkinson, Jr., and **C. L. Peterson.** 1990. Reproductive patterns of five plethodontid salamanders from the Ouachita Mountains. Southwest. Nat. 35:468-472.

Winter, D. A., W. M. Zawada, and **A. A. Johnson.** 1986. Comparison of the symbiotic fauna of the family Plethodontidae in the Ouachita Mountains of western Arkansas. Proc. Arkansas Acad. Sci. 40:82-85.

Derivation of Equations of Motion for a Four Link Robotic Leg for a Walking Vehicle

Andrew B. Wright
Department of Applied Science
University of Arkansas at Little Rock
Little Rock, AR 72204

Abstract

A four degree of freedom leg for a walking robot has been modeled using Newton's method. Unlike robot manipulators, which have a fixed base, a leg model must include inertial forces due to base motion. These forces have been included in the formulation. These equations can be used for design, simulation, and control. The inverse kinematics for this leg are also presented. This allows the joint angles to be computed from a desired foot-hold position.

Introduction

Walking robots have been a topic of research and imagination since antiquity (Raibert, 1986). In the nineteenth century, mechanisms to achieve a repetitious gait were developed. These 'walking horses' suffered from the disadvantage that they could not automatically compensate for uneven terrain. Developments in automatic control theory and electronics have generated a resurgence in research into walking vehicles.

Applications of walking vehicles include interplanetary or off-road exploration, nuclear power-plant clean-up, and transportation for the handicapped (a walking "wheel" chair). These applications require a vehicle which can propel a payload while isolating that payload from the effects of uneven terrain.

Although a walking vehicle has many advantages over a wheeled vehicle, it suffers from technical disadvantages. Since the vehicle's legs, or active suspension, have many degrees of freedom, design, construction, and control are more difficult and expensive tasks. Studies of the Robotics Vehicles Group at the Jet Propulsion Laboratory (Private communication with Dr. Eddie Tunstel) have indicated that wheeled vehicles are more energy efficient than legged vehicles, a key disadvantage when energy resources are limited. Legs must also be light-weight and strong, since they must carry their own weight as well as the vehicle's payload (Eltze and Pfeiffer, 1995).

Initial control strategies focussed on quasi-static approaches (Klein et al., 1983). This involves updating the control signals to the legs so that a subset of the legs forms a static, stable platform (Klein and Chung, 1987; Liu and Wen, 1997). The drawbacks to this strategy include intensive inverse kinematic calculations and slow vehicle speed. This limitation comes partly from the force distribution problem, which requires a quasi-static formulation to avoid foot force discontinuity through the transition between ground-contacting legs (Gardner, 1991).

Modern control strategies eliminate some of these drawbacks. The dynamically stable controller (Raibert, 1990) converts the set of legs into an equivalent single leg which dynamically balances the center of mass of the vehicle. This vehicle is always falling in the right direction to achieve the desired motion. Several single- and multi-leg vehicles which use this strategy have been developed and demonstrated successfully.

New developments involve biologically inspired control strategies (Bems et al., 1999). These strategies use a paradigm derived from the nervous system of cockroaches or cats to generate nonlinear coupled oscillators which generate the control signals. This approach is simple to implement; however, it suffers the drawback of unpredictability. The controller is adaptive and requires some heuristic refinement to perform properly.

Another control approach is to use state-space based adaptive or nonlinear controllers. One example uses a model reference adaptive controller (Lee and Shih, 1986). State space controllers need model information governing how the actuators interact with the system they are controlling. In the case of a walking robot, this involves modeling the leg dynamics. A similar task occurs in the development of manipulator control systems (Asada and Slotine, 1986). However, the manipulator base is fixed, and the dynamics of the body do not influence the control or modeling of the manipulator. The controller presented by Lee and Shih (1986) does not include body motion in the model of the leg accelerations. This presents a severe drawback in the system's performance.

Regardless of the control strategy employed, it is desirable to test the controller in simulation prior to building and testing hardware. Consequently, equations of motion for a new configuration, including body dynamics, must be derived and simulated.

The work presented in this paper involves a new leg configuration. The equations of motion are derived using Newton's method. The inverse kinematics for this leg configuration are also presented.

Derivation of the Leg Equations of Motion

The basic design for this project uses four-link, bottom-mounted legs, similar to insect legs, where the fourth link is a flexible foot containing both a restoring spring and a force sensor system (see Fig. 1). This design has three controlled degrees of freedom, which allow the foot to be positioned arbitrarily within the limits of the link lengths. The foot-spring stores energy during foot placement and releases it when the foot leaves contact with the ground. This compliance is similar to the ankle in most mammals and has been used in shoe design to increase walking efficiency.

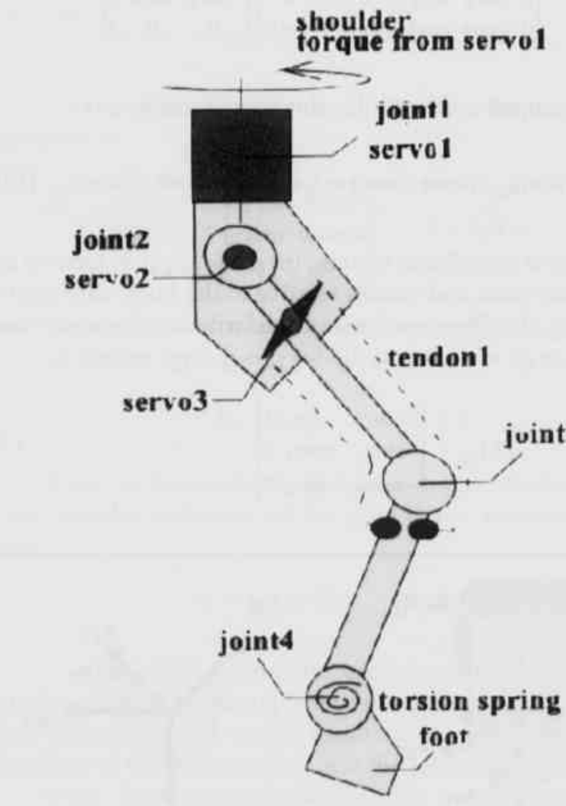


Fig. 1. Tendon Based Articulated Leg

The development of the Equations of Motion (EOM) is a time-consuming, effor-prone task (Asada and Slotine, 1986), especially when the six degrees of freedom (DOF) for body motion are included. Newton's method is used to determine the equations of motion. Although this method requires knowledge and experience to apply it, it is more efficient than Lagrange's method for this complicated case.

A Free-Body-Diagrarn (FBD) of each link and of the foot is shown in Fig. 2. The foot is subject to ground forces, F_G, gravity, G_4, a constraint force, F_4, and a constraint torque, τ_4, exerted by the preceding link. On each link other than the foot, the forces acting are the negative of the constraint exerted by the following link, $-F_{i+1}$, and $-\tau_{i+1}$, gravity, G_i, and the forces exerted by the preceding link, F_i and τ_i. The inertial terms are the rate of change of linear momentum for the link, $\frac{d(p_i)}{dt} = \frac{d(m_i v_i)}{dt} = m_i \frac{dv_i}{dt}$, and the rate of change of angular momentum about the link's center of mass, $\frac{d(I_i \cdot \omega_i)}{dt}$. Here, v_i is the velocity of the link's center of mass, m_i the link's mass, ω_i is the link's angular velocity, and I_i is the link's moment of inertia tensor.

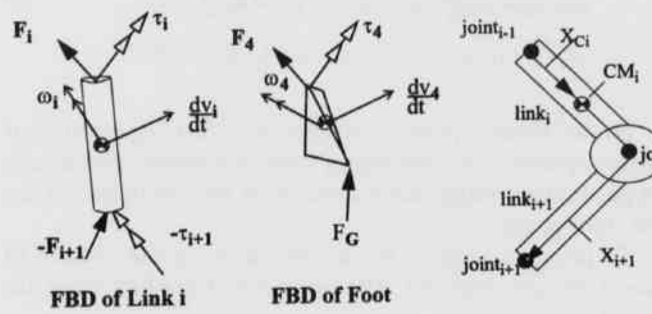


Fig. 2. Free Body Diagram of Link and Foot

A vector sum of the forces and moments about the center of mass acting on each FBD is performed and generates four sets of two vector equations.

$$F_4 + F_G + G_4 = m_4 \frac{dv_4}{dt} \quad (1)$$

$$\tau_4 - x_{C4} \times F_4 + (x_4 - x_{C4}) \times F_G = \frac{d(I_4 \cdot \omega_4)}{dt} \quad (2)$$

$$F_i - F_{i+1} + G_i = m_i \frac{dv_i}{dt} \qquad i = 1, 2, 3 \quad (3)$$

$$\tau_i - \tau_{i+1} - x_{Ci} \times F_i - (x_i - x_{Ci}) \times F_{i+1} = \frac{d(I_i \cdot \omega_i)}{dt} \qquad i = 1, 2, 3. \quad (4)$$

In Equations 1 through 4, x_{ci} is the location of the center of mass of link i with respect to joint i-1, and x_i is the location of joint i with respect to joint i-1.

Equations 1 through 4 contain constraint forces, F_1, F_2, F_3, F_4, which must be eliminated. Later, if these forces are required for design work, they can be explicitly determined. When the four vector contraint forces are eliminated, the eight vector equations become four vector equations, containing only the constraint torques, gravity forces, and inertial terms.

$$\underline{\tau}_4 = \frac{d(\underline{I}_4 \bullet \underline{\omega}_4)}{dt} + \underline{x}_{C4} \times \left[m_4 \frac{d\underline{v}_4}{dt} - \underline{G}_4\right] - \underline{x}_4 \times \underline{F}_G \tag{5}$$

$$\underline{\tau}_3 = \frac{d(\underline{I}_3 \bullet \underline{\omega}_3 + \underline{I}_4 \bullet \underline{\omega}_4)}{dt} + \underline{x}_{C3} \times \left[m_3 \frac{d\underline{v}_3}{dt} - \underline{G}_3\right] + (\underline{x}_3 + \underline{x}_{C4}) \times \left[m_4 \frac{d\underline{v}_4}{dt} - \underline{G}_4\right] - (\underline{x}_3 + \underline{x}_4) \times \underline{F}_G \tag{6}$$

$$\begin{aligned}\underline{\tau}_2 = {} & \frac{d(\underline{I}_2 \bullet \underline{\omega}_2 + \underline{I}_3 \bullet \underline{\omega}_3 + \underline{I}_4 \bullet \underline{\omega}_4)}{dt} + \underline{x}_{C2} \times \left[m_2 \frac{d\underline{v}_2}{dt} - \underline{G}_2\right] + (\underline{x}_2 + \underline{x}_{C3}) \times \left[m_3 \frac{d\underline{v}_3}{dt} - \underline{G}_3\right] + \\ & (\underline{x}_2 + \underline{x}_3 + \underline{x}_{C4}) \times \left[m_4 \frac{d\underline{v}_4}{dt} - \underline{G}_4\right] - (\underline{x}_2 + \underline{x}_3 + \underline{x}_4) \times \underline{F}_G\end{aligned} \tag{7}$$

$$\begin{aligned}\underline{\tau}_1 = {} & \frac{d(\underline{I}_1 \bullet \underline{\omega}_1 + \underline{I}_2 \bullet \underline{\omega}_2 + \underline{I}_3 \bullet \underline{\omega}_3 + \underline{I}_4 \bullet \underline{\omega}_4)}{dt} + \underline{x}_{C1} \times \left[m_1 \frac{d\underline{v}_1}{dt} - \underline{G}_1\right] + \\ & (\underline{x}_1 + \underline{x}_{C2}) \times \left[m_2 \frac{d\underline{v}_2}{dt} - \underline{G}_2\right] + (\underline{x}_1 + \underline{x}_2 + \underline{x}_{C3}) \times \left[m_3 \frac{d\underline{v}_3}{dt} - \underline{G}_3\right] + \\ & (\underline{x}_1 + \underline{x}_2 + \underline{x}_3 + \underline{x}_{C4}) \times \left[m_4 \frac{d\underline{v}_4}{dt} - \underline{G}_4\right] - (\underline{x}_1 + \underline{x}_2 + \underline{x}_3 + \underline{x}_4) \times \underline{F}_G\end{aligned} \tag{8}$$

So far, these equations are general. Any leg composed of four separate links will follow these equations. The details of a particular configuration depend on the evaluation of the time derivatives.

To proceed further, the accelerations of the centers of mass (CM) are required. The positions of the link CMs are (Fig. 3)

$$\underline{R}_{Ci} = \underline{R}_0 + \underline{X}_0 + \sum_{j=1}^{i-1} \underline{x}_j + \underline{x}_{Ci} \qquad i = 1, 2, 3, 4, \tag{9}$$

where R_0 is the location of the vehicle's center of mass, and X_0 is the location of the shoulder joint with respect to the vehicle's center of mass.

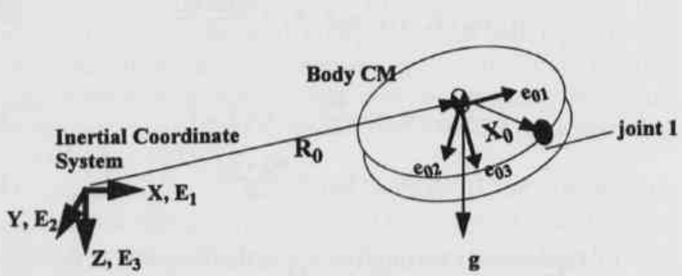


Fig. 3. Inertial Coordinate System and Euler Angles

In order to evaluate derivatives, it is necessary to define coordinate systems in which to express the joint and CM positions. The first, inertial coordinate system is fixed to the ground at some convenient reference point. The unit vectors for this system are (E_1, E_2, E_3), where E_1 is initially aligned with the vehicle's direction of travel, E_2 is aligned with gravity, and E_3 is orthogonal to both E_1 and E_2 in a right hand sense. This coordinate system will be thrown away once velocities are evaluated.

The second coordinate system is affixed to the vehicle body's CM and has unit vectors, (e_{01}, e_{02}, e_{03}), which are initially aligned with (E_1, E_2, E_3). The lower case e's for the unit vectors indicate that this system is rotating and not inertial. The coordinate transformation between the inertial system and the body fixed coordinate system is expressed in terms of Euler angles (Greenwood, 1965)

$$[A]_{01} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\phi & \sin\phi \\ 0 & -\sin\phi & \cos\phi \end{bmatrix} \begin{bmatrix} \cos\theta & 0 & -\sin\theta \\ 0 & 1 & 0 \\ \sin\theta & 0 & \cos\theta \end{bmatrix} \begin{bmatrix} \cos\psi & \sin\psi & 0 \\ -\sin\psi & \cos\psi & 0 \\ 0 & 0 & 1 \end{bmatrix}, \tag{11}$$

where the angular velocity for this transformation is

$$\underline{\omega}_0 = (\dot{\phi} - \dot{\psi}\sin\theta)\underline{e}_{01} + (\dot{\theta}\cos\phi + \psi\sin\phi\cos\theta)\underline{e}_{02} + (\dot{\psi}\cos\phi\cos\theta - \dot{\theta}\sin\phi)\underline{e}_{03}. \tag{12}$$

The next coordinate system, (e_{11}, e_{12}, e_{13}), is located at the shoulder joint and rotates relative to the body with angle q_1 (see Fig. 4). The coordinate transformation between the (e_{01}, e_{02}, e_{03}) system and the (e_{11}, e_{12}, e_{13}) system is

$$[A]_{10} = \begin{bmatrix} 0 & 0 & 1 \\ -\sin q_1 & \cos q_1 & 0 \\ -\cos q_1 & -\sin q_1 & 0 \end{bmatrix}. \tag{13}$$

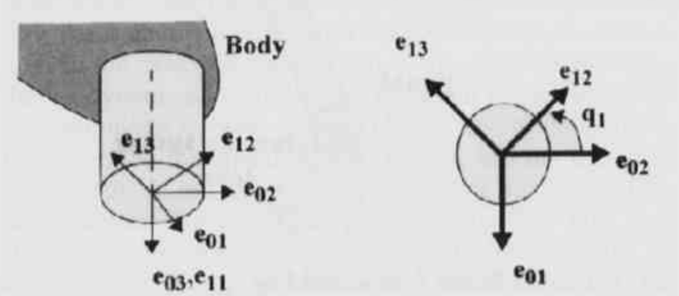


Fig. 4. Definition of Shoulder Joint Angles (Link !)

The angular velocity of the (e_{11}, e_{12}, e_{13}) system with respect to the (e_{01}, e_{02}, e_{03}) system is

$$\underline{\Omega}_1 = \dot{q}_1 \underline{e}_{11}. \tag{14}$$

The next three coordinate systems are similarly defined (see Fig. 5). The unit vector, e_{i1}, points from the i-1[th] joint to the i-[th] joint through the center of mass. The unit vector, is aligned with the motor torque. The final unit vector, e_{i2}, is orthogonal to e_{i1}, and e_{i3}. The joint angle, q_i, is the angle between e_{i1} and $e_{i+1,1}$.

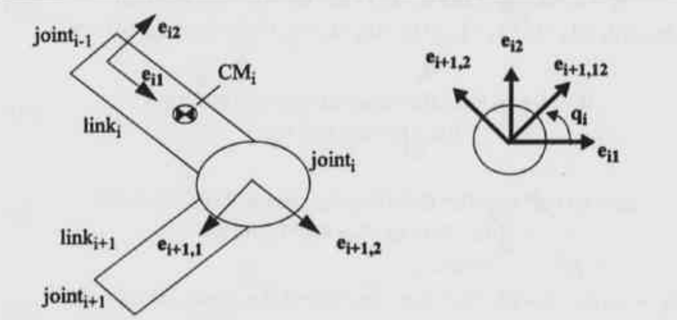


Fig. 5. Defition of Hip, Knee, and Ankle Joint Angles (Links 2, 3, 4)

The coordinate transformation tensor for each of these systems is

$$[A]_{i,i-1} = \begin{bmatrix} \cos q_i & \sin q_i & 0 \\ -\sin q_i & \cos q_i & 0 \\ 0 & 0 & 1 \end{bmatrix} \qquad i = 2, 3, 4, \tag{15}$$

and the angular velocity of system i with respect to system i-1 is

$$\Omega_i = \dot{q}_i e_{i3} \qquad i = 2, 3, 4. \tag{16}$$

Since each coordinate system is chained to the previous one, angular velocities of the joint-based reference frames are

$$\omega_i = \omega_{i-1} + \Omega_i \qquad i = 1, 2, 3, 4. \tag{17}$$

The accelerations for use in equations 5 through 8 are determined by taking two derivatives of equation 9. This is a tedious process which results in the accelerations as a function of the Euler angles and the joint angles.

Only four components of the vector equations 5 through 8 contain information which is useful. The other eight contain information about the eight constraint torques in the pin joints. The torque provided by the motor (or torsion spring) at the joint is the component in the e_{13} direction. Otherwise the joint is free to move in that direction. The torques, $\tau_1 = \tau_1 e_{11}$ and $\tau_i = \tau_i e_{i3}$ for i=2,3,4, are the independent variables in these equations. The joint accelerations are the dependent variables.

The EOM for this leg configuration are

$$[H]\begin{bmatrix} \ddot{q}_1 \\ \ddot{q}_2 \\ \ddot{q}_3 \\ \ddot{q}_4 \end{bmatrix} + [B]\begin{bmatrix} \dot{q}_1^2 \\ \dot{q}_1\dot{q}_2 \\ \dot{q}_1\dot{q}_3 \\ \dot{q}_1\dot{q}_4 \\ \dot{q}_2^2 \\ \dot{q}_2\dot{q}_3 \\ \dot{q}_3^2 \end{bmatrix} + g[G]\begin{bmatrix} \cos q_1 \sin\theta - \sin q_1 \sin\phi\cos\theta \\ \cos\phi\cos\theta \\ \sin q_1 \sin\theta + \cos q_1 \sin\phi\cos\theta \end{bmatrix} = [A]\begin{bmatrix} F_{G1} \\ F_{G2} \\ F_{G3} \end{bmatrix} + \begin{bmatrix} d_1 \\ d_2 \\ d_3 \\ d_4 \end{bmatrix} + \begin{bmatrix} \tau_1 \\ \tau_2 \\ \tau_3 \\ -kq_4 \end{bmatrix}. \tag{18}$$

The matrices, [H], [B], [G], and [A] can be written by defining the following constants

The damping matrix, [B], is

$$\begin{aligned}
S_2 &= \sin(q_2) & C_2 &= \cos(q_2) \\
S_{23} &= \sin(q_2 + q_3) & C_{23} &= \cos(q_2 + q_3) \\
S_{234} &= \sin(q_2 + q_3 + q_4) & C_{234} &= \cos(q_2 + q_3 + q_4) \\
\alpha_{11} &= x_{C2}S_2 & \alpha_{21} &= x_{C2}C_2 \\
\alpha_{12} &= x_{C3}S_{23} & \alpha_{22} &= x_{C3}C_{23} \\
\alpha_{13} &= x_{C4}S_{234} & \alpha_{23} &= x_{C4}C_{234} \\
\beta_{11} &= L_2S_2 & \beta_{21} &= L_2C_2 \\
\beta_{12} &= L_3S_{23} & \beta_{22} &= L_3C_{23} \\
\beta_{13} &= L_4S_{234} & \beta_{23} &= L_4C_{234} \\
\gamma_{11} &= L_3S_4 & \gamma_{21} &= L_3C_4 \\
\gamma_{12} &= L_2S_{34} & \gamma_{22} &= L_2C_{34} \\
\gamma_{13} &= L_2S_3 & \gamma_{23} &= L_2C_3 \\
\gamma_{14} &= L_4 & \gamma_{24} &= L_3C_{34}
\end{aligned} \tag{19}$$

where

The force transformation matrix, [A], is

$$\begin{aligned}
J_1 &= I_{4,33} + m_4x_{C4}^2 \\
J_2 &= J_1 + I_{3,33} + m_3x_{C3}^2 \\
J_3 &= J_2 + I_{2,33} + m_2x_{C2}^2 \\
K_1 &= 2(I_{2,11} - I_{2,22})S_2C_2 \\
K_2 &= 2(I_{3,11} - I_{3,22})S_{23}C_{23} \\
K_3 &= 2(I_{4,11} - I_{4,22})S_{234}C_{234}
\end{aligned} \tag{20}$$

The mass matrix, [H], is

$$[H] = \begin{bmatrix} h_{11} & 0 & 0 & 0 \\ 0 & h_{22} & h_{23} & h_{24} \\ 0 & h_{23} & h_{33} & h_{34} \\ 0 & h_{24} & h_{34} & h_{44} \end{bmatrix}, \tag{21}$$

where $h_{11} = I_{1,11} + I_{2,11}C_2^2 + I_{2,22}S_2^2 + m_2\alpha_{11}^2 + I_{3,11}C_{23}^2 + I_{3,22}S_{23}^2 + m_3(\beta_{11} + \alpha_{12})^2 + I_{4,11}C_{234}^2 + I_{4,22}S_{234}^2 + m_4(\beta_{11} + \beta_{12} + \alpha_{13})^2$,

$h_{22} = J_3 + m_3(L_2^2 + 2x_{C3}\gamma_{23}) + m_4[L_2^2 + L_3^2 + 2(L_3\gamma_{23} + x_{C4}(\gamma_{24} + \gamma_{21}))]$,

$h_{23} = h_{32} = J_2 + m_4L_3^2 + (m_3x_{C3} + m_4L_3)\gamma_{23} + m_4x_{C4}(2\gamma_{21} + \gamma_{22})$, $h_{33} = J_2 + m_4(L_3^2 + 2x_{C4}\gamma_{21})$, $h_{42} = h_{24} = J_1 + m_4x_{C4}(\gamma_{22} + \gamma_{21})$,

$h_{43} = h_{34} = J_1 + m_4x_{C4}\gamma_{21}$, and $h_{44} = I_{4,33} + m_4x_{C4}^2$.

The damping matrix, [B], is

$$[B] = \begin{bmatrix} 0 & b_{12} & b_{13} & b_{14} & 0 & 0 & 0 \\ b_{21} & 0 & 0 & 0 & 0 & b_{26} & b_{27} \\ b_{31} & 0 & 0 & 0 & b_{35} & 0 & 0 \\ b_{41} & 0 & 0 & 0 & b_{45} & b_{46} & b_{47} \end{bmatrix}, \tag{22}$$

where $b_{12} = K_1 + K_2 + K_3 + 2m_2\alpha_{11}\alpha_{21} + 2m_3(\beta_{11} + \alpha_{12})(\beta_{21} + \alpha_{22}) + 2m_4(\beta_{11} + \beta_{12} + \alpha_{13})(\beta_{21} + \beta_{22} + \alpha_{23})$,

$b_{13} = K_2 + K_3 + 2m_3(\beta_{11} + \alpha_{12})\alpha_{22} + 2m_4(\beta_{11} + \beta_{12} + \alpha_{13})(\beta_{22} + \alpha_{23})$, $b_{14} = K_3 + 2m_4(\beta_{11} + \beta_{12} + \alpha_{13})\alpha_{23}$,

$b_{21} = \frac{1}{2}(K_1 + K_2 + K_3) - m_2\alpha_{11}\alpha_{21} - m_3(\beta_{11} + \alpha_{12})(\beta_{21} + \alpha_{22}) - m_4(\beta_{11} + \beta_{12} + \alpha_{13})(\beta_{21} + \beta_{22} + \alpha_{23})$,

$b_{26} = -2(m_3x_{C3}\gamma_{13} + m_4x_{C4}\gamma_{12})$, $b_{27} = -(m_3x_{C3}\gamma_{13} + m_4x_{C4}\gamma_{12})$,

$b_{31} = \frac{1}{2}(K_2 + K_3) - m_3(\beta_{11} + \alpha_{12})\alpha_{22} - m_4(\beta_{11} + \beta_{12} + \alpha_{13})(\beta_{22} + \alpha_{23})$, $b_{35} = (m_3x_{C3} + m_4L_3)\gamma_{13} + m_4x_{C4}\gamma_{12}$,

$b_{41} = \frac{1}{2}K_3 - m_4(\beta_{11} + \beta_{12} + \alpha_{13})\alpha_{23}$, $b_{45} = m_4x_{C4}(\gamma_{11} + \gamma_{12} + x_{C4})$, $b_{46} = 2m_4x_{C4}(\gamma_{11} + \gamma_{12} + x_{C4})$, and

$b_{47} = m_4x_{C4}(\gamma_{11} + \gamma_{12} + x_{C4})$.

The force transmission matrix, [A], is

$$[A] = \begin{bmatrix} 0 & 0 & a_1 \\ a_2 & a_3 & 0 \\ a_4 & a_5 & 0 \\ 0 & a_6 & 0 \end{bmatrix}, \tag{23}$$

where $a_1 = -\beta_{11} - \beta_{12} - \beta_{13}$, $a_2 = \gamma_{11} + \gamma_{12}$, $a_3 = \gamma_{21} + \gamma_{22} + \gamma_{14}$, $a_4 = \gamma_{11}$, $a_5 = \gamma_{21} + \gamma_{14}$, and $a_6 = \gamma_{14}$.

The gravity matrix, [G], is

$$[G] = \begin{bmatrix} g_1 & 0 & 0 \\ 0 & g_1 & g_2 \\ 0 & g_3 & g_4 \\ 0 & g_5 & g_6 \end{bmatrix}, \tag{24}$$

where $g_1 = m_2\alpha_{11} + m_3(\beta_{11} + \alpha_{12}) + m_4(\beta_{11} + \beta_{12} + \alpha_{13})$,

$g_2 = -m_2\alpha_{21} - m_3(\beta_{21} + \alpha_{22}) - m_4(\beta_{21} + \beta_{22} + \alpha_{23})$, $g_3 = m_3\alpha_{12} + m_4(\beta_{12} + \alpha_{13})$, $g_4 = -m_3\alpha_{22} - m_4(\beta_{22} + \alpha_{23})$, $g_5 = m_4\alpha_{13}$,

and $g_6 = -m_4\alpha_{23}$.

In order to evaluate the inertial term, the following terms are defined

$$\underline{\alpha}_0 = \frac{d\underline{\omega}_0}{dt} \tag{25}$$

$$\underline{a}_1 = \frac{d^2\underline{R}_0}{dt^2} + \underline{\alpha}_0 \times \underline{X}_0 + \underline{\omega}_0 \times (\underline{\omega}_0 \times \underline{X}_0) \tag{26}$$

$$\underline{p}_1 = \underline{a}_1 + \underline{\alpha}_0 \times \underline{x}_{C1} + \underline{\omega}_0 \times (\underline{\omega}_0 \times \underline{x}_{C1}) + 2\underline{\omega}_0 \times (\underline{\Omega}_1 \times \underline{x}_{C1}) \tag{27}$$

$$\begin{aligned} \underline{p}_2 = {} & \underline{a}_1 + \underline{\alpha}_0 \times (\underline{L}_1 + \underline{x}_{C2}) + \underline{\omega}_0 \times (\underline{\omega}_0 \times (\underline{L}_1 + \underline{x}_{C2})) + \\ & 2\underline{\omega}_0 \times (\underline{\Omega}_1 \times (\underline{L}_1 + \underline{x}_{C2}) + \underline{\Omega}_2 \times \underline{x}_{C2}) \end{aligned} \tag{28}$$

$$\begin{aligned} \underline{p}_3 = {} & \underline{a}_1 + \underline{\alpha}_0 \times (\underline{L}_1 + \underline{L}_2 + \underline{x}_{C3}) + \underline{\omega}_0 \times (\underline{\omega}_0 \times (\underline{L}_1 + \underline{L}_2 + \underline{x}_{C3})) + \\ & 2\underline{\omega}_0 \times (\underline{\Omega}_1 \times (\underline{L}_1 + \underline{L}_2 + \underline{x}_{C3}) + \underline{\Omega}_2 \times (\underline{L}_2 + \underline{x}_{C3}) + \underline{\Omega}_3 \times \underline{x}_{C3}) \end{aligned} \tag{29}$$

$$\begin{aligned} \underline{p}_4 = {} & \underline{a}_1 + \underline{\alpha}_0 \times (\underline{L}_1 + \underline{L}_2 + \underline{L}_3 + \underline{x}_{C4}) + \underline{\omega}_0 \times (\underline{\omega}_0 \times (\underline{L}_1 + \underline{L}_2 + \underline{L}_3 + \underline{x}_{C4})) + \\ & 2\underline{\omega}_0 \times (\underline{\Omega}_1 \times (\underline{L}_1 + \underline{L}_2 + \underline{L}_3 + \underline{x}_{C4}) + \underline{\Omega}_2 \times (\underline{L}_2 + \underline{L}_3 + \underline{x}_{C4}) + \underline{\Omega}_3 \times (\underline{L}_3 + \underline{x}_{C4}) + \underline{\Omega}_4 \times \underline{x}_{C4}) \end{aligned} \tag{30}$$

$$\begin{aligned} \underline{Q}_1 = {} & \underline{I}_1 \bullet (\underline{\alpha}_0 + \underline{\omega}_0 \times \underline{\Omega}_1) + [(\underline{\omega}_0 \times \underline{I}_1) - (\underline{I}_1 \times \underline{\omega}_0)] \bullet (\underline{\omega}_0 + \underline{\Omega}_1) + \\ & [(\underline{\Omega}_1 \times \underline{I}_1) - (\underline{I}_1 \times \underline{\Omega}_1)] \bullet \underline{\omega}_0 \end{aligned} \tag{31}$$

$$\begin{aligned} \underline{Q}_2 = {} & \underline{I}_2 \bullet (\underline{\alpha}_0 + \underline{\omega}_0 \times (\underline{\Omega}_1 + \underline{\Omega}_2)) + [(\underline{\omega}_0 \times \underline{I}_2) - (\underline{I}_2 \times \underline{\omega}_0)] \bullet (\underline{\omega}_0 + \underline{\Omega}_1 + \underline{\Omega}_2) + \\ & [((\underline{\Omega}_1 + \underline{\Omega}_2) \times \underline{I}_2) - (\underline{I}_2 \times (\underline{\Omega}_1 + \underline{\Omega}_2))] \bullet \underline{\omega}_0 \end{aligned} \tag{32}$$

$$\begin{aligned} \underline{Q}_3 = {} & \underline{I}_3 \bullet (\underline{\alpha}_0 + \underline{\omega}_0 \times (\underline{\Omega}_1 + \underline{\Omega}_2 + \underline{\Omega}_3)) + [(\underline{\omega}_0 \times \underline{I}_3) - (\underline{I}_3 \times \underline{\omega}_0)] \bullet (\underline{\omega}_0 + \underline{\Omega}_1 + \underline{\Omega}_2 + \underline{\Omega}_3) + \\ & [((\underline{\Omega}_1 + \underline{\Omega}_2 + \underline{\Omega}_3) \times \underline{I}_3) - (\underline{I}_3 \times (\underline{\Omega}_1 + \underline{\Omega}_2 + \underline{\Omega}_3))] \bullet \underline{\omega}_0 \end{aligned} \tag{33}$$

$$\begin{aligned} \underline{Q}_4 = {} & \underline{I}_4 \bullet (\underline{\alpha}_0 + \underline{\omega}_0 \times (\underline{\Omega}_1 + \underline{\Omega}_2 + \underline{\Omega}_3 + \underline{\Omega}_4)) + \\ & [(\underline{\omega}_0 \times \underline{I}_4) - (\underline{I}_4 \times \underline{\omega}_0)] \bullet (\underline{\omega}_0 + \underline{\Omega}_1 + \underline{\Omega}_2 + \underline{\Omega}_3 + \underline{\Omega}_4) + \\ & [((\underline{\Omega}_1 + \underline{\Omega}_2 + \underline{\Omega}_3 + \underline{\Omega}_4) \times \underline{I}_3) - (\underline{I}_3 \times (\underline{\Omega}_1 + \underline{\Omega}_2 + \underline{\Omega}_3 + \underline{\Omega}_4))] \bullet \underline{\omega}_0 \end{aligned} \tag{34}$$

The vector disturbance terms are

$$\begin{aligned} \underline{d}_1 = {} & -\underline{Q}_1 - \underline{Q}_2 - \underline{Q}_3 - \underline{Q}_4 - m_1\underline{x}_{C1} \times \underline{p}_1 - m_2(\underline{L}_1 + \underline{x}_{C2}) \times \underline{p}_2 \\ & -m_3(\underline{L}_1 + \underline{L}_2 + \underline{x}_{C3}) \times \underline{p}_3 - m_4(\underline{L}_1 + \underline{L}_2 + \underline{L}_3 + \underline{x}_{C4}) \times \underline{p}_4 \end{aligned} \tag{35}$$

$$\underline{d}_2 = -\underline{Q}_2 - \underline{Q}_3 - \underline{Q}_4 - m_2\underline{x}_{C2} \times \underline{p}_2 - m_3(\underline{L}_2 + \underline{x}_{C3}) \times \underline{p}_3 - m_4(\underline{L}_2 + \underline{L}_3 + \underline{x}_{C4}) \times \underline{p}_4 \tag{36}$$

$$\underline{d}_3 = -\underline{Q}_3 - \underline{Q}_4 - m_3\underline{x}_{C3} \times \underline{p}_3 - m_4(\underline{L}_3 + \underline{x}_{C4}) \times \underline{p}_4 \tag{37}$$

$$\underline{d}_4 = -\underline{Q}_4 - m_4\underline{x}_{C4} \times \underline{p}_4 \tag{38}$$

Only the component from each vector which is aligned with the joint motor torque is required. The resulting vector of inertial torques is

$$\begin{bmatrix} d_1 \\ d_2 \\ d_3 \\ d_4 \end{bmatrix} = \begin{bmatrix} \underline{d}_1 \bullet \underline{e}_{11} \\ \underline{d}_2 \bullet \underline{e}_{23} \\ \underline{d}_3 \bullet \underline{e}_{33} \\ \underline{d}_4 \bullet \underline{e}_{43} \end{bmatrix}. \tag{39}$$

Inverse Kinematics of Leg

Given the desired foot position, $R_d = R_{d1}E_1 + R_{d2}E_2 + R_{d3}E_3$, the inverse kinematic problem involves determining what joint angles, q_1, q_2, q_3, q_4, generate that position. This can be expressed mathematically as (see Fig. 6)

$$\underline{x}_1 + \underline{x}_2 + \underline{x}_3 + \underline{x}_4 = \underline{R}_d - \underline{R}_0 - \underline{X}_0 = \underline{X}_d. \tag{40}$$

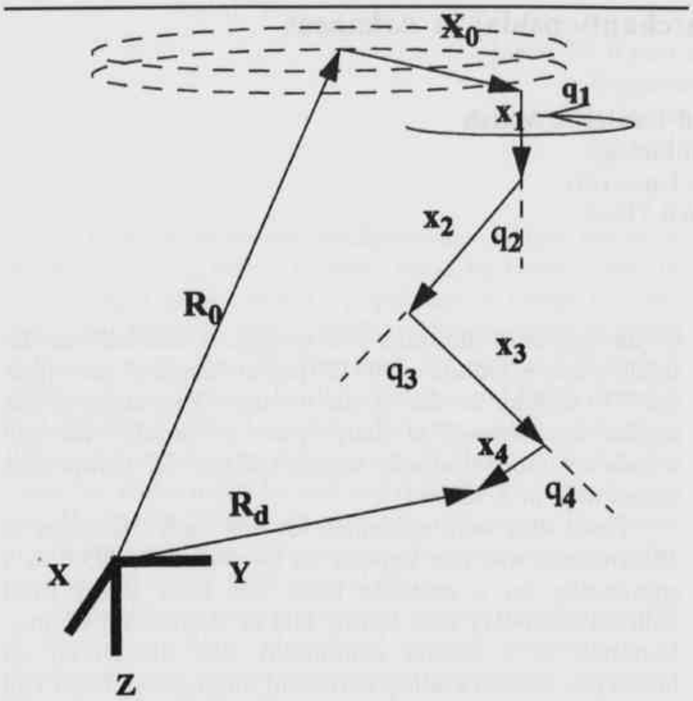


Fig. 6. Leg Vectors for Inverse Kinematics

It is sufficient to specify X_d, the desired foot position relative to the shoulder position. The foot-hold equation becomes

$$L_1 e_{11} + L_2 e_{21} + L_3 e_{31} + L_4 e_{41} = X_{d1} e_{01} + X_{d2} e_{02} + X_{d3} e_{03}. \quad (41)$$

This equation can be written entirely in the (e_{01}, e_{02}, e_{03}) coordinate system

$$[A]^T_{10}\left(\begin{bmatrix} L_1 \\ 0 \\ 0 \end{bmatrix} + [A]^T_{21}\begin{bmatrix} L_2 \\ 0 \\ 0 \end{bmatrix} + [A]^T_{21}[A]^T_{32}\begin{bmatrix} L_3 \\ 0 \\ 0 \end{bmatrix} + [A]^T_{21}[A]^T_{32}[A]^T_{43}\begin{bmatrix} L_4 \\ 0 \\ 0 \end{bmatrix}\right) = \begin{bmatrix} X_{d1} \\ X_{d2} \\ X_{d3} \end{bmatrix}. \quad (42)$$

Since the leg is a four degree of freedom system, one more foot position quantity can be specified. This is the cosine of the global angle of the foot with respect to the ground, n_{d3}. In order to determine the desired joint angles that give a foot position in global cartesian coordinates, the kinematics of the manipulator must be inverted, yielding

$$\begin{aligned} \tan(q_1) &= -\left(\frac{X_{d1}}{X_{d2}}\right) \\ \cos(q_2 + q_3 + q_4) &= n_{d3} \\ \rho_1 &= X_{d3} - L_1 - L_4\cos(q_2 + q_3 + q_4) \\ \rho_2 &= \sqrt{X_{d1}^2 + X_{d2}^2} - L_4\sin(q_2 + q_3 + q_4) \\ \cos(q_3) &= \frac{\rho_1^2 + \rho_2^2 - L_2^2 - L_3^2}{2L_2L_3} \\ \tan(q_2) &= \frac{(L_3\cos(q_3) + L_2)\rho_2 - L_3\sin(q_3)\rho_1}{(L_3\cos(q_3) + L_2)\rho_1 + L_3\sin(q_3)\rho_2} \end{aligned} \quad (43)$$

Conclusions

Equations of motion for a four link manipulator have been derived. These equations include terms resulting from base motion. The equations can be used for simulation to test controllers, for state space controller formulations, and for optimization of the leg parameters.

Inverse kinematics for this leg configuration have been derived. These equations can be used to calculate joint angles to achieve desired foot position.

Further work needs to be done in the basic leg design and the total vehicle design. In particular, the correct optimization criteria need to be chosen and the significant independent variables identified.

ACKNOWLEDGMENTS.—Preliminary work on leg design has been funded through an Arkansas Space Grant Consortium Grant number UALR0111.

Literature Cited

Asada, J., and **J. J. Slotine.** 1986, Robot Analysis and Control, Wiley and Sons, New York, 215 pp.

Berns, K., W. Ilg, M. Deck, J. Albiez, and **R. Dillmann.** 1999. Mechanical construction and computer architecture of the four-legged walking machine BISAM, IEEE/ASME Trans. on Mechatronics, 4:32-38.

Eltze, J., and **F. Pfeiffer.** 1995, Optimization of leg design, J. Robotic Systems, 12:757-765.

Gardner, J. F. 1991, Force distribution in walking machines over rough terrain, J. Dynamics Systems, Measurements, and Control, 113:754-758.

Greenwood, D. T. 1965 Principles of dynamics, Prentice-Hall, New York, 518 pp.

Klein, C. A., K. W. Olson, and **D. R. Pugh.** 1983, Use of force and attitude sensors for locomotion of a legged vehicle over irregular terrain," Internat. J. Robot. Res. 2:3-17.

Klein, C. A. and **T. S. Chung.** 1987. Force interaction and allocation for the legs of a walking vehicle, IEEE J. of Robotics and Automation, RA-3:546-555.

Lee, T. and **C. Shih.** 1986, Real time computer control of a quadruped walking robot," J. Dynamic Systems, Measurements, and Control, 108:346-353.

Liu, H. and **B. Wen.** 1997. Force distribution for the legs of a quadruped walking vehicle," J. Robotic Systems, 14:1-8.

Raibert, M. 1986. Legged robots, Communications of the ACM, 29:499-514.

Raibert, M. H. 1990. Trotting, pacing and bounding by a quadruped robot: J. Biomechanics, 23(Suppl. 1): 79-98.

GENERAL NOTES

Variations in *Sphaerocarpos* (Marchantiopsida) in Arkansas

Timothy A. Golden and Daniel L. Marsh
Department of Biology
Henderson State University
Arkadelphia, AR 71923

Sphaerocarpos texanus Aust. is a very common winter liverwort of disturbed sites in North America, Europe, and occasionally elsewhere in the world. R. M. Schuster (The Hepaticae and Anthocerotae of North America, vol. 5, Field Museum of Natural History. p. 817, 1992) wrote "This is so 'weedy' a plant in disturbed sites that often I have not bothered to collect it." Schuster (op. cit., pp. 811-827) treats three species of *Sphaerocarpos* occurring in North America east of the hundredth meridian, but only *S. texanus* is listed for Arkansas. This species probably occurs in every county of the state, and the field botanist is prone to identify all occurrences of the genus in the state as belonging to that species.

During field studies undertaken in the winter of 1998-99, Golden noticed differences among clumps of *Sphaerocarpos* in the same community and began collecting material for examination in the laboratory. Some of the collections clearly matched Schuster's descriptions (op. cit.) of *S. michelii* Bellardi and *S. donnellii* Aust. Both of these species occur sympatrically with *S. texanus* in other areas. *S. michelii* is widespread in Europe and has been reported from Texas and Kansas. On both continents it usually occurs with *S. texanus*. *S. donnellii* is known from the Gulf Coastal Plain of the southeastern United States from South Carolina to Florida and Mississippi. In his 1992 publication Schuster noted that the species is "probably more widely spread than existing reports would indicate."

The three species may be distinguished to some extent by differences in the female involucres, but critical separation of the taxa requires microscopic examination of the spores. Spores differ in size and ornamentation. *S. donellii* has relatively large spores (tetrads ca. 140-185 µm in diameter) and is coarsely areolate (6-7 areolae across the tetrad face). There is a tendency for some of the female involucres to have flared mouths, especially those not fertilized. Mature female involucres are often purplish tinged. Although Schuster states that the other two species never have purplish or reddish pigment in the female involucres, we observed such pigmentation in these species quite often in unshaded plants. The purplish color of the female involucres is more subtle than in the deep purplish color of the male "flasks." *S. texanus* has spores of intermediate size (tetrads ca. 120-175 µm in diameter), and there are 5-7 distinct areolae across the face. The angles of the areolae are not sharply elevated to give the spiny appearance displayed by the spores of the other two species. *S. mitchelii* has the smallest spore (tetrads ca. 80-120 µm in diameter), and there are 8-10 distinct areolae across the face. The angles of the areolae are elevated as sharp spines in profile. Also the tetrads are more distinctly segmented into the component spores than in *S. texanus*.

Three sites were examined for this study. Variation in *Sphaerocarpos* was first noticed on December 5, 1998, in a community on a roadside bank and field across from Sullivan Cemetary near Spring Hill in Hempstead County. Variation in a second community was discovered on January 6, 1999 in a fallow corn field southwest of Boyd Hill in Lafayette County. Populations on the Henderson State University campus were selected for further comparison. Studies were continued through March, 1999.

In the laboratory sporangia were dissected out of the involucres and placed on slides in Frahm's Mounting Medium (1:1:1 mucilage, glycerine, water). This medium proved to be an excellent clearing agent enhancing microscopic examination of spore ornamentation.

Different spore types were found in material from each of the three study sites. The spore types correlated with variation in the morphology of the female involucres. Plants from Spring Hill and the Henderson campus were identified as *S. mitchelii* and *S. texanus*. The Boyd Hill site had some plants definitely identified as *S. donnellii*, as well as *S. texanus* and *S. mitchelii*. In all sites, some plants seemed to display intermediate traits. During examination of material from Boyd Hill, Golden discovered capsules from the same gametophyte thallus that had produced different spore types, strongly suggesting the occurrence of hybridization among the species. Subsequently, two different spore types were found in the same clumps from the Henderson site. Schuster (op. cit. p. 820) cited several cases of intergradation that was interpreted as evidence for hybridization between sympatric species. We believe that *S. mitchlii* is a common associate of *S. texanus* in southwestern Arkansas (and probably other parts of the state) and suspect that *S. donnellii* may also occur widely in the state. It is quite possible that three different hybrids may occur in a manner similar to the three sympatric species of *Lycopodiella* and their three hybrids (Peck et al., Proc. Arkansas Acad. Sci. 41:112-113, 1987).

Occurrences of *Petalophyllum* (Fossombroniaceae) in the Interior Highlands of Arkansas

Jared W. Kyzer and Daniel L. Marsh
Department of Biology
Henderson State University
Arkadelphia, AR 71923

In 1914 the liverwort *Petalophyllum* was first found in North America in Brazos County, Texas, by Evans (1919). In 1950 Dwight Moore found a population in Union County, Arkansas (Wittlake, 1951). Wittlake (1954) observed plants at the same site the following year, but was unable to find additional populations. In 1971 Schuster and Reese found it in Lafayette Parish, Louisiana (Schuster, 1992). Schuster's 1992 publication termed it a rarity in North America, but suggested that it might be less rare than the few stations suggest. He listed it for only six sites: four counties in Texas, one in Arkansas, and one in Louisiana. The three areas are widely separated on the Gulf Coastal Plain.

An Arkansas bryophyte floristic project initiated in 1997 at Henderson State University located populations of *Petalophyllum* in eleven additional counties in Arkansas (Marsh et al., 1997). These populations were found in or around rural cemeteries and church yards, a habitat not previously known for *Petalophyllum.* One of the populations was at the edge of the Interior Highlands in Hot Spring County; the others were in the Gulf coastal Plain. During the next two collection seasons for this plant species (late October to May) the authors and Tim Golden found enough additional populations on the Gulf Coastal Plain of Arkansas, Louisiana, and Texas between the three areas known earlier to suggest a more or less continuous geographical range for the taxon.

After Kyzer noticed cemeteries in the Ouachita Mountain region of Arkansas that appeared similar to those of the Gulf Coastal Plain, he suggested a search for *Petalophyllum* in the Interior Highlands. During February and March, 1999, four populations were found in different subdivisions of the Ouachita Province. Observation of similar cemeteries in the Arkansas Valley suggests that populations are likely to be found in that geographic division also.

The northernmost populations found were in the Fourche Mountains subdivision in Perry County. *Kyzer 046* was found on February 6 at Nimrod Cemetery in the valley of the Fourche La Fave River just south of an upland escarpment. *Kyzer 058* was found on March 27 near Hollis in the Goat Bluff Cemetery just north of the South Fourche La Fave River. It is 10.5 km overland SSE of the Nimrod site. A series of high ridges separates the two sites.

Two populations were found in the Mazarn Basin of the Central Ouachita Subdivision. *Kyzer 052* was found on February 20 in Montgomery County at Old Mt. Tabor Cemetery east of Welsh off U.S. 70. Although it is in the Mazarn Basin according to generalized maps, it is drained by Little Sugarloaf Creek, a tributary of the Caddo River. *Kyzer 056*, found on March 20 in Garland County east of Meyers at Cross Roads Cemetery, is in the drainage valley of Meyers Creek, a tributary of Mazarn Creek.

Another subdivision of the Ouachita Mountains, the Athens Piedmont Plateau, is represented by the population reported by Marsh et al. (1997) just north of the "fall line" boundary between the Interior Highlands and the Gulf Coastal Plain. Additional locations in other subdivisions of the Interior Highlands seem likely.

All voucher specimens cited were deposited in the Henderson State University Herbarium (HEND); duplicate specimens with mature sporophytes were sent to the bryological team at Southern Illinois University for their monographic study of the Fossombroniineae.

All the *Petalophyllum* populations we found in the Interior Highlands are in grassy cemeteries associated with key indicator species: *Asterella tenella, Fossombronia foveolata* and other species of *Fossombronia, Ophioglossum crotalophoroides,* and *O. nudicaule.* Other associates are various grasses, mosses, and often common species of *Hedyotis.* One frequent associate of *Petalophyllum* on the Gulf Coastal Plain is *Lepuropetalon spathulatum.* This species was abundant at the Old Mt. Tabor site in Montgomery County, but was not found at the other Interior Highlands sites.

Human cultural features such as rural cemeteries provide similar habitats in different natural divisions of the landscape and consequently may offer opportunities for geographic expansion of species adapted for such habitats. *Petalophyllum* and other small plants may be easily overlooked anywhere because they are often nearly hidden among the grasses with which they grow. They are even more likely to be overlooked in geographic areas where they are unexpected. It seems likely that other small plants of the Gulf Coastal Plain may be found in similar habitats of the Interior Highlands.

In the above report we have deliberately avoided identifying the species of the American *Petalophyllum.* It has been treated as conspecific with a European species, first as *P. lamellatum* (Nees) Lindb. (Evans, 1919; Frye and Clark, 1937). Frye and Clark (1947) corrected their nomenclature to *P. ralfsii* (Wils.) Nees & Gottsche ex Lehm., but Wittlake (1951, 1954) continued to use the binomial *P. lamellatum.* Schuster's (1992) treatment of American populations as *P. ralfsii* was followed by Marsh et al. (1997). Based on photographs of *P. ralfsii* from Wales (the type area of the European species) and its very different ecology, Marsh is strongly inclined to think the American populations do not belong in *P. ralfsii.* The bryological group at Southern Illinois University is now comparing Arkansas and Texas material with plants obtained from Europe, and they have indicated tentative agreement with Marsh's position (personal communication). In addition, they find that variation in the Arkansas populations suggests that more than one taxonomic entity may be present within American *Petalophyllum.*

Literature Cited

Evans, A.W. 1919. Notes on North American Hepaticae. 8. Bryologist 22:54-73.

Frye, T.C. and **L. Clark.** 1937-47. Hepaticae of North America. Univ. Wash. Publ. Biol. 6(1-5):1-1018.

Marsh, D.L., T.A. Golden, D.L. McDaniel, G.A. Nunley, and **W.D. Crank.** 1997. New records for the distribution of an unusual liverwort, *Petalophyllum ralfsii* (Fossombroniaceae). J. Arkansas Acad. Sci. 51:204.

Schuster, R.M. 1992. The Hepaticae and Anthocerotae of North America. Vol. 6. Field Museum of Natural History, Chicago, xvii + 937 pp.

Wittlake, E.B. 1951. A new record for *Petalophyllum lamellatum* (Nees.) Lindb. Bryologist 54:76.

Wittlake, E.B. 1954. The Hepaticae of Arkansas. I. Bryologist 57:7-18.

Synthesis and molecular structure of [CpRu(PPh_3) (pms)$_2$]1OTf1• 3/4 $C_2H_4C1_2$

Paul M. Nave*, M. Draganjac
Department of Chemistry and Physics
Arkansas State University
State University, AR 72467

A. W. Cordes, Tosha M. Barclay
Department of Chemistry and Biochemistry
University of Arkansas
Fayetteville, AR 72701

*Corresponding Author

The cyclooligomerization of thietane in the presence of metal carbonyl clusters to yield cyclothioethers has been demonstrated by Adams and coworkers (Adams and Falloon, 1995). The reaction of the cyclothioethers, 1,3-dithiane and 1,4-dithiane, on a single metal species was investigated by Sabo-Etienne, Chaudret, and coworkers, using the Cp^*Ru^+ moiety (Rondon, et al., 1994). In this paper, we report the synthesis and molecular structure of the [CpRu (PPh_3) (pms)$_2$] OTf1• 3/4 $C_2H_4Cl_2$, continuing our studies of the coordination of sulfur donor ligands to $CpRu(PPh_3)_2^+$.

Syntheses were carried out under a dry nitrogen atmosphere using Schlenk techniques. All other reagents were used as purchased without further purification.

For the synthesis of [CpRu(PPh_3) (pms)$_2$]OTf1• 3/4 $C_2H_4Cl_2$, I, a 0.0506 g (0.0744 mmol) sample of (CpRu(PPh_3) (tht)$_2$]OTfl was dissolved in 3 mL of 1,2-dichloroethane. A large excess (1 mL) of pentamethylene sulfide was added and the solution stirred under nitrogen for 5 days. The mixture was evaporated under a stream of nitrogen and the solid, yellow residue was recrystallized from 1,2-dichloroethane. The product was washed with hexane and dried. Yield = 0.0364 g, 57.1%.

[CpRu(PPh_3) (tht)$_2$]OTf1 was prepared from [CpRu(PPh_3)$_2$(tht)] OTFl (Jiang, et al., 1996) by dissolving approx. 1.0 g (1.1 mmol) of [CpRu(PPh_3)$_2$(tht)]OTfl in 20 mL of tetrahydrothiophene, THT. The mixture was refluxed for 2.5 hr. Upon cooling, [CpRu(PPh_3)(tht)$_2$]OTfl precipitated from solution. The yellow product was filtered, washed with 50:50 hexane:CH_2Cl_2 solution and dried. Yield = 0.5678 g, 46.1%.

The X-Ray structure analysis of [CpRu(PPh_3)(pms)$_2$]OTf1• 3/4 $C_2H_4Cl_2$, I, is described below. A crystal of I (isolated from the reaction flask) was mounted in a glass capillary. The crystallographic data are given in Table 1. Data were collected at ambient temperature on an Enraf-Nonius CAD-4 diffractometer using MoKα (λ=0.71073 Å) graphite-monochromated radiation. A total of 6884 unique reflections was collected using the e-2e scan technique to a maximum 2e value of 50°. Absorption corrections were made using psi scans data from three reflections. The instrument factor p in the weighting expression $W^{-1} = [0^2(I) + pI^2] /4F^2$ was 0.05.

The structure was solved by the Patterson method and refined by full matrix least-squares. All programs used for the solution and refinement were those of the NRC386 (PC version of NRCVAX) package (Gabe, et al., 1989). All non-H atoms were refined with anisotropic displacement parameters except the C atoms of the solvate molecule. H atoms were constrained to idealized positions (C-H = 0.95 Å) with isotropic thermal parameters U equal to 0.01 plus the U of the attached C atom. The solvate molecule was modeled at 0.75 occupancy. The maximum shift for the last cycle of full-matrix least-squares was 0.00 sigma.

Final atomic coordinates and equivalent thermal parameters for the non-hydrogen atoms are given in Table 2. Selected bond distances and angles are given in Table 3.

Dissolution of $CpRu(PPh_3)(tht)_2^+$ in PMS/1,2-dichloroethane with stirring yields the compound [CpRu(PPh_3) (pms)$_2$]OTf1• 3/4 $C_2H_4Cl_2$, I. The structure of I is seen in Fig. 1. The Ru-S distances of 2.363(2) and 2.362(2)Å in I are comparable to the Ru-S distances of 2.365(3)Å in (CpRu(PPh_3)$_2$(pms)]OTf1. These distances are slightly longer than the Ru-S distance of 2.3459(20)Å in the thietane complex, (CpRu(PPh_3)$_2$ (SC_3H_6)]$S0_3CF_3$ (Park et al., 1994). In the Os-octaethylporphyrin complexes,

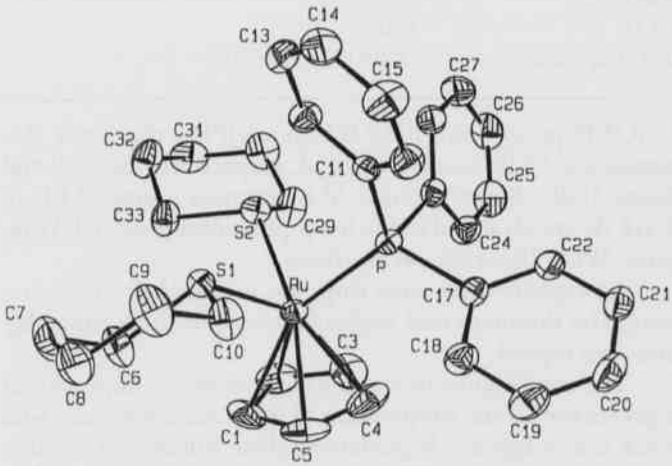


Fig. 1 ORTEP plot of the cation of I (30% probability ellipsoids) showing atom labeling scheme. Hydrogen atoms are omitted for clarity.

Table 1. Crystal and Refinement Data for $[CpRu(PPh_3)(pms)_2]OTf1 \cdot 3/4\ C_2H_4Cl2$.

formula	$RuPS_3F_3O_3C_{35.5}H_{43}Cl_{1.5}$
fw	856.12
size, mm	0.10, 0.22, 0.48
a, Å	11.033(4)
b, Å	11.4395(18)
c, Å	16.582(2)
α, deg	75.858(13)
β, deg	81.48(2)
γ, deg	75.960(18)
V, Å	1960.1(8)
2θ for cell	16-19
d_{cal}, gcm^{-3}	1.45
space group	$P\bar{1}$
Z	2
F000	877.7
abs coef, mm^{-1}	0.73
2θ max, deg	50
h, k, l ranges	0, 13 -13, 13 -19, 19
std refl	-4, 0, -3 -3, 2, -2 -2, -3, 3
stds drift, %	1.1
absorp range	0.87 - 1.00
refl meas	7278
unique refls	6884
R for merge	0.022
I>3σ(I) data	3758
parameters	432
$R(F^2)$	0.052
$Rw(F^2)$	0.072
GOF	1.10
diff map, $eÅ^{-3}$	-0.36(107), 0.76(10)

$Os(OEP)(pms)_2$ and $[Os(OEP)(pms)_2]PF_6$, the Os-S distances are 2.352(2) and 2.382(2)Å, respectively (Scheidt and Nasri, 1995). Slightly longer M-S distances (range: 2.401 to 2.418 Å) are observed in the tris-μ-pms compound, Cl_3W (u-pms)$_3WCl_3$ (Boorman et al., 1998).

As expected, the pms rings are in the chair configuration. The distances and angles (Table 3) in these sulfur ligands are typical.

The significance of complex I may prove important as a precursor for the preparation of other Ru complexes with weak donor ligands. If pentamethylene sulfide can displace tht from the $CpRu(PPh_3)(tht)_2^+$ moiety, similar substitutions using $(CpRu(PPh_3)(pms)_2]OTf1$ should be possible.

ACKNOWLEDGMENTS.—Funding for $RuCl_3$ was provided by the A.S.U. Faculty Research Committee and

Table 2. Atomic Parameters (x, y, z) and Beq for $[CpRu(PPh_3)(pms)_2]OTfl \cdot 3/4\ C_2H_4C1_2$. E.S.D.'s refer to the last digit printed.

	x	y	z	Biso/Beq
Ru	0.05056 (6)	0.29895 (6)	0.22157 (4)	2.93 (3)
P	0.01141 (19)	0.18333 (17)	0.13496 (13)	2.85 (9)
S1	−0.02942 (19)	0.17440 (18)	0.34380 (13)	3.26 (9)
S2	0.24444 (19)	0.15705 (19)	0.24074 (14)	3.53 (10)
S3	0.5117 (3)	0.5185 (3)	0.2728 (2)	5.70 (15)
F1	0.5368 (11)	0.7403 (9)	0.2686 (7)	12.6 (7)
F2	0.3920 (11)	0.7360 (9)	0.2050 (7)	13.6 (7)
F3	0.3739 (12)	0.6966 (9)	0.3349 (7)	15.5 (8)
O1	0.4090 (10)	0.4698 (11)	0.2698 (8)	12.2 (8)
O2	0.5710 (11)	0.4738 (10)	0.3458 (7)	11.5 (7)
O3	0.5947 (12)	0.5257 (10)	0.2012 (8)	13.8 (8)
C1	0.0190 (13)	0.4714 (8)	0.2684 (7)	6.0 (6)
C2	0.1260 (10)	0.4639 (8)	0.2153 (9)	5.7 (6)
C3	0.0965 (14)	0.4651 (9)	0.1364 (8)	6.5 (7)
C4	−0.0262 (14)	0.4701 (9)	0.1395 (10)	6.7 (7)
C5	−0.0816 (10)	0.4753 (8)	0.2198 (10)	6.1 (7)
C6	−0.0488 (10)	0.2512 (10)	0.4297 (6)	5.5 (6)
C7	−0.1124 (12)	0.1815 (11)	0.5092 (6)	6.6 (7)
C8	−0.2446 (10)	0.1776 (10)	0.4962 (6)	5.8 (6)
C9	−0.2506 (11)	0.1140 (12)	0.4266 (7)	6.6 (7)
C10	−0.1948 (8)	0.1790 (9)	0.3432 (6)	4.7 (5)
C11	−0.0221 (7)	0.0289 (6)	0.1805 (5)	2.8 (3)
C12	0.0591 (8)	−0.0561 (8)	0.2346 (6)	4.0 (4)
C13	0.0330 (10)	−0.1719 (8)	0.2715 (6)	4.9 (5)
C14	−0.0729 (11)	−0.2011 (8)	0.2558 (7)	5.4 (6)
C15	−0.1525 (10)	−0.1181 (9)	0.2033 (7)	5.4 (5)
C16	−0.1276 (9)	−0.0053 (8)	0.1657 (6)	4.3 (4)
C17	−0.1179 (8)	0.2537 (7)	0.0682 (5)	3.3 (4)
C18	−0.2283 (8)	0.3209 (8)	0.1011 (6)	4.4 (4)
C19	−0.3311 (9)	0.3682 (9)	0.0540 (7)	5.2 (5)
C20	−0.3234 (10)	0.3473 (9)	−0.0249 (7)	5.0 (5)
C21	−0.2128 (9)	0.2820 (8)	−0.0584 (5)	4.1 (4)
C22	−0.1105 (8)	0.2346 (7)	−0.0118 (5)	3.7 (4)
C23	0.1442 (8)	0.1548 (7)	0.0577 (5)	3.3 (4)
C24	0.1787 (9)	0.2552 (8)	0.0017 (5)	4.4 (4)
C25	0.2883 (10)	0.2421 (10)	−0.0542 (6)	5.4 (5)
C26	0.3605 (9)	0.1267 (11)	−0.0553 (6)	5.5 (6)
C27	0.3269 (9)	0.0254 (9)	−0.0009 (7)	5.2 (5)
C28	0.2194 (8)	0.0396 (8)	0.0543 (5)	3.9 (4)
C29	0.3722 (9)	0.2100 (11)	0.1719 (6)	5.7 (6)
C30	0.4966 (9)	0.1212 (11)	0.1917 (7)	5.7 (6)
C31	0.5293 (9)	0.1135 (10)	0.2790 (8)	6.0 (6)
C32	0.4305 (9)	0.0713 (11)	0.3456 (6)	5.8 (6)
C33	0.3019 (8)	0.1565 (10)	0.3370 (6)	5.0 (5)
C34	0.4441 (14)	0.6778 (14)	0.2716 (8)	7.7 (8)
C11	0.1566 (4)	0.4619 (5)	0.4866 (4)	10.2 (3)
C12	0.3285 (6)	0.1894 (4)	0.5525 (3)	9.6 (3)
C35	0.3057 (17)	0.4317 (17)	0.5133 (11)	8.0 (4)
C36	0.3786 (20)	0.3174 (20)	0.5174 (13)	9.5 (5)

Beq is the Mean of the Principal Axes of the Thermal Ellipsoid

Table 3. Selected Bond Distances and Angles for [CpRu (PPh_3) (pms)$_2$]OTF1• 3/4 $C_2H_4C1_2$.

Distances (Å)		Angles (°)	
Ru-P	2.321 (2)	P-Ru-S1	93.27 (7)
Ru-S1	2.363 (2)	P-Ru-S2	87.47 (8)
Ru-S2	2.362 (2)	S1-Ru-S2	86.26 (8)
Ru-C1	2.224 (9)	Ru-S1-C6	109.1 (4)
Ru-C2	2.215 (9)	Ru-S1-C10	112.2 (3)
Ru-C3	2.193 (9)	C6-S1-C10	95.9 (5)
Ru-C4	2.154 (10)	Ru-S2-C29	112.5 (4)
Ru-C5	2.180 (9)	Ru-S2-C33	111.0 (3)
S1-C6	1.811 (9)	C29-S2-C33	96.7 (5)
S1-C10	1.813 (9)	S1-C6-C7	111.9 (7)
S2-C29	1.805 (10)	C6-C7-C8	110.9 (9)
S2-C33	1.802 (9)	C7-C8-C9	113.9 (8)
C6-C7	1.533 (15)	C8-C9-C10	111.2 (9)
C7-C8	1.517 (18)	S1-C10-C9	112.1 (7)
C8-C9	1.524 (16)	S2-C29-C30	110.6 (7)
C9-C10	1.521 (14)	C29-C30-C31	112.6 (9)
C29-C30	1.522 (15)	C30-C31-C32	112.0 (8)
C30-C31	1.519 (16)	C31-C32-C33	113.1 (9)
C31-C32	1.509 (15)	S2-C33-C32	110.3 (7)
C32-C33	1.518 (13)		

Competitive Applied Research Grant. We thank Mrs. Betty Pulford for assistance in the manuscript preparation.

Supplementary Material Available

Hydrogen atomic coordinates and isotropic thermal parameters (Table 4S), anisotropic displacement parameters (Table 5S), bond distances and angles (Table 6S), least-square planes (Table 7S), observed and calculated structure factors (Table 8S, 35 pages) are available from the authors upon request.

Literature Cited

Adams, R. D. and **S. B. Falloon.** 1995. The chemistry of thietane ligands in polynuclear metal carbonyl complexes. Chem. Rev. 95:2587-2598.

Boorman, P. M., N. L. Langdon, V. J. Mozol, M. Parvez and **G. P. A. Yap.** 1998. Syntheses, crystal structures, spectroscopic characterization, and electrochemical studies of the ditungsten(III) complexes $Cl_3W(\mu\text{-}L)_3WCl_3$ and $[Cl_3W(\mu\text{-}L)_2(\mu\text{-}Cl)WCl_3]^-$ (L=1,4-dithiane, 1,4-thioxane, pms = pentamethylene sulfide). C-S bond cleavage of the bridging thioether(s) in $Cl_3W(\mu\text{-}L)_3WCl_3$. Inorg. Chem. 37:6023-6029

Gabe, E. J., Y. LePage, J. P. Charland, F. L. Lee, and **P. S. White.** 1989. NRCVAX-an interactive program system for structure analysis. J. Appl. Cryst. 22:384-387.

Jiang, Y., M. Draganjac, and **A. W. Cordes.** 1996. Molecular structure of $[CpRu(PPh_3)_2(tht)]BF_4$, tht = tetrahydrothiophene. J. Cryst. Chem. 26:657-660.

Park, H., M. Draganjac, S. R. Scott, A. W. Cordes, and **G. Eggleton.** 1994. The reaction of $CpRu(PPh_3)_2^+$ with trimethylenesulfide. Synthesis and molecular and crystal structure of $[CpRu(PPh_3)_2(SC_3H_6)]CF_3SO_3$. Inorg. Chim. Acta 221:157-160.

Rondon, D., J. Delbeau, X.-D. He, S. Sabo-Etienne, and **B. Chaudret.** 1994. Activation of carbon-sulfur and carbonchlorine bonds by the electrophilic ruthenium fragment `$Ru(\eta\text{-}C_5Me_5)^+$'. J. Chem. Soc., Dalton Trans. 1895-1901.

Scheidt, W. R. and **H. Nasri.** 1995. Synthesis and molecular structures of the redox pair (octaethylporphinato) bis (pentamethylene sulfide) osmium(II) and (octaethylporphinato)bis(pentamethylene sulfide)osmium(III) hexafluorophosphate. Inorg. Chem. 34:2190-2193.

Evaluation of Three Types of Forest Openings as Habitat for Wild Turkeys

Thomas A. Nelson
Department of Biological Sciences,
Eastern Illinois University, Charleston, IL 61920

The eastern wild turkey (*Meleagri gallopavo silvestris*) is common throughout the Ozark National Forest and is an important species to sportsmen and wildlife enthusiasts. The Land and Resources Management Plan (LRMP) for the forest suggests the importance of the species by proposing it as the "featured species" on 37% of the forest (USDA Forest Service, 1986). Management guidelines outlined in the LRMP include establishment of "four well-distributed 1 to 5-A openings per 640-A habitat unit" with "improved wildlife forage species on at least one opening per habitat unit, where natural forage is inadequate". Provision of wildlife openings in a manner consistent with these guidelines has required considerable capital expenditure by the USDA Forest Service over the 10-year period covered by the LRMP.

Provision of forest openings to improve turkey habitat has long been advocated (Stoddard, 1935; Holbrook and Lewis, 1967; Shaffer and Gwynn, 1967). Openings are of particular importance to poults during summer providing relatively high concentrations of insects and seeds required for growth (Martin and McGinnes, 1975). The types of openings provided for turkeys on public and private forests may vary however from clearcuts, to openings maintained in native herbaceous cover, to food plots planted in grasses or grass-legume mixes. Relative costs involved in establishing and maintaining each type of opening vary considerably. Further, few data are available to assess the relative values of openings for meeting the needs of turkeys and other wildlife species (Hurst, 1978; Krusac and Michael, 1979; Healy and Nenno, 1983).

No studies of this type have been conducted in the Ozarks. The objectives of this study were to (1) assess the relative amounts of herbaceous biomass, preferred seeds, and insects provided during the summer by each of 3 types of forest openings used on the Ozark National Forest, (2) investigate the extent to which turkeys use each type of opening, and (3) compare the relative costs of providing openings by each method.

Study Areas.--The 9 openings selected for this study are located in the Pleasant Hills District of the Ozark National Forest in Johnson Co., AR. Regional topography varies from rolling hills to steep mountains, but the study sites were on relatively flat ridge tops and benches. Soils are loamy and stony at the surface, moderately erodible, and better suited to forest management than more intensive uses. These soils are rated from good to fair for production of native herbaceous plants and fair to poor for production of cultivated grasses and legumes (Garner et al., 1977).

Forests are dominated by white oak (*Quercus alba*), black oak (*Q. velutin*), southern red oak (*Q. falcata*), various hickories (*Carya* spp.), and shortleaf pine (*Pinus echinata*) on upland sites. Ground cover tends to be sparse with lowbush blueberry (*Vaccinium pallidum),* poison ivy (*Toxicodendron radicans*) and greenbriers (*Smilax* spp.) sometimes forming thick cover (Pell, 1984). Common species that invade clearings after disturbance include goldenrods (*Solidago* spp.), beggarweeds (*Desmodium* spp.), ragweed (*Ambrosi* spp.), blackberries (*Rubus* spp.), and persimmon (*Diospyros virginiana*).

Wild turkeys were common throughout the study area. Local population densities varied with quality of habitat, but approximated 6 birds/km^2 (USDA Forest Service, 1980). Populations have increased dramatically during the past 20 years in part due to a successful trap-transplant program conducted by the Arkansas Game and Fish Commission.

To compare the amounts of seeds and invertebrates produced in different types of forest openings, we selected 9 openings for study. These included 3 clearcuts, 3 cultivated food plots, and 3 openings created by using herbicide to kill trees (hereafter called herbicide openings). All openings were within 15 km of each other, with similar site index, age, topography, and turkey density. Clearcuts were 5-8 ha in size and were 1-2 years old when sampled; slash had been left on each site, and no site preparation had occurred prior to sampling. Food plots were 1 ha in size and had been disked, seeded, and fertilized in September of the previous year. The seed mix included wheat, ryegrass, ladino clover, and orchard grass. Food plots were fertilized with 1400 kg/ha (250 lbs/A) of 12-24-12 fertilizer. Herbicide openings were 1 ha in size and had been created 2 years prior to the study using hexazinone (Velpar L liquid) applied at a rate of 19L/ha (2 gal/A). The herbicide had been applied in May by a biologist using a backpack sprayer and had resulted in a nearly complete root-kill of woody vegetation. Hexazinone is commonly applied in the spring to facilitate root absorption when more rainfall is expected (Brooks et al., 1992).

Sampling.--Total herbaceous biomass and the biomass of preferred seeds were measured in each opening during the first 2 weeks of June. Herbaceous biomass was estimated in each opening by clipping 18 randomly-selected 1-m^2 plots at ground level. Clippings were separated by species, air-dried to constant weight, and weighed. Seeds of those species known to be utilized by turkeys were stripped by hand and weighed. For purposes of this study, preferred seeds included those of wheat, ryegrass, panic grasses (*Panicum* spp.), paspalums (*Paspalum* spp.), crabgrass (*Digitaria sanguinalis*), sprangletop (*Leptochloa panicoides*), sedges (*Carex* spp.), beggarweeds, ragweeds, and lespedezas (*Lespedeza* spp.).

Invertebrates were sampled twice weekly in each opening from mid-June through August using a 40 cm-diameter sweep net. Each sample consisted of 150 sweeps conducted along three 100-m transects uniformly distributed parallel to the long axis of each opening. Samples were collected only on calm days with no precipitation. No attempt was made to sample invertebrates in the litter or soil. Invertebrates were preserved in ethyl-acetate, then counted, oven-dried, and weighed. Mean biomass and number of invertebrates per sample were used as indices of invertebrate abundance (Healy and Nenno, 1983).

The relative use of each opening by turkeys was estimated using track plots. Tracks were counted in 1m x 2m rectangular plots established at a density of 10 plots/ha. We made track plots by removing all vegetation and litter, and raking the surface to a soft, smooth texture. Plots were inspected twice each week from June through August. The percentage of days that turkey tracks were observed in each opening was an index of use. The mean herbaceous biomass, seed biomass, and invertebrate abundance and biomass produced by each type of opening were compared using ANOVA with Tukey's mean comparison test to find differences of means. Percent use data were arcsine transformed prior to the ANOVA test. All tests were conducted at $\alpha = 0.05$.

The production of herbaceous biomass was greatest in the food plots and herbicide openings which averaged 290 and 225 g/m^2, respectively (Table 1). Herbaceous biomass was significantly lower in clearcuts ($p = 0.003$). Dense stands of wheat, ryegrass, and orchard grass were produced on two of the food plots, accounting for the majority of biomass on these sites. The third food plot was dominated by ladino clover with some orchard grass, wheat, and fescue (*Festuca* spp.). This plot was on a ridge which received little precipitation during May and June resulting in sparse stands of grasses and less herbaceous biomass than the others.

Herbicide openings were dominated by a wide variety of grasses, forbs, and woody plants including goldenrods, beggar's tick (*Bidens frondosa)*, beggarweeds, ragweed, partridge pea (*Cassia fasciculata*), pokeberry (*Phytolacca americana*), lowbush blueberry, and blackberries. Most of the plants on these sites were herbaceous annuals that had germinated and grown after the application of herbicide. These were complemented by some woody stems that had resprouted from plants which were not killed by the herbicide treatment. The vegetation in the 3 clearcuts was dominated by woody vegetation, much of it sprouts from cut stems. Herbaceous vegetation was more sparse and patchy on these sites and was dominated by native brome grasses (*Bromus* spp.) and various forbs.

Food plots generally produced the largest quantity of preferred seed and produced significantly more seed than clearcuts ($P = 0.04$; Table 1). However, seed production in the food plots was variable depending on site conditions. Production was highest in food plots #1 and #2 where wheat and orchard grass contributed greatly to total biomass. However, the food plot dominated by clover produced only sparse stands of grasses and little seed relative to the others. Consequently, although seed production was high in 2 of 3 food plots, the mean production of preferred seeds was not significantly greater in food plots compared to herbicide openings. Herbicide openings produced between 10.5 and 13.7 g/m^2 of a wide variety of preferred seeds (Table 1).

Table 1. Total herbaceous biomass, seed biomass, and invertebrate biomass produced in 3 types of forest openings on the Ozark National Forest, AR.

		Total herbaceous biomass (g/m^2)		Seed biomass (g/m^2)		Invertebrate biomass (g/transect)		Invertebrate abundance (no./transect)	
Type of Opening	N	$\bar{X}$	SE	$\bar{X}$	SE	$\bar{X}$	SE	$\bar{X}$	SE
Food Plot	3	289.7^a	25.2	51.3^a	17.9	6.0^a	2.1	354.3^a	128.7
Herbicide opening	3	225.3^a	25.1	12.3^{ab}	0.9	6.3^a	0.9	336.0^a	55.6
Clearcut	3	104.3^b	17.2	5.3^b	2.3	2.3^a	0.9	99.0^b	37.4

Means followed by different letters differ significantly at $\alpha = 0.05$.

Seed biomass as a proportion of total herbaceous biomass was greatest in the food plots where preferred seeds were approximately 18% of total biomass. In contrast, herbicide openings produced similar levels of herbaceous biomass, but seeds comprised only 5% of the total biomass. The native plants which predominated in the herbicide openings did not produce the large seeds and seedheads which are typical of the cultivated varieties of wheat and orchard grass planted in food plots.

Invertebrate abundance and biomass fluctuated dramatically between sampling periods and sites. We found no significant difference in invertebrate biomass ($P = 0.16$) or abundance ($P = 0.13$) among treatments (Table 1). However, a significant positive correlation existed between total herbaceous biomass and invertebrate biomass in the 9 plots ($r = 0.68$; $P = 0.04$). Food plots and herbicide openings with abundant vegetation generally contained abundant invertebrates. Clearcuts with their sparse patches of herbaceous vegetation typically produced only about 1/3 the abundance of invertebrates found in the other types of openings.

Eight of 9 openings were used by turkeys during this 3-month study; no evidence of turkeys was found in 1 clearcut. Food plots and herbicide openings were used more frequently than clearcuts ($P = 0.03$). Turkey tracks were found in food plots during 34% of the surveys, in herbicide openings during 33% of the surveys, and in clearcuts during 9% of the surveys. The use of openings was highly correlated with total herbaceous biomass ($r = 0.89$; $P = 0.001$), invertebrate biomass ($r = 0.87$; $P = 0.002$), and invertebrate abundance ($r = 0.89$; $P = 0.001$), but less correlated with seed biomass ($r = 0.63$; $P = 0.07$). Use of openings declined as summer progressed; most tracks and sightings of hens and poults were recorded between June 1 and July 15. By August, turkeys were rarely using any of the openings.

Numerous studies suggest that forest openings enhance turkey habitat (Stoddard, 1935 Blackburn et al., 1975; Martin and McGinnes, 1975; Pack et al., 1980). Openings provide a number of benefits to turkeys, but probably have the greatest influence on the survival and growth of young poults, particularly during the first month of life (Healy and Nenno, 1983). Openings with adequate herbaceous vegetation provide necessary food and cover during the first critical weeks when survival rates are lowest (Hurst and Stringer, 1975; Pack et al., 1980).

Seed production was particularly high in food plots planted to wheat and orchard grass when adequate precipitation was available. However, herbicide openings also produced large quantities of seeds and a broader diversity of seeds from native plants than food plots. This diversity may be beneficial to turkeys if it provides a broader range of nutrients or reduces the probability of crop failure due to weather or disease. Clearcuts provided relatively little food in the first 2 years after cutting, and the patchy distribution of herbaceous vegetation provided less protective cover for turkey broods. These results are consistent with those of a West Virginia study that concluded that unmanaged grass-forb openings provided as much food for poults as managed grass-legume food plots (Healy and Nenno, 1983).

Turkeys used forest openings more frequently when they provided abundant herbaceous vegetation and seeds. Sightings of turkeys and their tracks were common in food plots and herbicide openings. The dense stands of grasses and forbs in these openings provided the critical protective cover and foods needed by poults and adults in early summer (Pack et al., 1980). Use was most heavy in early summer coinciding with the time that broods are most dependent on forest openings for insects. Presumably the use of openings declined later in the summer as diets shifted towards more plant matter and food requirements could be met in other plant communities (Blackburn et al., 1975; Hurst and Stringer, 1975; Healy and Nenno, 1983).

Healy and Nenno (1983) recommended managing for early brood habitat by using the simplest, most cost-effective technique that maintains the herbaceous community. In the Ozarks it appears that both food plots and herbicide openings provide sufficient quantities of herbaceous biomass, preferred seeds, and invertebrates to be readily used by turkeys. However, herbicide openings provide several advantages that food plots do not. First, the cost and effort of establishing herbicide openings is less. Wildlife openings can be created using hexazinone at a cost of approximately $140/ha. The costs of planting, fertilizing, and maintaining grass-legume food plots are 6-8 times higher (G. Leeds, USDA Forest Service, pers. comm.). Second, herbicide openings can be created and maintained without heavy equipment, reducing soil disturbance and compaction. Third, food plots must be situated on roads to provide access by farm vehicles, but herbicide openings can be established away from roads, reducing disturbance (including poaching) at these sites and expanding the opportunity to create openings in optimal locations to meet management goals. Finally, herbicide openings provide a large number of snags which benefit a variety of snag-dependent and cavity-dwelling wildlife species. The abundance of woodpeckers in these openings was evident throughout the summer.

The Forest Service recently eliminated the use of hexazinone to manage vegetation on national forests. Different herbicides can dramatically alter the composition of the redeveloping plant community and shift species composition in ways that may be beneficial or detrimental to wildlife depending on their habitat requirements (Brooks et al., 1992). A study conducted in Georgia indicated that hexazinone-treated sites produced more desirable food plants for bobwhite (Colinus virginianus) and white-tailed deer (Odocoileus virginianus) than sites treated with picloram and triclopyr or imazapyr. Additional research should be conducted to assess the relative habitat value of forest openings created using alternative herbicides in the Ozarks.

While maintained openings in forested landscapes have traditionally been used to enhance habitat for many wildlife species, concerns exist that these openings may contribute to forest fragmentation and be detrimental to forest-interior species (Overcash et al., 1989). The extent to which openings contribute to forest fragmentation is influenced by their size, vegetative composition, and spatial distribution. It is not the purpose of this paper to evaluate the optimal size or distribution of managed openings. However, it is important to note that the ONF has become more heavily forested in the past 50 years due to natural succession, the planting of pines in former open habitat, fire suppression, and the acquisition of private land. Further, it is likely that open habitat will continue to decline on the ONF since the Forest Service eliminated clearcutting and replaced it with alternative harvest methods which maintain greater forest canopy. In this context, the continued maintenance of forest openings will become increasingly important as a means to enhance habitat for a wide variety of game and nongame species, and the use of suitable herbicides to create these openings appears to be a cost-effective alternative to managed food plots.

Literature Cited

Blackburn, W. E., J. P. Kirk, and **J. E. Kennamer.** 1975. Availability and utilization of summer foods by eastern wild turkey broods. Proc. Natl. Wild Turkey Symp. 3:86-96.

Brooks, J. L., A. S. Johnson, and **K. V. Miller.** 1992. Effects of chemical site preparation on wildlife habitat and plant species diversity in the Georgia Sandhills. Biennial Southern Silvicultural Research Conf. 7:605-612.

Garner, B. A., F. M. Vodrazka, W. K. Goddard, and **J. W. Venard.** 1977. Soil survey of Johnson County, Arkansas USDA Soil Conserv. Serv and Forest Serv. 82 pp.

Healy, W. M., and **E. S. Nenno.** 1983. Minimum maintenance versus intensive management of clearings for wild turkeys. Wildl. Soc. Bull. 11:113-120.

Holbrook, H. L., and **J. C. Lewis.** 1967. Management of the eastern turkey in the southern Appalachian and Cumberland Plateau Region. Pp 343-370 *In* O. H. Hewitt, ed. The wild turkey and its management. The Wildlife Society, Washington, D.C.

Hurst, G. A. 1978. Effects of controlled burning on wild turkey poult food habits. Proc. Annu. Conf. Southeast. Fish and Wildl. Agencies 32:30-37.

Hurst, G. A., and **B. D. Stringer, Jr.** 1975. Food habits of wild turkey poults in Mississippi. Proc. Natl. Wild Turkey Symp. 3:76-85.

Krusac, D. L., and **E. D. Michael.** 1979. Management of wildlife food plots: a regional comparison. Trans. Northeast Section, The Wildlife Society 36:88-96.

Martin, D. D., and **B. S. McGinnes.** 1975. Insect availability and use by turkeys in forest clearings. Proc. Natl. Wild Turkey Symp. 3:70-75.

Overcash, J. L., J. L. Roseberry, and **W. D. Klimstra.** 1989. Wildlife openings in the Shawnee National Forest and their contribution to habitat change. Trans. Illinois Acad. Sci. 82:137-142.

Pack, J. C., R. P. Burkhert, W. K. Igo, and **D. J. Pyrus.** 1980. Habitat utilization by wild turkey broods within oak-hickory forests of West Virginia. Proc. Natl. Wild Turkey Symp. 4:213.224.

Pell, W. F. 1984. Plant communities. Pp 71-96 *In* B. Shepherd, ed. Arkansas' natural heritage. August House, Little Rock, AR.

Shaffer, C. H., and **J. V. Gwynn.** 1967. Management of the eastern turkey in oak-pine and pine forests of Virginia and the Southeast. Pp 303-342 *In* O. H. Hewitt, ed. The wild turkey and its management. The Wildlife Society, Washington, D.C.

Stoddard, H. L. 1935. Wild turkey management. Trans. N. Am. Wildl. Conf. 21:326-333.

USDA Forest Service. 1986. Land resources management plan: Ozark-St. Francis National Forests. USDA Forest Serv. 97 pp.

Electron Shock Waves

Frances Terry and Mostafa Hemmati
Physical Science Department
Arkansas Tech University
Russellville, AR 72801

Electron shock waves are luminous pulses that propagate through a long discharge tube subjected to a large (20,000-40,000 volts) potential pulse. A dramatic, natural example of shock (or breakdown) waves can be seen in lightening. Though this example has been observed for centuries, little scientific study of the phenomenon had been recorded until the late 19th century. Early experimental work supplied information that led to an approximation of wave speed and a probable mode of propagation. Through subsequent investivations, an approximate mathematical model was developed. This model has been refined to the point that it can now be applied to correctly model breakdown wave characteristics such as wave speed, electron temperature, electron number density, and electric field strength distributions inside the wave.

J. J. Thompson (1893) reported the first observation of waves propagating down the length of a discharge tube. Using a rotating beam arrangement, Thompson was able to determine a propagation velocity of about one-half the speed of light for waves propagating down a 15 meter long discharge tube. Thompson also noticed an absence of Doppler effect in the emitted light.

Using an apparatus similar to that of Thompson, Beams (1930) was able to confirm the approximate wave speed determined by Thompson. Beams went on to repeat the experiment and, by varying discharge tube parameters, found that the wave velocity increased with increasing pressure (to about three Torr), diameter of the tube, discharge potential and displacement down the tube. Beams also found that the breakdown waves travel from the discharge electrode to ground regardless of potential polarity. Along with this discovery, a nomenclature for the wave direction developed. Proforce waves refer to waves that have a velocity in the same direction as the electric field force. Antiforce waves refer to the opposite case. As well as his experimental findings, Beams proposed a qualitative explanation of the wave propagation. He explained that in the neighborhood of the discharge electrode, a strong electric field causes intense ionization. Due to higher mobility electrons, a space charge is formed in the ionized gas. This space charge reduces the net electric field in that region and is pushed down the discharge tube regardless of applied potential polarity. The ionized gas left behind is conductive and carries the potential of the discharge electrode. Therefore, the intense ionization, and consequently the luminosity, propagates down the discharge tube. This mode of propagation is still accepted by current researchers.

Like Thompson and other observers, Shelton and Fowler (1968) detected no Doppler effect in the spectral lines of the emitted light, showing that the atoms that are emitting the light are not accelerating. Since there is no heavy particle acceleration, Shelton and Fowler stated that the phenomenon was due to electron fluid action, and a better name for the propagating waves would be 'Electron Fluid Dynamical Waves'.

In an attempt to develop a theoretical model for the breakdown waves, Paxton and Fowler (1962) developed a three-component, one-dimensional, steady state fluid model to describe the phenomena. Considering no heavy particle (ions and neutral atoms) acceleration, a zero current condition and a heavy shock at the front of the wave, a successful set of equations has been found. The three fluid equations coupled with Poisson's equation and written for proforce waves with modifications by Fowler et al. (1984) are

$$\frac{dE}{dx} = \frac{e}{\varepsilon_o} n\left(\frac{v}{V} - 1\right),$$

$$\frac{d(nv)}{dx} = \beta n$$

$$\frac{d}{dx}\left[mnv(v - V) + nkT_e\right] = -enE - Kmn(v - V),$$

and

$$\frac{d}{dx}\left[mnv(v - V)^2 + nkT_e(5v - 2V) + 2e\phi_i nv - \frac{5nk^2T_e}{mK}\frac{dT_e}{dx}\right] = -3\frac{m}{M}nkKT_e - \frac{m}{M}Kmn(v - V)^2$$

where the variables are electron mass m, neutral particle mass M, wave velocity V, ionization potential ϕ, electric field E, electron temperature T_e, electron concentration n, electron velocity v, position inside the wave profile x, ionization frequency β, and elastic collision frequency K.

To reduce the set of electron fluid dynamical equations to nondimensional form, Shelton (1968) introduced a set of dimensionless variables. This set with modifications by Fowler et al. (1984) is:

$$\nu = \frac{2e\phi_i}{\varepsilon_0 E_0^{\,2}} n, \quad \psi = \frac{v}{V}, \quad \theta = \frac{kT_e}{2e\phi}, \quad \eta = \frac{E}{E_0}, \quad \xi = \frac{eE_0}{mV^2} x, \quad \mu = \frac{\beta}{\kappa}, \quad \alpha = \frac{2e\phi_i}{mV^2}, \quad \kappa = \frac{mVK}{eE_o}$$

In the above set of dimensionless variable equations, the variables υ, ψ, θ, η, κ, and ξ represent electron density, electron velocity, electron temperature, electric field strength, ionization rate, elastic collision frequency, and position inside the wave, respectively. The equation set for proforce waves is written as

$$\frac{d}{d\xi}(\nu\psi) = \kappa\mu\nu$$

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

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

$$\frac{d\eta}{d\xi} = \frac{\nu}{\alpha}(\psi-1)$$

with variables defined as above.

Hemmati et al. (1998) and more recently Hemmati and George (1999) have succeeded in integrating this set of nondimensional fluid equations through the dynamical transition region for a wide range of wave speeds with results that conform to the boundary conditions and are consistent with observed experimental results for those wave speeds measured by Blais and Fowler (1973) and Uman (1993).

Recent work in the field of ionization waves by A. N. Lagarkov and I. M. Rutkevich (1993) of the former Soviet Union, has been found to correlate well with the work discussed to this point. Lagarkov and Rutkevich have performed experimental and theoretical investigations of ionizing waves in a variety of tube geometries with shielded and unshielded tubes. Though in their publications the same basic concepts have been used, some of the theoretical derivations and variables differ from those of this work. It is hoped that investigation of their recent experimental work will help to further the success of the fluid model being developed by the Arkansas Tech University group.

ACKNOWLEDGMENTS.—The authors would like to express their gratitude to the Scientific Information Liaison Office for their financial support of this research project.

Literature Cited

Beams, J. W. 1930. Propagation of luminosity in discharge tubes. Physical Review. 36:998-1001.

Blais, R. N. and **R. G. Fowler**. 1973. Phys. Fluids, 16:2149.

Fowler, R. G., M. Hemmati, R. P. Scoff and S. Parsenahadh. 1984. Electric breakdown waves: Exact numerical solutions. Part1. Phys. Fluids. 27:1521-1526.

Hemmati, M., S. Doss and E. George. 1998. Speed Cut-off for antiforce waves. J. Arkansas Acad. Sci. 52:63-66.

Hemmati, M., E. George and **F. Terry.** 1999. Speed Rrange for breakdown waves. J. Arkansas Acad. Sci. 53:80-82.

Lagarkov, A. N. and **I. M. Rutkevich.** 1994. Ionization waves in electrical breakdown of gases. New York. Springer-Verlag.

Paxton, G. W. and **R. G. Fowler**. 1962. Theory of breakdown wave propagation. Physical Review. 128:993-997.

Shelton, G. A. 1968. Ph.D. dissertation, University of Oklahoma, Norman.

Shelton, G. A. and **R. G. Fowler.** 1968. Nature of electron-fluid dynamical waves. Phys. Fluids. 11:740-746.

Thompson, J. J. 1893. Recent researches in electricity and magnetism. Oxford Univ. Press, New York, 115 pp.

Uman, M. A. 1993. Natural Lightning. Proc. IEEE Industrial and Commercial Power Systems Technical Conference. Vol. 93ch3255-7 pp. 1-7.

The First Report of *Lampetra appendix* (DeKay) from the Black River Drainage of Arkansas

Daniel D. Ward, Denver Dunn, Hilary Worley, Martin Ruane, Vernon Hoffman, Grace Troutman and Stanley E. Trauth
Department of Biological Sciences
Arkansas State University
State University, AR 72467

The American Brook lamprey, *Lampetra appendix* (DeKay), is a non-parasitic agnathan that occurs throughout the eastern United States and Canada from the Mississippi River drainage to the Great Lakes and in several Atlantic slope drainages (Seagle and Nagel, 1982). Arkansas specimens have only been found in the White and Ouachita River drainages (Harp and Matthews, 1975; Robison and Buchanan, 1992; Tumlison and Tumlison, 1999). On 13 February 1999, one adult specimen of *L. appendix* (total length 156 mm) was collected by seine from Jane's Creek, 6 km N Ravenden Springs (Sec 19, T20N, R2W), Randolph County, Arkansas, a tributary of the Black River drainage system. Fowler and Harp (1974) described Jane's Creek as a clear, spring-fed Ozark stream with high alkalinity and dissolved oxygen, low carbon dioxide, and a constant pH of 7.8-8.2. Pflieger (1975) reported one locality of *L. appendix* in the Black River system in Missouri. Our identification was confirmed by George L. Harp, Arkansas State University, and Henry W. Robison (pers. comm.), Southern Arkansas University, verified this find as a new record for the Black River drainage in Arkansas. The specimen was deposited in the Arkansas State University Museum of Zoology (ASUMZ 12919). The authors thank Dr. G.L. Harp, who confirmed the specimen; Dr. H. W. Robison provided distribution records, and Daniel Dye aided in collection.

Literature Cited

Fowler, C. L., and G. L. Harp. 1974. Ichthyofaunal diversification and distribution in Jane's Creek watershed, Randolph County, Arkansas. Proc. Arkansas Acad. Sci. 28:13-18.

Harp, G. L. and W. J. Matthews. 1975. First Arkansas records of *Lampetra* spp. (Petromyzontidae). Southwest. Nat. 20:414-416.

Pflieger, W. L. 1975. The fishes of Missouri. Missouri Dept. of Conservation, Jefferson City. 343 pp.

Robison, H. W., and T. M. Buchanan. 1988. Fishes of Arkansas. The University of Arkansas Press, Fayetteville. 536 pp.

Seagle, H. H., and J. W. Nagel. 1982. Life cycle and fecundity of the American brook lamprey, *Lampetra appendix*, in Tennessee. Copeia 1982:362-366.

Tumlison, R., and C. Tumlison. 1999. An extralimital population of *Lampetra appendix* (Petromyzontidae) in southwestern Arkansas. Southwest. Nat. (in press).

Recent Documentation of Mountain Lion (*Puma concolor*) in Arkansas

Theo Witsell, Gary A. Heidt*, Parker L. Dozhier, Tom Frothingham, and Mark Lynn
Department of Biology
University of Arkansas at Little Rock
Little Rock, AR 72204 and Hot Springs, AR (PLD)

*Corresponding Author

Sealander and Gipson (1973) stated that the mountain lion (*Puma concolor*) was probably never extirpated in Arkansas, and that populations may be expanding with the growing white-tailed deer (*Odocoileus virginiana*) herd. Because of persistent reports of mountain lion sightings and vocalizations, the Arkansas Game and Fish Commission conducted a field search (1988-89), led by an qualified lion hunter/tracker, for evidence of mountain lions in Arkansas. This study suggested "there are no wild, reproducing populations of mountain lions in Arkansas" (McBride et al., 1993).

Herein we report five localities in which hard evidence of mountain lions was found in late 1998 and early 1999 by the authors. Evidence can be assigned to one of two categories: soft or hard evidence. Soft evidence is that evidence which cannot be documented for future reference, such as sight/vocalization reports that are not accompanied by tracks, scat, photographs, audio/video recordings, or other documentable evidence. All hard evidence (scat, plaster casts, photographs) was deposited in the vertebrate collections at the University of Arkansas at Little Rock.

On 1 October, 1998 one of the authors (PLD) found a 45 cm long scat in a stone quarry near Magnet Cove, Hot Spring County (T3S R17W S28). In November 1998, a second scat (33 cm long) was found in a quarry near Lonsdale, Garland County (T2S, R17W, S18). On 31 December 1998, T. Witsell and C. Tracey found a 30 cm scat at an elevation of 268 m on a steep rock outcrop on the south-facing slope of the western-most peak of the Maumelle Pinnacles (T3N, R14W, S31) in western Pulaski County. The scat consisted almost entirely of white-tailed deer hair and bone fragments. A second scat was found 19 February 1999 by Witsell at an elevation of 177 m on the south-facing slope of Buzzard Mountain (T2N, R15W, S21), Pulaski County, along an old logging road. Mountain lion scat is usually deposited in large amounts and varies from masses to irregular shapes. The scat contains hair and possibly bone fragments from the animal's prey (Rezendes, 1992).

Also on 19 February 1999, further down Buzzard Mountain, at an elevation of 145 m, along the same road, a set of approximately 15 tracks were found under a high voltage power line. The front prints measured 12 cm long by 11 cm wide. The hind prints measured 10 cm wide by 10 cm long. The stride was 56 cm. Plaster casts and photographs were made from the prints. Mountain lion tracks are typical of cats in general, with four toes on both the front and hind feet. Tracks are wider than long and the claws are not observed. Typical front tracks measure approximately 7-11 cm long by 9-12 cm wide; hind tracks are slightly smaller 5-7 cm long by 6-8 cm wide. The animal's stride is 50-80 cm (Rezendes, 1992).

A fresh white-tailed deer kill was found 27 February, 1999 by T. Frothingham along Nowlin Creek (T2N, R14W, S6), Pulaski County at an elevation of 90 m. Though the carcass had been scattered by dogs, drag marks and a trail of blood and hair indicated that the deer had been dragged from a field of broomsedge (*Andropogon virginicus*), over a fence and into an area of dense bottomland forest where the carcass was consumed. The hindquarters and head of the deer were never found. Two mountain lion prints were found in mud along Nowlin Creek near the carcass.

In early March 1999, S. O'Quinn of the Little Rock Parks and Recreation Department contacted the authors about the sighting of mountain lion tracks at Otter Creek Park (on the border of Pulaski and Saline counties) during the winter of 1998. Witsell, Frothingham, and O'Quinn searched the 50 ha park and found several ambiguous scats composed largely of animal hair that had been weathered by the elements. At least two of these scats were of dimensions consistent with that of a mountain lion. A single track was found in a wet depression along a powerline right of way. Although this track wasn't as well preserved as the others found, it had the same size and shape of an adult mountain lion track (11 cm long by 11 cm wide, large heel pad, and no claw marks). A plaster cast was made.

All of the areas where evidence was found are within a 40 km radius. Hornocker (1969, 1970) found western mountain lion home ranges to be quite large (13-52 km^2 for females and 39-78 km^2 or larger for males). Thus, our evidence may well represent one or more mountain lions. DNA analysis could be used to determine how many lions might be in the area.

Aside from the availability of prey items, the main limiting factor for mountain lion populations is the availability of sufficiently large, rugged forested areas removed from human activity (Sealander and Heidt, 1990). Now, more than ever before, such areas are disappearing from the Arkansas landscape. All three areas where evidence was found in Pulaski County are now either being developed or are marked for development in the near future. Smallwood (1994) found that loss of forest was strongly correlated with decline of some populations of mountain lions in California and concluded that forest management must be the focus for their conservation. If it is proven that there is a reproducing population of mountain lions in Arkansas, remaining areas providing suitable forested habitat will need preservation if this species is to be part of our wildlife heritage for future generations (Sealander and Heidt, 1990). Clearly, more research needs to be conducted to gather and evaluate information on the presence of the mountain lion in Arkansas.

Questions remain as to whether these recent reports are of the endangered native Florida panther (*Puma concolor coryi*) or are of introduced individuals of other subspecies (Young and Goldman, 1946). Introductions can take place either by natural movements from populations in neighboring states or result from individuals releasing captive lions. Again, DNA analysis can possibly answer where existing mountain lions originated.

Ongoing research includes historical cataloging of sightings from 1973 to present. DNA analysis of collected scat and scent rubs, follow-up of sight/vocalizations reports, and placement of motion-triggered cameras in areas of suspected activity.

Literature Cited

McBride, R. T., R. M. McBride, J. L. Cashman., and **S.S. Maehr.** 1993. Do mountain lions exist in Arkansas?. Proc. Annu. Conf. Southeast Fish and Wildl. Agencies. 47:394-402.

Hornocker, M. G. 1969. Winter territoriality in mountain lions. J. Wildl. Manage. 33:457-464.

Hornocker, M. G. 1970. An anlysis of mountain lion predation upon mule deer and elk in the Idaho primitive area. Wildl. Monogr. No. 21, 39 pp.

Rezendes, P. 1992. Tracking and the art of seeing - how to read animal tracks and signs. Camden House Publishing, Inc., Charlotte, VT. 320 pp.

Sealander, J. A., and **P. S. Gipson**. 1973. Status of the mountain lion in Arkansas. Proc. Arkansas Acad. of Sci. 27:38-41.

Sealander, J. A., and **G. A. Heidt**. 1990. Arkansas Mammals: their natural history, classification, and distribution. The University of Arkansas Press, Fayetteville. 308 pp.

Smallwood, S. K. 1994. Trends in California mountain lion populations. Southwest. Nat. 39:67-72.

Young, S. P., and **E. A. Goldman.** 1946. The puma: mysterious American cat. American Wildlife Institute, Dover Reprints, New York. 385 pp.

PUBLICATION POLICIES AND SUGGESTIONS FOR AUTHORS

The JOURNAL OF THE ARKANSAS ACADEMY OF SCIENCE appears annually. It is the policy of the Arkansas Academy of Science that 1) at least one of the authors of a paper submitted for publication in the JOURNAL must be a member of the Arkansas Academy of Science, 2) that only papers presented at the annual meeting are eligible for publication, and 3) that the manuscript is due at the time of presentation. In accordance with this policy, manuscripts submitted for publication should be given to the section chairman at the time the paper is being presented. Correspondence after this time should be directed to David A. Saugey, Managing Editor, U.S. Forest Service, P.O. Box 189, 8607 North Highway 7, Jessieville, AR 71949.

Each submitted paper should contain results of original research, embody sound principles of scientific investigation, and present data in a concise yet clear manner. The COUNCIL OF BIOLOGY EDITORS STYLE MANUAL, published by the American Institute of Biological Sciences, is an example of a convenient and widely consulted guide for scientific writers. Authors should strive for directness and lucidity, achieved by use of the active voice. Special attention should be given to consistency in tense, unambiguous reference of pronouns, and to logically placed modifiers. It is strongly recommended that all authors 1) inspect the existing format for feature articles and general notes in the JOURNAL OF THE ARKANSAS ACADEMY OF SCIENCE and follow that format while drafting their submission, and 2) submit their manuscript to another qualified person for a friendly review to appraise it for clarity, brevity, grammar, and typographical errors.

Preparation of Manuscript

The author should submit three copies of the manuscript, tables, and figures. Manuscripts must be double spaced on 8-1/2 x 11 inch bond paper with at least one inch margins on all sides. Do not staple pages together. Do not hyphenate words on the right-hand margin; do not submit word processed copy printed with justified right-hand margins. Do not submit copy in italics; underline words to be set in italics. If co-authored, designate which author is to receive correspondence and at what address.Correspondence author should also include e-mail address, daytime telephone number and fax number. Minimum font size is 12 for text.

An abstract summarizing in concrete terms the methods, findings and implications discussed in the body of the paper must accompany a feature article. The abstract should be completely self-explanatory.

A feature article comprises approximately six or more typewritten pages. A JOURNAL printed page is equal to approximately three and one-half typewritten pages and the author is assessed a PAGE CHARGE (see Procedure section). A separate title page, including authors names and addresses should be included with the manuscript. Feature articles are divided into the following sections: abstract, introduction, materials and methods, results, discussion, conclusions, acknowledgments, and literature cited. These sections should be centered. Subheadings should begin at the left -hand margin, but more than one subheading should be avoided.

A general note is usually one to five typewritten pages and rarely utilizes subheadings. A note should have the title at the top of the first page with the body of the paper following. Abstracts are not used for general notes.

Abbreviations: Use of abbreviations and symbols can be ascertained by inspection of recent issues of the JOURNAL. Suggestions for uniformity include the use of numerals before units of measurements (5 m), but nine animals (10 or numbers above, such as 13 animals). Abbreviations must be defined the first time they are used. The metric system of measurements and weights must be employed.

The literature cited section for feature articles should include six or more references; entries should take the following form:

Davis, D. H. S. 1993. Rhythmic activity in the short-tailed vole, *Microtus*. J. Anim. Ecol. 2:232-238.

Hudson, J. W., and **J. A. Rummell.** 1966

Fleming, T. H. 1969. Population ecology of three species of neotropical rodents. Unpublished Ph.D. Dissertation. Univ. Michigan, Ann Arbor. 231 pp.

Jones, I. C. 1957. The adrenal cortex. Cambridge Univ. Press, London, 316 pp.

Wright, P. L.1966. Observations on the reproductive cycle of the American badger (*Taxides taxus*). Pp. 27-45, *In* Comparative biology of reproduction in mammals (I. W. Rowlands, ed.) Academic Press, London. xxi + 559 pp.

If the references are cited in a general note, they should be inserted in text and take these forms: (Jones, The adrenal cortex, Cambridge Univ. Press. p. 210, 1957); (Davis, J. Anim. Ecol., 2:232-238, 1933).

Tables and Illustrations: Tables and figures (line drawings, graphs, or black and white photographs) should not repeat data contained in the text. The author must provide numbers and short legends for illustrations and tables and place reference to each of them in the text. Legends for figures should be typed on a separate piece of paper at the end of the manuscript. Do not run tables in the text. **Illustrations must be of sufficient size and clarity to permit reduction to standard page size (or 1/2 page);** ordinarily they should be no larger then twice the size of intended reduction and whenever possible no larger than a manuscript page for ease of handling. Photographs must be printed on glossy paper. Sharp focus and high contrast are essential for good reproduction. Figures and labeling must be of professional quality. Notations identifying author, figure number, and top of print must be made on the back of each illustration. All illustrations must be submitted in duplicate. Tables must be of professional quality when submitted. Note preferred placement of figures and tables in the margins of the manuscript. Do not submit original artwork, photos, tables or figures with review copies of the manuscript.

Review Procedure

Evaluation of a paper submitted to the JOURNAL begins with a critical reading by the Managing Editor. The paper is then submitted to referees for checking of scientific content, originality, and clarity of presentation. Attention to the preceeding paragraphs will greatly speed up this process. Judgments as to the acceptability of the paper and suggestions for strengthening it are sent to the author. If the paper is tentatively accepted, the author will rework it, where necessary, and return two copies of the revised manuscript together with the original to the Managing Editor. Usually a time limit for this revision will be requested. If the time limit is not met, the paper may be considered to be withdrawn by the author and rejected for publication. All final decisions concerning the acceptance or rejection of a manuscript are made by the Managing Editor and/or Editor-in-Chief.

When a copy of the proof, original manuscript, and reprint order blanks reach the author, they should be carefully read for errors and omissions. The author should mark corrections on the proof and return both the proof and manuscript to the Managing Editor within 48 hours or the proof will be judged correct. Printing charges accruing from excessive additions to or changes in the proofs must be assumed by the author. Reprint charges are placed with the printer, not the Managing Editor. Page changes are $40 printed page. These changes and excessive printing charges will be billed to the author by the Academy of Science ($4.00 per word). A page charge will be billed to the author of errata.

ABSTRACT COVERAGE

Each issue of the JOURNAL is sent to several abstracting and review services. The following is a partial list of this coverage.

Abstracts in Anthropology
Abstracts of North America Geology
Biological Abstracts
Chemical Abstracts
Mathematical Reviews
Recent Literature of the Journal of Mammalogy
Science Citation Index
Sport Fishery Abstracts
Zoological Record
Review Journal of the Commonwealth Agricultural Bureau

BUSINESS AND SUBSCRIPTION INFORMATION

Remittances and orders for subscriptions and for single copies and changes of address should be sent to Michael Soulsby, UAMS, Dept. of Physiology and Biophysics, 4301 W. Markham, Little Rock, AR 72205.

Members receive one copy with their undergraduate membership of $15.00, regular membership of $30.00, sustaining membership of $35.00, sponsoring membership of $45.00 or life membership of $200.00. Institutional members and industrial members receive two copies with their membership of $100.00. Library subscription rates for 1997 are $25.00. Copies of most back issues are available. The Secretary should be contacted for prices.

TABLE OF CONTENTS